IRON AND STEEL CCS STUDY (TECHNO-ECONOMICS INTEGRATED STEEL MILL)

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Understanding the Techno-Economics of Deploying CO_2 Capture Technologies in an Integrated Steel Mill

IEAGHG OVERVIEW

KEY MESSAGES

The global steel industry has made significant investment in reducing CO_2 emissions mostly by raising their energy efficiency. However, to achieve a reduction of the direct CO_2 emissions per tonne of steel produced from BF-BOF route by greater than 50%, CO_2 capture and storage is required.

Development of breakthrough technology such as oxy-blast furnace (OBF) is currently on-going within the steel industry but will require large scale demonstration to validate engineering design and optimisation of the process. This study presented one of the several options that could be employed for a steel mill with OBF and CO_2 Capture.

Deployment of post-combustion capture technology, capturing CO_2 from various sources of flue gases within the integrated steel mill is technically possible and could be readily retrofitted to an existing steel mill. However, this study has demonstrated that this option could have significant costs implications on steel production which could affect the commercial viability of the steel plants fitted with CCS.

The steel industry is a globally competitive industry and hence they will be reluctant to introduce cost disadvantages like adding CCS without some global agreement on emissions reduction.

BACKGROUND

The iron and steel industry is one of the largest industrial sources of CO_2. Globally, it accounts for about 6% of anthropogenic CO_2 emissions (approx. 1.2 Gt CO_2/year). Currently, two main processes dominate global steel production:

- the integrated steel mill in which steel is made by reducing iron ore in a blast furnace and subsequent processing in a primary steelmaking plant (BF-BOF Route); and
- the mini-mill in which steel is made by melting scrap steel or scrap substitutes in an electric arc furnace (EAF Route).

In 2011, around 1.5 billion tonnes of crude steel are produced worldwide. Roughly, ~69% of the steel produced are from BF-BOF steelmaking route; and ~29% of the steel produced are from recycled scrap using EAF steelmaking route. Currently, China is responsible for nearly 45% of the steel produced worldwide. Alternative iron and steel making processes based on direct or smelting reduction technologies - such as COREX, FINEX, DRI, Midrex and many others - are also used to produce steel in various sites worldwide. Several of these technologies are commercially proven; however, they only account for a small share of steel produced globally. It is expected that steel production via BF-BOF and EAF routes would still dominate steel production in several decades to come.

To reduce CO_2 emissions from steel mills, one of the leading options being considered by iron and steel stakeholders is CO_2 capture and storage (CCS). Development of this technology for application in iron and steel production is still on-going (i.e. ULCOS project, World's Steel CO_2 Breakthrough Programme, etc…).

This project, by IEA Greenhouse Gas R&D Programme (IEAGHG) in collaboration with Swerea MEFOS AB was developed with co-funding support from Swedish Energy Agency, SSAB, LKAB and Swerea MEFOS member companies. The project was initiated in January 2010. This was managed by a Steering Committee whose members include representatives from the funding partners. Swerea MEFOS AB led and coordinated this project. Corus Consulting PLC (now TATA Steel Consulting) undertook the cost evaluation and financial modelling; and SINTEF Materials and Chemistry undertook the evaluation of post-combustion capture CO_2 modelling.

STUDY DESCRIPTION

Objectives of the Study

The primary goal of this project is to establish a methodology to evaluate the cost of steel production when deploying CO_2 capture technology in an integrated steel mill. The objectives of this study were:

- To specify a "REFERENCE" steel mill typical to Western European configuration; and assess the techno-economic performance of the integrated steel mill without and with CO_2 capture.

- To evaluate the techno-economic performance, the breakdown of the CO_2 emissions; and estimating the CO_2 avoidance cost of the following cases:
  - Case 1: An integrated steel mill typical to Western Europe as the base case.
  - Case 2: Post-Combustion CO_2 capture using conventional MEA at two different levels of CO_2 capture rate (End of Pipe Cases or EOP)
  - Case 3: An Oxygen Blown Blast Furnace (OBF) with top gas recycle and the use of MDEA/Pz as solvent for CO_2 capture

Scope of the Study

The scope of the study was to:

- Provide a description of the integrated steel mill,
- Evaluate the performance and economics of steel production without and with CO_2 capture,
- Develop the financial cost model that could be used in future studies and capable of incorporating various site specific conditions of the steel mill,
- Identify key areas of development that could be recommended for future studies.

Study Basis

The technical and economic assessments were based on a new build integrated steel mill situated in the coastal region of Western Europe producing 4 MTPY of HRC using processes that are typical to any average steel mill. The Reference Steel Mill (without CO_2 capture) consists of 12 different major processes and various auxiliaries. Figure 1 schematically presents the battery limit of the steel mill without CO_2 capture representing various input and output of raw materials, product, by-products and waste products.

For an integrated steel mill with CO_2 capture, this study evaluated two possible capture options namely:

(1) Steel mill with Post-Combustion Capture using standard MEA solvent for capturing CO_2 from the flue gases of various combustion processes;

(2) Steel mill equipped with OBF and using MDEA/Pz solvent for capture of CO_2 from the top gas.

Both technology options for CO_2 capture are considered either as existing technologies that could be deployed in an integrated steel mill with moderate risk; or technologies that are currently being developed and could be deployed in the near future.

Table 1 summarises the battery limit of the integrated steel mill without and with CO_2. This table also presents an overview to the modification made to the integrated steel as compared to the REFERENCE case when CO_2 capture plants were installed.

The cost of HRC production and CO_2 capture were estimated assuming a 10% annual discount rate in constant money values, a 25 year economics plant life, a fixed price input for various raw materials, energy and reductant, fluxes and other consumables. A full list of the economic criteria used in the study is given in the main reports.

RESULTS AND DISCUSSION

Steel Production

Steel is predominantly produced from reduction of iron ore or melting of recycled scrap. Hot Rolled Coil (HRC) is one of the several standard products that could be produced from a steel mill. The production of HRC based on integrated steelmaking routes involves various processes which include:

- Raw materials preparation (sinter, coke and lime production),
- Iron making process (hot metal production and desulphurisation),
- Steelmaking process (basic oxygen steelmaking process, ladle metallurgical refining),
- Casting (continuous slab casting),
- Reheating and Rolling (finishing mill),

To support the iron and steel production processes, power plant and air separation units are generally included as part of the integrated steel mill. Typically, surplus off-gases from the steel mill are used by the power or cogeneration plant as fuel to produce electricity or steam (in several cases, hot water is also produced for district heating). The main purpose of the air separation unit is to deliver large amount of oxygen needed by both iron making and steelmaking processes. Other industrial gases such as nitrogen and argon are also used as utility gases for these processes.

CO_2 Capture Technologies for an Integrated Steel Mill – An Overview

CO_2 emissions from an integrated steel mill come from various sources. For the REFERENCE steel mill without CO_2 capture, the top 5 sources of CO_2 emissions are from the flue gases of the hot stoves, power plant, sinter plant, coke ovens' underfired heaters and lime kilns. This consists of ~90% of the total direct CO_2 emissions of the steel mill. The addition of CO_2 capture plant to an integrated steel mill could practically reduce CO_2 emission by 50 to 60%. However, this would consequently increase the steel mill's overall energy consumption (steam, electricity or fuel gases).The study evaluated three different scenarios for deployment of CO_2 capture technologies in a conceptual integrated steel mill.

Two scenarios involved the deployment of post-combustion capture technology using MEA as solvent achieving two level of CO_2 avoidance. For Case 2A (EOP-L1), this involved the capture of CO_2 from flue gases of the hot stoves (Unit 300) and the steam generation plant (Unit 2000). For Case 2B (EOP-L2), additional CO_2 could be captured from flue gases of the coke ovens' underfired heaters (Unit 100) and the lime kilns (Unit 1000).

The third scenario (Case 3) involved the deployment of oxygen blown blast furnace or OBF. CO_2 in the top gas produced by the OBF are captured using MDEA/Pz solvent. The majority of the top gas is recycled back to the shaft of the OBF which should reduce coke consumption of the OBF, compared to the conventional blast furnace.

Post-Combustion Capture Technology

The choice of post-combustion capture technologies (i.e. use of chemical absorption technology capturing CO_2 from different flue gases within the steel mill) means that there will be no major modifications to the core iron and steel production. The main modification to the steel mill will involve only the addition of:

- Flue gas processing (i.e. deeper SOx and NOx removal, direct contact coolers)
- CO_2 capture plant
  - absorber and stripper columns,
  - heat exchangers,
  - reboiler and
  - condensers
- CO_2 compressors and dehydration unit

Additionally, to meet the increase energy demand of the CO_2 capture plant, the steel mill would require the expansion of their power plant and steam generation plant to provide additional steam and electricity generation capacity.

Oxy- Blast Furnace (OBF) and CO_2 Capture

The oxy-blast furnace involves the replacement of hot blast with pure oxygen and recycled top gas or OBF process gas (OBF-PG). This process comes with several versions. ULCOS[1] has developed this technology and evaluated three different versions. This is illustrated in the figure overleaf.

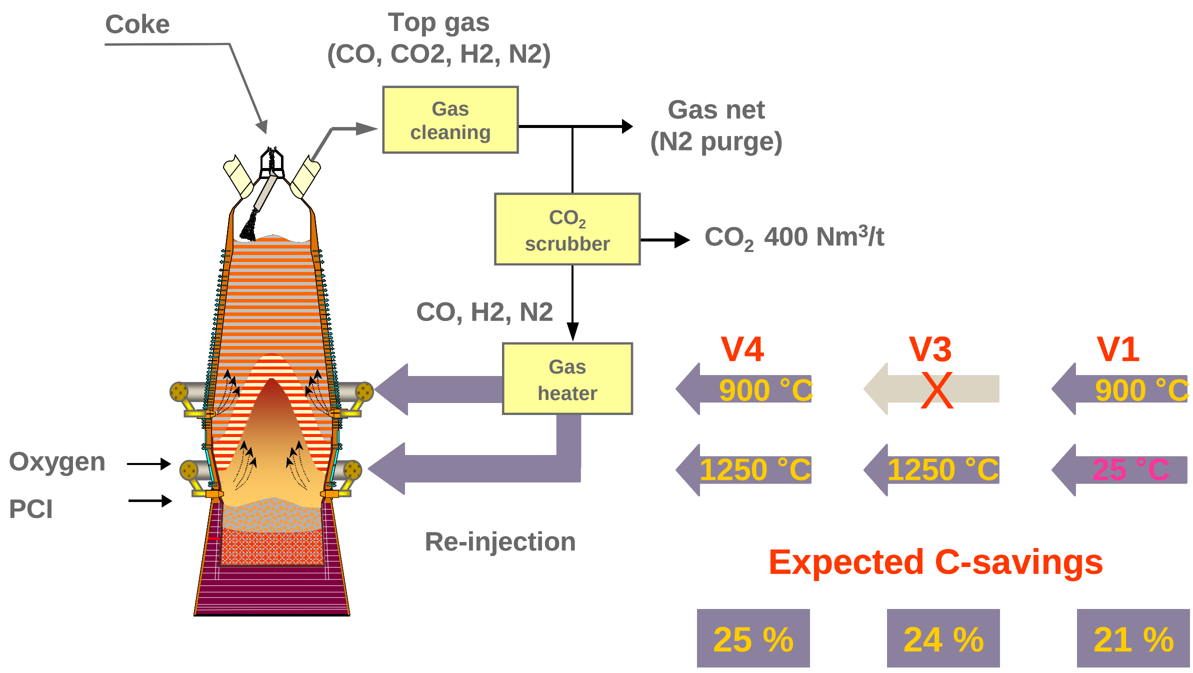
In general, the OBF technology involves the removal of CO_2 from the top gas to produce the OBF-PG. Part of the OBF-PG (with option to pre-heat or not) are mixed with oxygen and injected at the tuyeres of the blast furnace; whilst another part of the OBF-PG are preheated and injected into the middle shaft of the blast furnace. Another version of this process involves the preheating and recycling of the all the OBF-PG together with cold oxygen into the tuyeres of the furnace.

OBF together with CO_2 capture has several advantages to reduce CO_2 emissions which include:

- The top gas with CO_2 removed could be recycled to the blast furnace which should lower the coke consumption and also reduce direct CO_2 emissions of the coke plant.
- A higher concentration of CO_2 in top gas and smaller volume of gas to be processed (as compared to flue gases) could be expected. This should lower the energy requirements of the CO_2 capture plant.
- Higher pressure of the OBF Top Gas (and higher partial pressure of CO_2) as compared to flue gases should make it feasible to employ several other CO_2 capture technology options. This include but not limited to:
  - Chemical absorption using solvent such as MDEA/Pz, AMP, etc… which are suitable for high partial pressure of CO_2.
  - PSA or VPSA
  - Cryogenic separation.

ULCOS has selected the use of OBFv4 and PSA together with cryogenic separation for their Florange Demonstration Project[2]. It should be noted that the selected OBF version of ULCOS is totally different from the version of OBF presented in study this study which is nearly similar to OBFv1 and it varies only to the technology used to capture of CO_2. In this study, the use MDEA/Pz solvent has been selected but it should be noted that this is not recommended as the best available technology; but is used only to serve as an example to evaluate the cost of capturing CO_2 from an integrated steel mill.

[1] ULCOS stands for the Ultra Low CO_2 Steel, it is an EC funded projects of some 20 partners from the steel and associated organisations that have been working on topics related to CO_2 reduction, including CCS in the steel industry since 2010.
[2] Florange Project was submitted to the EC for NER300 application. However, due to technical and commercial reason, their application to the NER300 has not been successful.



Different Versions of Oxy-Blast Furnace Configuration Evaluated by ULCOS

Performance of the Integrated Steel Mill with CO_2 Capture – Summary of Results

The overall energy consumption of the steel mill without and with CO_2 capture is summarised in Table 2. From the results, the following could be summarised.

REFERENCE Steel Mill (Case 1)

- For Case 1, REFERNECE Steel Mill (Base Case), would require a net energy input of ~21.27 GJ/t HRC. Around 96% of the energy input (net) to the steel mill is provided by the coking coal and PCI coal. Natural gas is only used by the captive power plant to supplement the energy requirements of the steel mill.
- Also, for the REFERENCE Steel Mill, it was demonstrated that the overall energy consumption could be reduced by improving the efficiency of the power plant that provides the electricity to the steel mill. This is illustrated in various step-off cases showing a reduction of at least 0.85 GJ/t HRC could be possibly achieved (for Case 1B, 1C and 1D).
- It could also be noted that several improvements could still be deployed to increase the energy efficiency of the iron and steel making processes[3]. However, these energy saving measures could be very site specific and mostly dependent on payback period of the CAPEX needed to deploy these technologies.

Steel Mill with Post-Combustion CO_2 Capture (Case 2)

- For Cases 2A and 2B, the overall energy consumption of ~24.64 GJ/t HRC (Case 2A) and ~25.94 GJ/t HRC (Case 2B) were reported respectively. Compared to the REFERENCE Steel Mill (Case 1), the additional energy requirements for both Case 2A and Case 2B are mainly due to the increase in natural gas consumption by the steam generation plant (Unit 2000) and the power plant (Unit 1200).
- Natural gas consumption of the steel mill with CO_2 capture have increased from 0.85 GJ/t HRC (REFERENCE Case) to 4.21 GJ/t HRC (Case 2A) and 5.52 GJ/t HRC (Case 2B). Bulk of the increase is mainly due to the natural gas consumption of the captive power plant providing all of the electricity required by the steel mill. This constitutes to about ~86.5% and ~71.2% of the total

[3] This has been demonstrated from the comments and data provided by ULCOS (as reported in ANNEX 3 of the Report Overview).

natural gas consumed by the steel mill for Case 2A and Case 2B respectively; and the balance of which are consumed by the steam generation plant.

- Electricity demand of the steel mill with CO_2 capture have increased from 400.1 kWh/t HRC (REFERENCE Case) to 572.6 kWh/t HRC (Case 2A) and 621.7 kWh/t HRC (Case 2B). For both cases, the bulk of the increase in electricity demand is mainly due to the electricity demand of the CO_2 capture plant including compression (delivering the CO_2 at 110 bar_a).

Steel Mill with OBF and MDEA CO_2 Capture (Case 3)

- The deployment of OBF has resulted in major modifications to the design and operation of the iron making processes. This includes changes to the coke and sinter production. One of the key changes is the reduced coke consumption of the OBF compared to that of the conventional blast furnace by ~25%. Additionally, the productivity of the blast furnace is expected to increase. Consequently, this reduces the required hearth diameter of the blast furnace from 11 m (for REFERENCE Case) to 8.5 m (for OBF Steel Mill). A more detailed description to the different changes to the steel mill design and operation has been presented in the main report (Vol. 3 Section C).
- For the steel mill with OBF and MDEA/Pz CO_2 capture, the overall energy consumption of ~21.82 GJ/t HRC has been reported. This is an increase of ~0.55 GJ/t HRC compared to the overall energy consumption of the REFERENCE Steel Mill (21.27 GJ/t HRC).
- It could be noted that there is an increase in natural gas consumption from 0.85 GJ/t HRC (REFERENCE Case) to 5.05 GJ/t HRC (Case 3). On the other hand, the reduction in coke consumption of the blast furnace has led to a reduction of coking coal required by the steel mill from 16.29 GJ/t HRC (REFERENCE Case) to 12.43 GJ/t HRC (Case 3). Consequently, the reduction in coking coal consumption has also reduced the coking by-products exported from the steel mill from 0.90 GJ/t HRC (REFERENCE Case) to 0.69 GJ/t HRC (Case 3).
- The bulk of the natural gas consumption is primarily due to the consumption of the power plant (72% of the total), steam generation plant (13%) and the OBF-PG heaters (15%).
- The installation of the OBF, CO_2 capture and recycling of the processed top gas to the blast furnace would involve major changes on how off-gases from the hot metal production are distributed and used within the steel mill. This is illustrated in Table 3 which summarises the gross and net fuel input to the hot metal production.
- The electricity demand of the steel mill with OBF and MDEA CO_2 capture has also increased to 573.4 kWh/t HRC (Case 3) from 400.1 kWh/t HRC (REFERENCE Case). Bulk of the increase is due to the changes to the electricity required by the iron making processes. Table 4 presents the breakdown of the electricity demand for the hot metal production without and with CO_2 capture.
- Improvement to the steam production for the steel mill with OBF and MDEA CO_2 capture were evaluated. Two different step-off cases (Case 3A and 3B) were examined. Both cases involved the use of CHP plant. Case 3A delivers the low pressure steam to the CO_2 capture plant based on a cycle with no steam reheat; whilst Case 3B provide the steam using a cycle with steam reheat. It could be summarised that consumption of natural gas by the steel mill with OBF and MDEA CO_2 capture has been reduced to 4.81GJ/t HRC (for Case 3A) and 4.65 GJ/t HRC (for Case 3B) respectively as compared to the 5.05 GJ/t HRC of natural gas consumed by the OBF Base Case (Case 3).

Overall CO_2 Emissions of the Steel Mill without and with CO_2 Capture

The breakdown of the CO_2 emissions from the integrated steel mill without and with CO_2 capture is presented in Table 5.

- The CO_2 avoided of 50.1% and 60.3% were reported from the steel mills with post-combustion capture using MEA for Case 2A (EOP-L1) and for Case 2B (EOP-L2) respectively; whilst CO_2 avoided of 46.5% was reported for the steel mill with OBF/MDEA CO_2 capture (Case 3).
- For the steel mill with OBF/MDEA CO_2 capture, achieving CO_2 avoidance of 46.5% would only need to capture 860 kg CO_2/t HRC; whilst for steel mill with post-combustion capture (Case 2A or EOP-L1), achieving a CO_2 avoidance of 50.1% would need to capture 1243 kg CO_2/t HRC. The lower CO_2 capture rate required for steel mill with OBF/MDEA CO_2 capture (Case 3) is mainly

contributed by the lower CO_2 emissions of the coke plant (Unit 300) due to the reduced coke consumption of the OBF as compared to the conventional BF of the REFERENCE Case.

- Additionally, this study also illustrated that by increasing the CO_2 avoidance from 50.1% to 60.3% for steel mills with post-combustion capture using MEA solvent (i.e. EOP-L1 vs. EOP-L2 Cases) would consequently result to an increase in the overall energy consumption of the steel mill of 24.64 and 25.94 GJ/t HRC respectively. Using the overall energy consumption for the REFERENCE Case (i.e. 21.27 GJ/t HRC) as basis, this corresponds to an increase in energy consumption of 3.37 GJ/t HRC to 4.67 GJ/t HRC.

Levelised Cost of Steel Production (Breakeven Price of the HRC Ex-Works)

The breakeven price of the HRC from the Integrated Steel Mill without and with CO_2 capture was evaluated. The total investment cost including recurring CAPEX (Table 6), the annual O&M cost (Table 7), and annual revenues from by-product sales (Table 8). The breakeven price of the HRC reported in this study should represent the levelised cost of HRC delivered at the gate of the steel mill.

The CO_2 avoidance cost is calculated from the difference of the breakeven price of the HRC produced for both steel mills without and with CO_2 capture and divided by the differences of their direct CO_2 emissions (Table 9). It should be noted that CO_2 avoidance cost reported in this study doesn't include the cost of CO_2 transport and storage.

From this study, the following key results could be summarised:

- The study provided a breakdown of the cash flow analysis of the different major processes of the steel mill without and with CO_2 capture. This also provides detailed information regarding the breakdown of the cost of direct CO_2 emissions per major processes of the steel mill. It should be noted that the cost model developed for this study could be adapted for future studies and could also incorporate several site specific conditions to evaluate the cost of CO_2 capture from an integrated steel mill.
- The breakeven price of the HRC produced from the RSM without CO_2 capture (Case 1) producing 4 MTPY was estimated at US$ 575.23/t HRC. Figure 2 presents the breakdown of the cost of HRC production. It could be noted that nearly 60% of the cost of steel produced consists of the different raw materials (i.e. iron ore burden, ferro-alloys, scrap and fluxes), fuel and reductant. The CAPEX only contribute to around 21% of the total cost. It could be concluded that the cost of steel produced (ex-works) could be strongly influenced by the different market drivers mainly the cost of iron ore, coking coal and energy (i.e. for this study, this is represented by the cost of natural gas consumed).
- The breakeven price of the HRC produced from the Steel Mill with post combustion CO_2 capture using MEA producing 4 MTPY was estimated at US$ 652.44/t HRC and US$ 677.70/t HRC for Case 2A (EOP-L1) and Case 2B (EOP-L2) respectively. The breakdown of this price is presented in Figures 3 and 4. As compared to the breakeven price of the HRC from the REFERENCE Case, this represents an increase of ~US$ 77.20 and ~US$ 102.50 per tonnes of HRC for Case 2A and 2B respectively.
- The breakeven price of the HRC produced from a Steel Mill with OBF and MDEA CO_2 capture (Case 3) producing 4 MTPY was estimated at US$ 630.22/t HRC. The breakdown of this price is presented in Figure 5. This represents an increase of ~US$ 55.00/t HRC as compared to the breakeven price of the HRC produced from REFERNECE Steel Mill.
- The estimated cost of CO_2 avoidance for HRC produced from steel mill with post-combustion capture are US$ 74/t CO_2 and achieving 50% CO_2 avoided (Case 2A) and US$81/t CO_2 and achieving 60% CO_2 avoided (Case 2B). On the other hand, the cost of CO_2 avoidance for the HRC produced from steel mill with OBF and MDEA/Pz CO_2 capture are significantly lower at US$57/t CO_2 and achieving 47% CO_2 avoided.

For all cases, it could be noted that the high cost of CO_2 avoidance is mainly due to the following:

[1] Additional cost of natural gas consumed by the steel mill (as compared to the REFERENCE Case)

[2] Additional total investment cost for the CO_2 capture plant, power plant and steam generation plant.

Both of these factors contribute to about 80 to 83% of the total price increase of the HRC.

The magnitude of the price increase for the HRC produced from the steel mill with OBF/MDEA CO_2 capture is lower as compared to the price increase for the steel produced from steel mill with post-combustion CO_2 capture using MEA (i.e. Case 2A – end of pipe case). Consequently, this also results to lower CO_2 avoidance cost for Case 3. This is attributed to the savings achieved from the reduced coke consumption of the OBF.

Sensitivity of CO_2 Avoidance Cost to the Price of Coking Coal and Natural Gas

This study has demonstrated that CO_2 avoidance costs for the HRC produced from the steel mill with CO_2 capture are strongly linked to the price of coking coal and natural gas and to sensitivity of the total investment cost.

Figure 6 presents the sensitivity of the CO_2 avoidance cost to the coking coal price for Case 2A and Case 3. This figure shows that the CO_2 avoidance cost for HRC produced from steel mill with Post-Combustion Capture is not sensitive to the coking coal price. However, this is not true to Case 3. It could be observed that an increase in the coking coal price should reduce the CO_2 avoidance cost for the HRC produced from steel mill with OBF and MDEA CO_2 capture.

For Case 2A, due to the fact that coke consumption has remained the same compared to the REFERENCE Steel Mill, it should not affect the cost of CO_2 avoidance for the range of coking coal price evaluated in this study. On the other hand, for Case 3, this result could only demonstrate the integrated nature of the steel mill. Due to the reduced coke consumption by the OBF, this should also reduce the coke production required. Consequently, this should also reduce the direct CO_2 emissions of the steel mill. Therefore, a higher coking coal price (which is the main raw material of the coke plant) should only reflect the magnitude of the cost reduction (which represents a cost saving) that could be achieved by the steel mill with OBF as compared to the REFERENCE Case, consequently lowering the CO_2 avoidance cost.

Figure 7 presents the sensitivity of the CO_2 avoidance cost to the natural gas price for Case 2A and Case 3. This figure should help illustrate the interaction between the coking coal price and natural gas price. At coking coal price of 1P (i.e. hard coking coal at \$220 and semi-soft coking coal at \$160 per tonne), it is necessary to have natural gas price of ~\$25/GJ to achieve the parity level of CO_2 avoidance cost for Case 2A and Case 3. This should hold true for coking coal price at 0.5P and 1.5P, it is necessary to have natural gas price of ~\$18/GJ and ~\$34/GJ to achieve the same effect on the CO_2 avoidance cost for both Case 2A and Case 3 respectively. It could be concluded that to make post-combustion capture option to be competitive as compared to the steel mill with OBF case, it is essential to achieve lower energy demand by the CO_2 capture plant.

Variability of the CO_2 Avoidance Cost

The variability of the CO_2 avoidance cost demonstrates the complexity of evaluating the cost of steel production from a steel mill without and with CO_2 capture. It should be noted that the reported CO_2 avoidance cost is very specific to the assumptions made in a study. This is illustrated by the range of CO_2 avoidance cost reported (\$48 to 66 per tonne CO_2 avoided) from the different step-off cases evaluated for the REFERENCE Steel Mill (Case 1) and steel mill with OBF/MDEA CO_2 capture.

It could be noted that the variability is caused by the site specific conditions such as the definition of the battery limit, iron burden distribution, the level of external scrap input, and the efficiency of the processes delivering the electricity and steam could influence the overall energy performance of the integrated steel mill and its direct CO_2 emissions. Likewise, any changes to the iron and steel production due to its site specific conditions should also impact the cost of steel production. Consequently, this make any CO_2 avoidance cost reported from various studies not easily comparable.

EXPERT REVIEWERS' COMMENT

The draft study report was reviewed by several external experts including representatives from industrial gas companies, steel industry including members of the ULCOS, and experts on post-combustion CO_2 capture technology. Not unexpectedly for a first of a kind study such as this, substantial numbers of comments were received.

Several experts from industrial gas companies have reviewed and raised various issues regarding the operation of the blast furnace and oxygen production. Most of these issues were clarified and if possible also incorporated in the final version of the report.

An example of this issue commented upon by the expert from the industrial gas companies is the possible discrepancy between the raceway adiabatic flame temperature (RAFT) of the blast furnace of the REFERENCE Case at 2056^{o}C as compared to the OBF Case at 2140^{o}C which makes it not comparable and could possibly favour the performance of the OBF case. This issue was clarified with Swerea MEFOS; and was addressed in the report.

Another example is on the different scenarios that could be possible for the operation of both low and high purity oxygen production. The central point of discussion involves the sale of Argon. In this study, the reduced high purity oxygen production for OBF case has led to reduced Argon sales reducing revenues by $20M/y. It was suggested that optimisation should be done to determine balance between production of low and high purity oxygen with respect to assumed price of Ar and energy requirements of both ASUs.

Members of the ULCOS consortium have been helpful in highlighting the importance of various factors that could impact the performance and cost of deploying CO_2 capture in an integrated steel mill. They have been critical with the selection of technology and provided their data for comparison. They have noted that the choice of the RSM presented in this study is an average steel mill which could be improved substantially. This comment was taken board and included in the recommendation that future study should include several other state of the art technologies that could be viably incorporated to achieve higher efficiency steel production.

Additionally, the ULCOS consortium has been critical with regard to the reported performance (i.e. steam demand of the reboiler) of the MDEA/Pz solvent. They believe that results presented are overly optimistic at 2.3 GJ/t CO_2. In this regard, IEAGHG consulted CSIRO (Australia) to provide an independent opinion regarding the results reported in this study. A detailed evaluation by CSIRO determined that the values reported for the reboiler duty are considered reasonable. From CSIRO's assessment and calculation, it was noted that reboiler duty could range between 2.5 and 2.7 GJ/t CO_2 depending on how the process is optimised. It was in their opinion that the value of 2.3 GJ/t CO_2 reported by SINTEF in this study has been optimised based on conventional configuration which are typically found in a natural gas treatment plant and value reported could be achievable for the given operating pressure. Furthermore, they have concluded that the lower value of 2.1 -2.2 GJ/t CO_2 could be achieved by using the split flow configuration which has been demonstrated to reduce energy consumption in pilot plant operated by CSIRO.

MAJOR CONCLUSIONS

The global steel industry has made significant investment in reducing CO_2 emissions mostly by raised energy efficiency. However, to achieve a reduction of CO_2 emissions greater than 50%, CO_2 capture is required. Development of breakthrough technology such as OBF is currently on-going. This will require large scale demonstration to validate engineering design and optimisation of the process. This study presented one of the several options that could be employed for a steel mill with OBF and CO_2 Capture.

Deployment of post-combustion capture technology, capturing CO_2 from various sources of flue gases within an integrated steel mill is technically possible. This could be readily retrofitted. However, this study has demonstrated that this option could have significant costs implications on steel production.

The following outcomes of this study could be summarised:

- Four different conceptual Steel Mills without and with CO_2 capture situated in the coastal region of Western Europe producing 4 MTPY standard grade Hot Rolled Coil were defined in significant detail. This report presented the following information:
  - Details of the Boundary limit
  - The Overall mass balance of the different major processes
  - Details of the gas network
  - Details of the electricity network
  - Breakdown of the CO_2 Emissions of the different major processes
- The deployment of post-combustion CO_2 capture from various flue gas sources within the boundary limit of an integrated steel mill would not require major modification to the iron and steel production processes. However, it would require significant considerations to meet the increasing demand of steam and electricity by the CO_2 capture plant.
- This study has shown that the addition of post-combustion capture using MEA as solvent has increased the overall energy consumption of the steel mill (as compared to REFERENCE Case) by 3.37 GJ/t HRC and 4.67 GJ/t HRC achieving 50 and 60% CO_2 avoided respectively.
- On the other hand, for a steel mill with OBF and MDEA CO_2 capture, this study has demonstrated an increase in the overall energy consumption of the steel mill (as compared to the REFERENCE Case) by 0.55 GJ/t HRC achieving 47% CO_2 avoided; which is significantly lower than the steel mill with post-combustion capture cases.
- This study has established a clear methodology to evaluate the cost of deploying the CO_2 capture plant in an integrated steel mill; it should be noted that cost of steel production could be very site specific.
- The estimated cost of CO_2 avoided for HRC produced from steel mill with post-combustion capture are US$ 74/t CO_2 achieving 50% CO_2 avoided (Case 2A) and US$81/t CO_2 for steel mill achieving 60% CO_2 avoided (Case 2B).
- The estimated cost of CO_2 avoided for HRC produced from steel mill with OBF and MDEA/Pz CO_2 capture are US$57/t CO_2 emissions avoided. This steel mill has achieved 47% CO_2 avoided.
- For all cases for steel mill with CO_2 capture, it could be concluded that significant portion (80 to 83%) of the increase in the breakeven price of the HRC is attributed to the additional total investment cost and increase in natural gas consumption.
- It could be concluded that breakeven price of the HRC produced from steel mill with OBF and MDEA CO_2 capture (US$ 630/t HRC for Case 3) is significant lower as compared the breakeven price of the HRC produced from steel mill with post-combustion CO_2 capture (US$ 650/t HRC for Case 2A). This is mainly due to the reduce coke consumption of the OBF.

RECOMMENDATIONS

After careful assessment and consideration of various comments from expert reviewers, the following are recommended as future studies:

It is essential to assess in more detail and incorporate other potential improvements to the cost and performance of the REFERENCE Steel Mill. This includes (but is not limited to) the evaluation of additional cases as described below:

- Removing one of the constraining extra-ordinary assumptions used in this study involving the principle of energy import and export from the steel mill. It should be noted that this assumptions has been employ to simplify the accounting of CO_2 emissions and cost. The removal of this assumption should consequently allow any surplus energy generated by the steel mill to be sold externally in the form of low grade heat or electricity. This should increase the energy utilisation efficiency of the steel mill. On the other hand, in case of any deficit, options to buy electricity from the grid could be evaluated, thus providing a more realistic scenario for European steel mill scenario.
- Improvement to the blast furnace operation by increasing oxygen enrichment and PCI coal injection, thereby reducing coke consumption.
- Incorporation of Top Gas Recycle Turbine (TRT) technology to increase electricity supply to the steel mill.
- Incorporation of hot stove oxygen enrichment technology. This should reduce consumption of other medium to high calorific value off-gases, therefore maximising the use of BFG during the heating cycle of the hot stoves.
- Incorporation of various waste heat recovery measures from the different processes of the steel mill. This could also include deployment of coke dry quenching, heat recovery from various flue gases of reheating furnaces, sinter plant (via flue gas recycling) and coke oven underfire heaters.

It is also recommended to evaluate other CO_2 capture options. This includes but is not limited to:

- Evaluation of other versions of ULCOS BF. This should demonstrate the sensitivity of the CO_2 avoidance cost to the different reduction level of coke consumption of the blast furnace. Furthermore, this should also evaluate other CO_2 capture technologies such as the use of PSA/VPSA or cryogenic separation.
- Assessment of other chemical absorption technologies capturing CO_2 from top gas of conventional blast furnaces. This represents part of the activities undertaken by the Japanese (Course 50) and South Korean (POSCO/RIST) R&D programmes; this activity should also include an assessment of the use of novel waste heat recovery (i.e. heat recovery from slag).
- Assessment of other novel CO_2 capture options. This includes: Air Products' BF plus technology, Linde's or LanzaTech's technology involving alcohol production from off-gases, and Praxair's technology involving hydrogen injection to the blast furnace.
- Assessment of integrated steel mill with DRI production unit and in combination with CO_2 capture. This option should open up several other opportunities for additional coke consumption reduction and at the same time achieving higher level CO_2 avoidance.

It is further recommended that other potential improvements to the operation of the Air Separation Unit to meet larger oxygen demand for the OBF based steel mill or AP's BF plus technology. This study could involve the evaluation of the following:

- Assessment of dual or split purity oxygen production.
- Optimisation of liquid argon production. Sensitivity to the assumed price of argon and energy demand of the ASU should be evaluated.

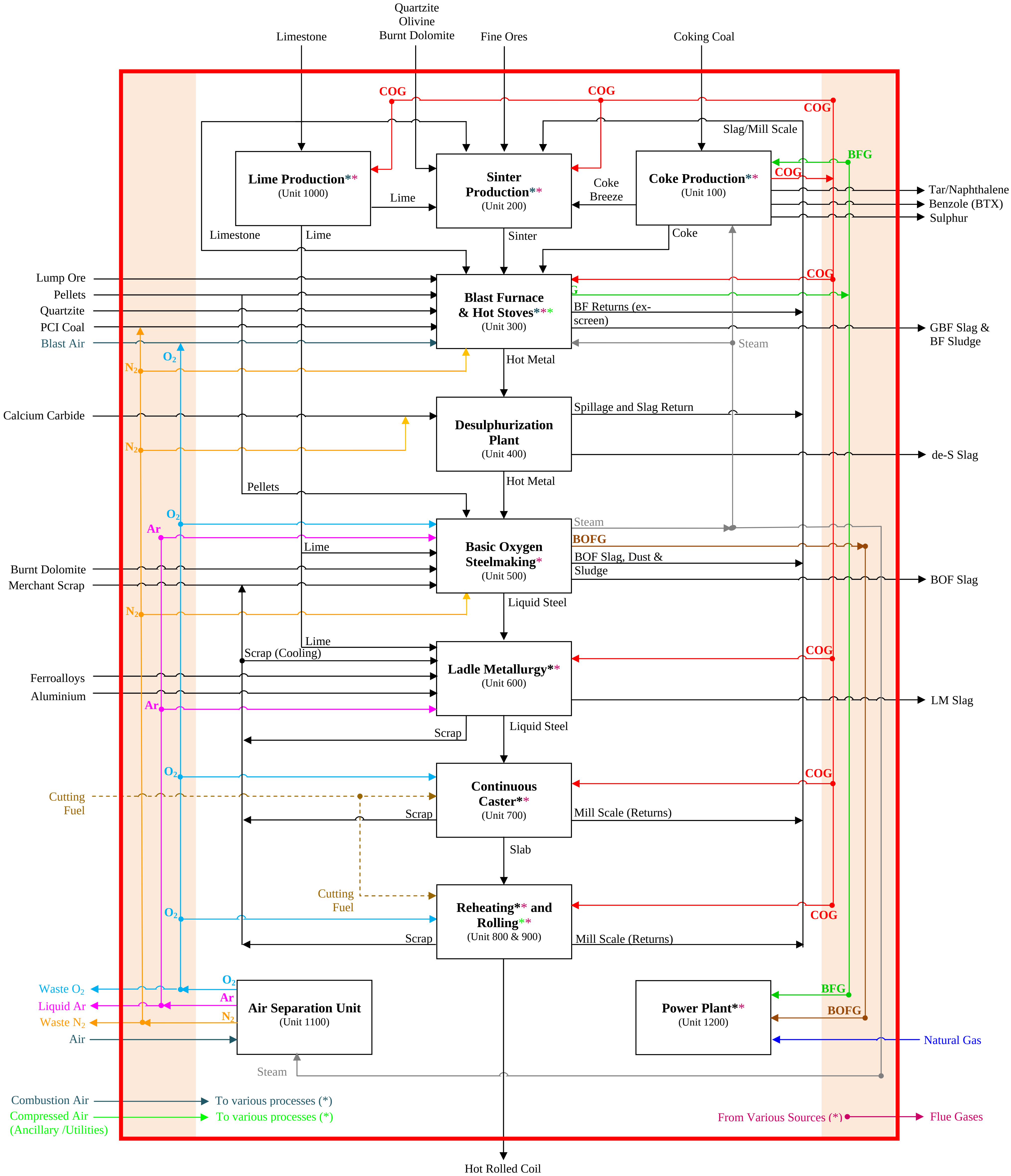


Figure 1: Process Flow Diagram of the "REFERENCE" Integrated Steel Mill

Table 1: Battery Limit of the Integrated Steel Mill without and with CO_2 Capture

(Illustrating the different processes with modification as compared to the REFERENCE Steel Mill)

Unit No.	Major Processes	Products	Reference Steel Mill (Case 1 – Base Case)	Steel Mill with Post-Combustion Capture (Case 2A – EOP-L1)	Steel Mill with Post-Combustion Capture (Case 2B – EOP-L2)	Steel Mill with OBF & MDEA CO_2 Capture (Case 3)
100	**Coke Plant**	Lump Coke and Coke Breeze	1.7 million tpy 3x Coke Batteries	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	1.3 million tpy 3x Coke Batteries
200	**Sinter Plant**	Sinter	4.5 million tpy 1x Fixed Bed Sinter Plant	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	Plant size the same but with slightly reduced sinter production
300	**Hot Metal Production**	Hot Metal	3.9 million tpy 2x Blast Furnace Each BF with 11 m. diameter	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	3.9 million tpy 2x Blast Furnace Each BF with 8.5 m. diameter
400	**Hot Metal Desulphurisation Plant**	Desulphurised Hot Metal	3.9 million tpy 2x Stations – using CaC_2 injection technology	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill
500	**Basic Oxygen Steelmaking**	Crude Liquid Steel	4.4 million tpy 2x 220 Tonnes Converter	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill
600	**Ladle Metallurgy**	Refined Liquid Steel	4.4 million tpy 2x Stations	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill
700	**Continuous Casting**	Slab	4.3 million tpy 2x Twin Strand Slab Caster	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill
800	**Reheating Furnace**	Reheated Slab	4.0 million tpy 4x Walking Beam Furnaces (2 Furnaces per HRM)	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill
900	**Hot Rolling Mill**	Hot Rolled Coil	4.0 million tpy 2x Trains Rolling Mills	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill
1000	**Lime Plant**	Lime (Lump & Fine)	0.4 million tpy 2x Lime Kiln (600 TPD)	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	Plant size the same but with slightly reduced lime production
1100	**Oxygen Plant**	HP Oxygen (99.9% O_2 Purity)	1900 TPD O_2 1x Air Separation Unit	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	1100 TPD O_2 1x Air Separation Unit
1200	**Power Plant**	Electricity	215 MWe Gas Fired Boiler (Off-Gases + NG)	292 MWe GTCC (Natural Gas)	308 MWe GTCC (Natural Gas)	292 MWe GTCC (Natural Gas)
1300	**Ancillary Plant**	-	This includes PCI coal dryer, material handling, common facilities, etc…	Same as REFERENCE Steel Mill	Same as REFERENCE Steel Mill	With changes to the Gas Network supplying heat & fuel to the coal dryer
2000	**Steam Generation Plant**	Steam (9 Bar_a Saturated)	-	1200 TPH Multiple train LP Steam Boilers	1550 TPH Multiple train LP Steam Boilers	450 TPH Multiple trains LP Steam Boiler
3000	**LP Oxygen Plant**	LP Oxygen (95% O_2 Purity)	-	-	-	4000 TPD O_2 1x Air Separation Unit
4000	**CO2 Capture & Compression Plant**	CO_2 @ 110 Bar_a	-	~5.0 million tpy CO_2 capture using MEA (achieving 50% CO_2 Avoided)	~6.2 million tpy CO_2 capture using MEA (achieving 60% CO_2 Avoided)	~3.5 million tpy CO_2 capture using MDEA/Pz (achieving 47% CO_2 Avoided)

Table 2: Overall Energy Consumption - Steel Mill without and with CO_2 Capture

	Steel Mill without CO_2 Capture (Case 1)		Steel Mill with Post-Combustion Capture (Case 2A - EOP-L1)		Steel Mill with Post-Combustion Capture (Case 2B - EOP-L2)		Steel Mill with OBF/MDEA CO_2 Capture (Case 3)	
Energy Input								
Coking Coal	16.292	GJ/t HRC	16.292	GJ/t HRC	16.292	GJ/t HRC	12.428	GJ/t HRC
PCI Coal	5.032	GJ/t HRC	5.032	GJ/t HRC	5.032	GJ/t HRC	5.032	GJ/t HRC
Natural Gas	0.849	GJ/t HRC	4.216	GJ/t HRC	5.518	GJ/t HRC	5.045	GJ/t HRC
Energy Out								
Coking By-Products	0.903	GJ/t HRC	0.903	GJ/t HRC	0.903	GJ/t HRC	0.689	GJ/t HRC
Total Energy Consumption	**21.270**	**GJ/t HRC**	**24.637**	**GJ/t HRC**	**25.939**	**GJ/t HRC**	**21.816**	**GJ/t HRC**

Table 3: Gross and Net Fuel Input to the Hot Metal Production of the Steel Mill without and with CO_2 capture

	REFERENCE Steel Mill without CO_2 Capture		Steel Mill with OBF/MDEA CO_2 Capture	
Fuel Input				
Coke	10.212	GJ/t HRC	7.442	GJ/t HRC
PCI Coal	5.032	GJ/t HRC	5.032	GJ/t HRC
COG (Hot Stove)	0.125	GJ/t HRC	-	GJ/t HRC
NG (PG Fired Heaters)	-	GJ/t HRC	0.745	GJ/t HRC
Gross Fuel Input	**15.369**	**GJ/t HRC**	**13.219**	**GJ/t HRC**
Fuel Output				
BFG (Export)	(3.566)	GJ/t HRC	-	GJ/t HRC
OBF-PG (Export)	-	GJ/t HRC	(1.674)	GJ/t HRC
BFG to Flare	(0.073)	GJ/t HRC	-	GJ/t HRC
Net Fuel Input	**11.730**	**GJ/t HRC**	**11.545**	**GJ/t HRC**

Table 4: Breakdown of the Electricity Consumption of the Hot Metal Production of the Steel Mill without and with CO_2 Capture

	REFERENCE Steel Mill without CO_2 Capture		Steel Mill with OBF/MDEA CO_2 Capture	
Main Air Compressors (Hot Blast)	68.286	kWh/t HRC	-	kWh/t HRC
OBF Process Gas Compressors	-	kWh/t HRC	54.770	kWh/t HRC
Other Consumers - BF Fans etc...	29.766	kWh/t HRC	29.765	kWh/t HRC
CO_2 Capture (excl. CO_2 Compression)	-	kWh/t HRC	18.481	kWh/t HRC
Sub-Total	98.051	kWh/t HRC	103.015	kWh/t HRC
ASU - Oxygen Production	26.138	kWh/t HRC	120.350	kWh/t HRC
Sub-Total	124.189	kWh/t HRC	223.365	kWh/t HRC
Coke Production for BF	12.322	kWh/t HRC	8.980	kWh/t HRC
Sinter Production for BF	35.564	kWh/t HRC	34.792	kWh/t HRC
Total (Electricity for HM Production)	**172.076**	**kWh/t HRC**	**267.138**	**kWh/t HRC**
CO_2 Compression (110 Bar_a)	-	kWh/t HRC	69.905	kWh/t HRC
Grand Total (incl. CO_2 delivery)	**172.076**	**kWh/t HRC**	**337.043**	**kWh/t HRC**

Table 5: Breakdown of CO_2 Emissions

UNIT	CO_2 Emissions Breakdown – Major Processes	REFERENCE Steel Mill without CO_2 Capture (Case 1) Emissions (kg/t HRC)	(Case 1) Annual Emission (t/y)	Steel Mill with Post-Combustion Capture (Case 2A - EOP-L1) Emissions (kg/t HRC)	(Case 2A) Annual Emission (t/y)	Steel Mill with Post-Combustion Capture (Case 2B - EOP-L2) Emissions (kg/t HRC)	(Case 2B) Annual Emission (t/y)	Steel Mill with OBF/MDEA CO_2 Capture (Case 3) Emissions (kg/t HRC)	(Case 3) Annual Emission (t/y)
100	Flue Gas – Coke Oven	191.37	765,495	191.37	765,495	19.14	76,550	125.09	500,350
100	Flare – Coke Oven	3.30	13,196	3.30	13,196	3.30	13,196	-	-
200	Flue Gas – Sinter Plant (incl. CO emissions as CO2)	289.46	1,157,825	289.44	1,157,757	289.44	1,157,757	265.65	1,062,582
300	Flue Gas – Hot Stoves	415.19	1,660,769	41.51	166,051	41.51	166,051	-	-
300	Flue Gas - OBF Process Gas Fired Heaters	-	-	-	-	-	-	43.05	172,215
400/1300	Diffuse Emissions - HM Desulph. & Ancillaries (PCI Drying et. al.)	7.76	31,042	7.76	31,042	7.76	31,042	8.74	34,967
300	Flare – Blast Furnace	19.73	78,931	19.73	78,931	19.73	78,931	-	-
500/600	Flare (incl. losses) - BOF, Diffuse Emissions from SM	51.02	204,089	51.02	204,089	51.02	204,089	51.02	204,084
700	Diffuse Emissions – Continuous Casting	0.80	3,188	0.80	3,188	0.80	3,188	0.80	3,183
800	Flue Gas – Reheating Furnaces	57.71	230,833	57.71	230,833	57.71	230,833	57.71	230,833
900	Diffuse Emissions – Hot Rolling Mills	0.04	179	0.04	179	0.04	179	0.04	179
1000	Flue Gas – Lime Plant	71.62	286,493	71.62	286,493	7.16	28,649	71.43	285,729
1200	Flue Gas – Power Plant	982.13	3,928,513	210.8	843,211	227.31	909,221	211.1	844,398
2000	Flue Gas - Steam Generation Plant	-	-	96.61	386,456	102.5	410,008	280.12	1,120,487
1300	Ancillaries transport fuel emissions (trucks and rails)	4.00	16,000	4.00	16,000	4.00	16,000	4.00	16,000
Total Emissions		**2094.14**	**8,376,554**	**1045.73**	**4,182,921**	**831.42**	**3,325,694**	**1118.75**	**4,475,007**
Total CO_2 Captured		**NA**	**NA**	**1243.13**	**4,972,525**	**1532.82**	**6,131,267**	**859.84**	**3,439,360**
% CO_2 Avoided		**NA**		**50.1%**		**60.3%**		**46.6%**	

Table 6: Breakdown of the Total Investment Cost

Unit	Item	REFERENCE Steel Mill without CO_2 Capture (Case 1) Cost Breakdown	REFERENCE Steel Mill without CO_2 Capture (Case 1) CAPEX (US$ Million)	Steel Mill with Post-Combustion Capture (Case 2A - EOP-L1) Cost Breakdown	Steel Mill with Post-Combustion Capture (Case 2A - EOP-L1) CAPEX (US$ Million)	Steel Mill with Post-Combustion Capture (Case 2B - EOP-L2) Cost Breakdown	Steel Mill with Post-Combustion Capture (Case 2B - EOP-L2) CAPEX (US$ Million)	Steel Mill with OBF/MDEA CO_2 Capture (Case 3) Cost Breakdown	Steel Mill with OBF/MDEA CO_2 Capture (Case 3) CAPEX (US$ Million)
Unit	**Plant and Equipment – Major Processes**		**$ 2,772**		**$ 2,993**		**$ 3,014**		**$ 2,940**
100	Coke Production	400		400		400		310	
200	Sinter Production	220		220		220		220	
300 & 400	Blast Furnace and Hot Metal Desulphurisation	622		622		622		610	
500 & 600	Basic Oxygen Steelmaking and Ladle Metallurgy	459		459		459		459	
700	Continuous Slab Caster	195		195		195		195	
800 & 900	Reheating Furnace & Hot Rolling Mills	450		450		450		450	
1000	Lime Production	16		16		16		16	
1100	ASU – O_2 Production (High Purity)	130		130		130		94	
1200	Power Plant	280		362		362		362	
2000	Steam Generation Plant	-		139		160		90	
3000	ASU – O_2 Production (Low Purity)	-		-		-		134	
	Plant and Equipment – Material Handling & Spare		**244**		**247**		**247**		**242**
	Raw Material Handling	128		128		128		128	
	Spare Parts and First Fill	116		119		119		114	
	Plant and Equipment – Auxiliary, Utilities and BOP		**350**		**350**		**350**		**350**
	Site Development, Construction & Project Eng'g		**562**		**562**		**562**		**562**
	Pre-operating Expenses	21		21		21		21	
	Land Preparation, Site Development & Waste Disposal	144		144		144		144	
	Buildings and Site Infrastructure	196		196		196		196	
	Project Engineering	201		201		201		201	
Total Installed Cost - Steel Mill (US$ Million)			**$ 3,928**		**$ 4,152**		**$ 4,173**		**$ 4,094**
Contingency @ 5% of Total Installed Cost - Steel Mill			**196**		**208**		**209**		**205**
Unit	**CO_2 Capture Plant**		**-**		**679**		**917**		**578**
4000	Plant & Equipment, First Fill, Spare Parts, BOP, Site Dev.	-		590		797		503	
	Contingency (15% of Installed Cost – CO_2 Capture Plant)	-		89		120		75	
Total Investment Cost – excl. Recurring CAPEX (US$ Million)			**$ 4,124**		**$ 5,038**		**$ 5,321**		**$ 4,877**
Recurring CAPEX (Blast Furnace Reline – Every 15th Year)			**232**		**232**		**232**		**232**
Specific Investment Cost – excl. Recurring CAPEX (US$/t HRC)			**$ 1,031**		**$ 1,259**		**$ 1,330**		**$ 1,219**

Table 7: Breakdown of the Annual O&M Cost

	REFERENCE Steel Mill without CO_2 Capture (Case 1)		Steel Mill with Post-Combustion Capture (Case 2A - EOP-L1)		Steel Mill with Post-Combustion Capture (Case 2B - EOP-L2)		Steel Mill with OBF/MDEA CO_2 Capture (Case 3)	
	Cost Breakdown	Annual OPEX (US$ Million/y)	Cost Breakdown	Annual OPEX (US$ Million/y)	Cost Breakdown	Annual OPEX (US$ Million/y)	Cost Breakdown	Annual OPEX (US$ Million/y)
Fixed O&M Cost		**422.72**		**454.29**		**464.76**		**445.29**
Maintenance	141.996		169.903		179.996		163.633	
Direct Labour	204.581		208.247		208.623		205.521	
Indirect Labour	76.140		76.140		76.140		76.140	
Variable O&M Cost		**1288.65**		**1438.36**		**1492.62**		**1369.90**
Fuel and Reductant	483.938		615.481		666.362		562.214	
Iron Ore (Fines, Lumps and Pellets)	492.054		492.054		492.054		492.291	
Purchased Scrap and Ferroalloys	218.228		218.228		218.228		218.228	
Fluxes	44.650		44.650		44.650		40.091	
Consumables & Other Utilities	49.781		67.943		71.326		57.080	
Miscellaneous Expense		**62.25**		**62.25**		**62.25**		**59.04**
Miscellaneous Works Expense	50.398		50.398		50.398		48.066	
Other Misc. OPEX (incl. environmental clean up)	11.849		11.849		11.849		10.970	
Other O&M Cost		**8.18**		**11.33**		**12.07**		**8.60**
Slag Processing	3.578		3.578		3.578		3.568	
On-Site Haulage	0.268		0.268		0.268		0.265	
Disposal and Landfill	4.335		7.488		8.222		4.769	
Annual O&M Cost (US$ Million/y)		**$ 1,781.80**		**$ 1,966.23**		**$ 2,031.69**		**$ 1,882.84**

Table 8: Breakdown of the Annual Revenues from By-Products Sale

	REFERENCE Steel Mill without CO_2 Capture (Case 1)		Steel Mill with Post-Combustion Capture (Case 2A - EOP-L1)		Steel Mill with Post-Combustion Capture (Case 2B - EOP-L2)		Steel Mill with OBF/MDEA CO_2 Capture (Case 3)	
	Cost Breakdown	Annual Sale (US$ Million/y)	Cost Breakdown	Annual Sale (US$ Million/y)	Cost Breakdown	Annual Sale (US$ Million/y)	Cost Breakdown	Annual Sale (US$ Million/y)
100: Coke By-Products		**21.42**		**21.42**		**21.42**		**16.34**
Crude Tar	11.806		11.806		11.806		9.005	
Benzole	9.197		9.197		9.197		7.016	
Sulphur	0.420		0.420		0.420		0.320	
Steel Mill Slag		**18.23**		**18.23**		**18.23**		**15.37**
300: Granulated BF Slag	17.780		17.780		17.780		14.922	
600: BOS Slag (LD Slag)	0.450		0.450		0.450		0.448	
1100: Liquid Argon Sale		**14.02**		**14.02**		**14.02**		**3.25**
Annual Sale (US$ Million/y)		**$ 53.67**		**$ 53.67**		**$ 53.67**		**$ 34.96**

Table 9: CO_2 Avoidance Cost

	HRC Breakeven Price	Direct CO_2 Emission	% CO_2 Avoided	CO_2 Avoidance Cost
REFERENCE Steel Mill (Case 1)	575.23	2090.14 kg/t HRC	-	-
Steel Mill with Post-Combustion Capture (Case 2A - EOP-L1)	652.44	1041.73 kg/t HRC	50.2%	$73.64/t CO_2 Avoided
Steel Mill with Post-Combustion Capture (Case 2B - EOP-L2)	677.70	827.42 kg/t HRC	60.4%	$81.15/t CO_2 Avoided
Steel Mill with OBF & MDEA CO_2 Capture (Case 3)	630.22	1114.75 kg/t HRC	46.6%	$56.38/t CO_2 Avoided

Figure 2: Breakeven Price of the HRC from the "REFERENCE" Integrated Steel Mill

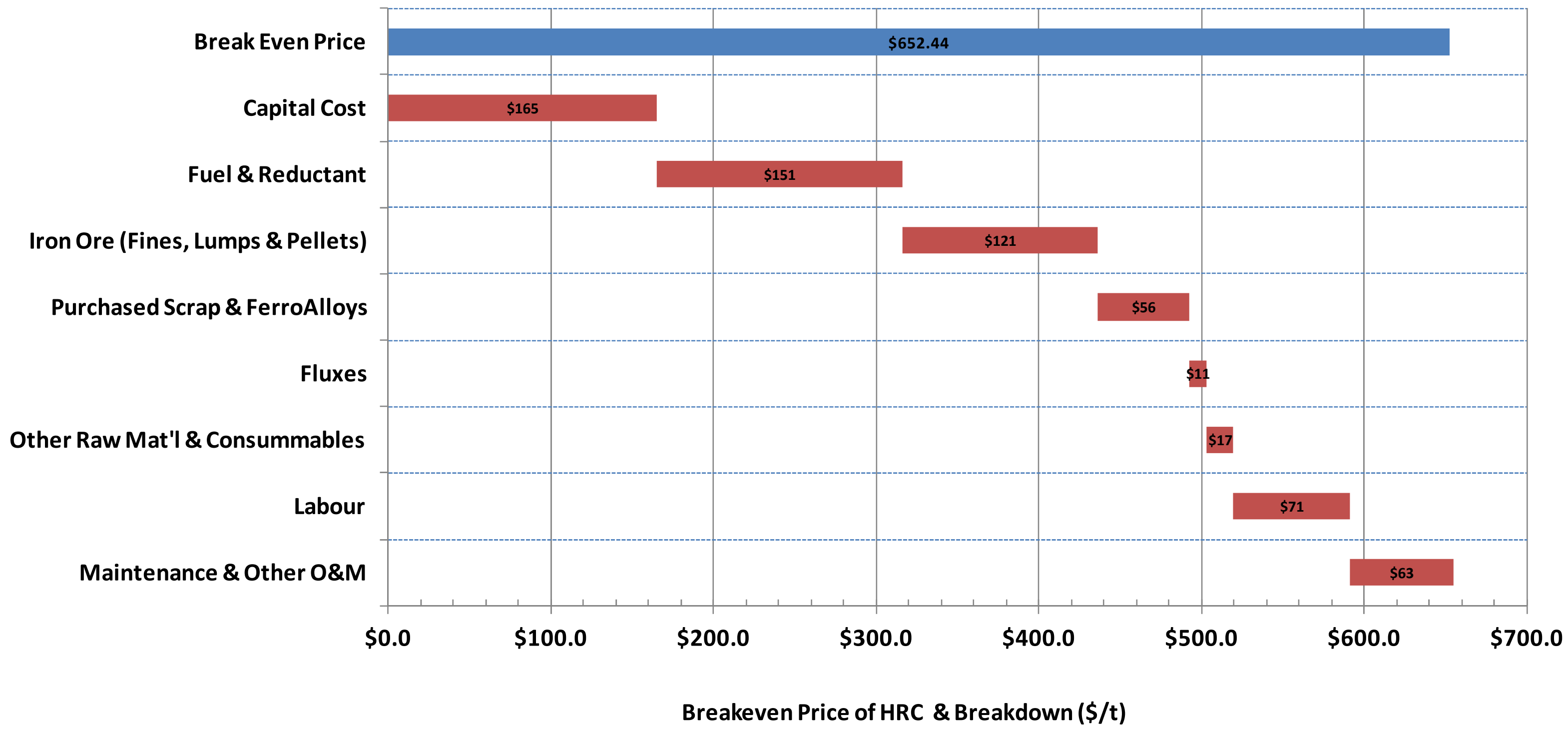


Figure 3: Breakeven Price of Hot Rolled Coil (Case 2A)
Integrated Steel Mill with Post-Combustion CO_2 Capture – EOP-L1 Case – $/t HRC (ex-works)

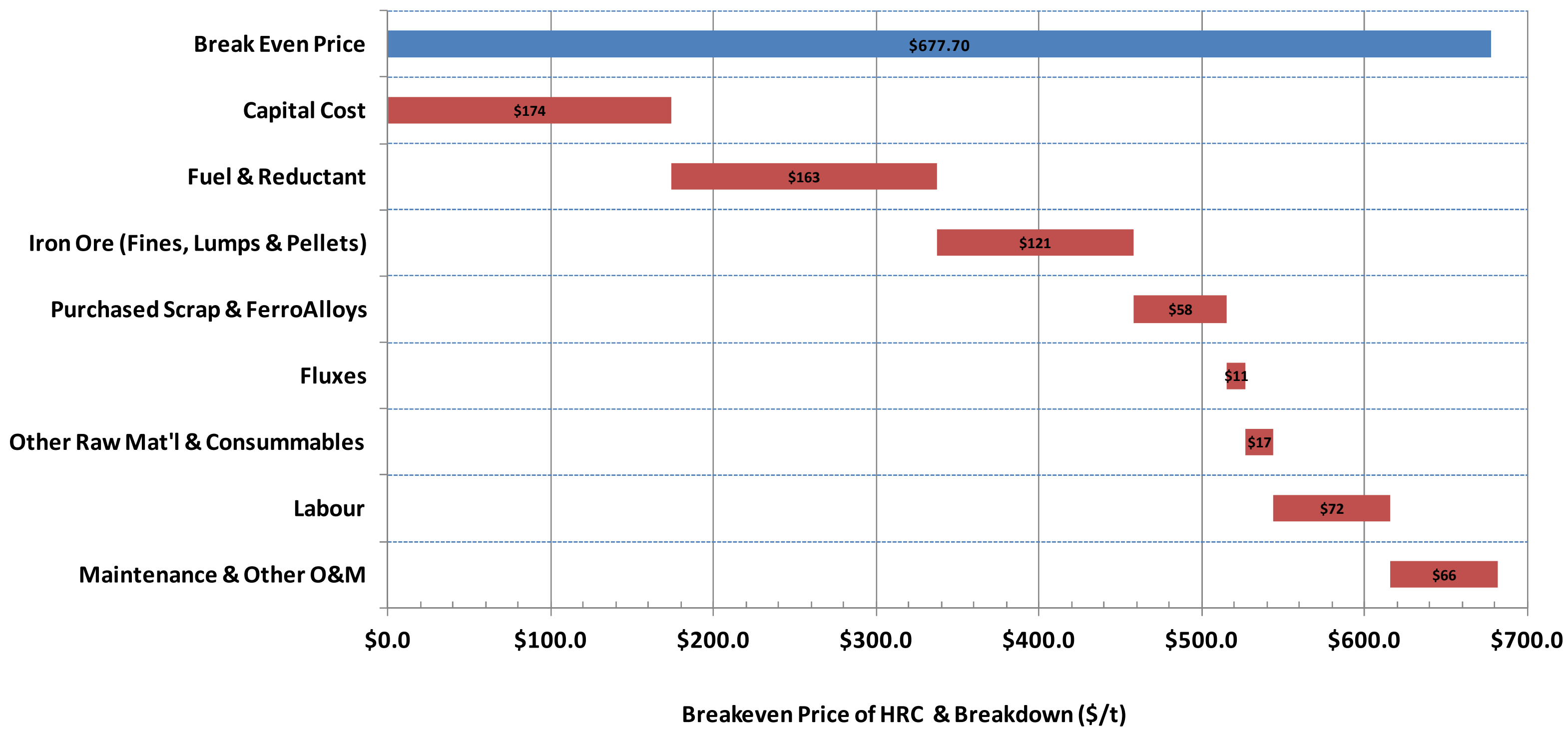


Figure 4: Breakeven Price of Hot Rolled Coil (Case 2B)
Integrated Steel Mill with Post-Combustion CO_2 Capture – EOP-L2 Case – $/t HRC (ex-works)

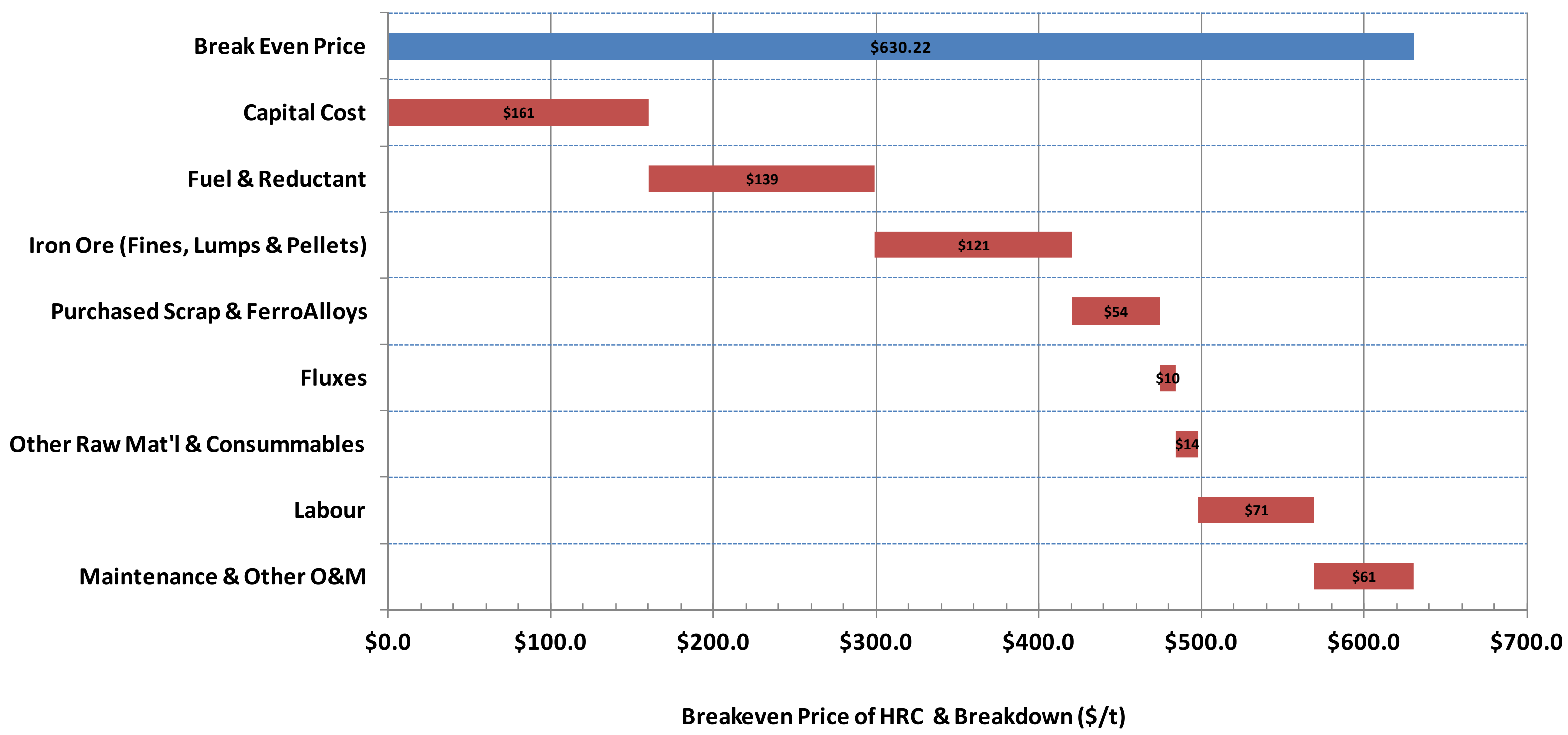


Figure 5: Breakeven Price of the Hot Rolled Coil (Case 3)
Integrated Steel Mill with OBF and MDEA CO_2 Capture – $/t HRC (ex-works)

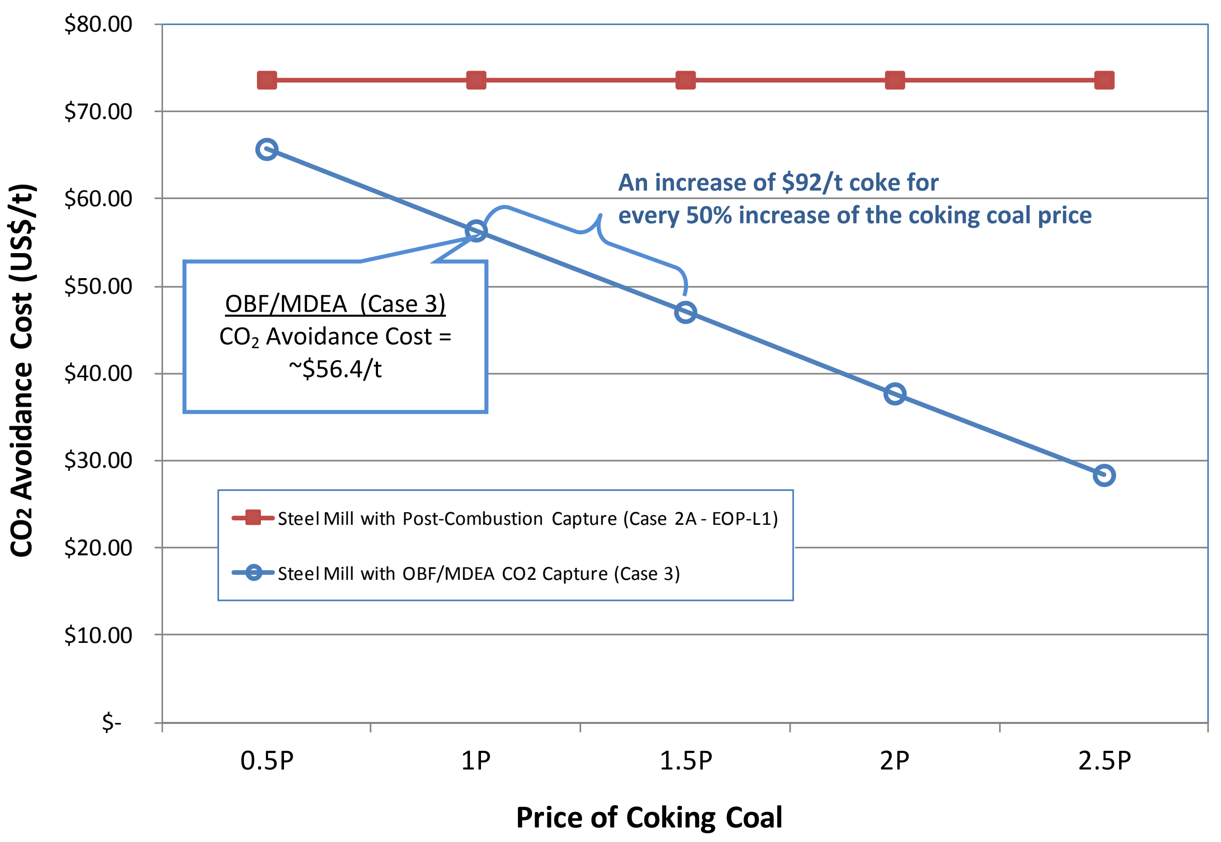


Figure 6: Sensitivity of the CO_2 Avoidance Cost to Coking Coal Price
(@ 1P → hard coking coal = US$220/t & semi-soft coking coal = US$160/t)

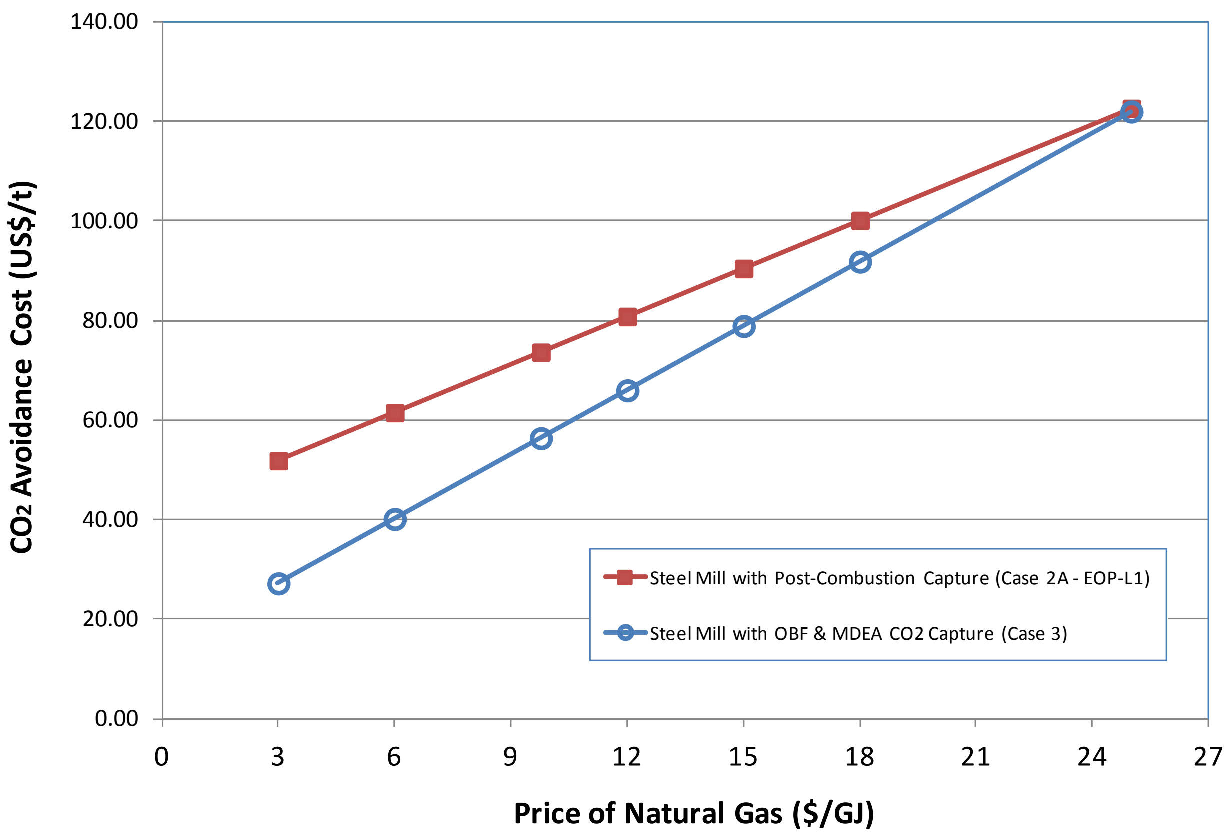


Figure 7: Sensitivity of the CO_2 Avoidance Cost to Natural Gas Price (at Coking Coal Price = 1P

Synthesis Report:

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Expert Reviewers Comments – Meeting Notes

Project Partners:

Swedish Energy Agency

swerea | MEFOS

ieaghg

SSAB

LKAB

Project Management, Implementation and Delivery:

swerea | MEFOS

TATA STEEL

Issued by:

IEA Greenhouse Gas R&D Programme
Cheltenham, UK

June 2013

1. INTRODUCTION

Given the complexity of the subject presented in this report with regard to the development and deployment of CCS in the iron and steel industry, IEA Greenhouse Gas R&D Programme (IEA GHG) has engaged several experts to review and discuss the outcome of this study.

Particular importance is the discussion with the team of experts from ULCOS. This document presents the key discussion points, response and recommendations for future studies.

2. ACKNOWLEDGEMENT

IEA Greenhouse Gas R&D Programme would like to acknowledge the following persons and organisations who have reviewed this document:

- Jean-Pierre Birat, Jean Borlée (ArcelorMittal)
- Chris Treadgold, Bert Gols, Jan van der Stel, Bruce Adderley (Tata Steel)
- Peter Sikström (LKAB)
- Kim Karsrud and Nils Edberg (SSAB)
- Hans Bodo Lungen (VDEH)
- Henk Reimink (World Steel)
- Joe Terrible, Michael Lanyi, Vince White, Ian Brass and Paul Higginbotham (Air Products)
- Andy Cameron (Linde)
- Jean Pierre Tranier, Nicolas Perrin (Air Liquide)
- Paul Ferron (CSIRO)

3. KEY DISCUSSION POINTS

(a.) Discussion on the assumption made for the REFERENCE Steel Mill

Experts from ULCOS have noted and presented in details the key differences between the selected REFERENCE steel mill of this study and compared them to the REFERENCE steel mill assumed by ULCOS in their economic analysis. They have noted that the difference between the energy and CO_2 ratios of the two reference steel mills range from 10 to 15%, with the reports' estimates on the higher side. The details of the differences are summarized in Annex I.

The author has agreed that this could be inevitable outcome of this study which only illustrates the importance of the site specific conditions that could impact the economics analysis of the deployment of CCS in an integrated steel mill.

This is an important key message presented in the report and has recommended a future study to look onto the cost of deployment of CCS in an integrated steel mill that incorporates most of the best available technology that could be economically deployed.

(b.) Use of assumptions of no export or import of electricity

The study has assumed that there will be no energy export or import into or out of the boundary limit.

Several experts have noted about this assumption as very unrealistic.

The authors have agreed that this unrealistic assumption tends to penalize energy efficiency gain. With this assumption in place, any improvement to the steel mill will consequently result to off-gases get flared or waste heat not recovered.

In reality, it is expected that any efficiency gain within the integrated steel would allow maximum utilization of waste heat and off-gases within the steel mill. This waste energy that could be recovered and can be converted into other form of energy (i.e. power, district heating, etc…) which should generate revenues therefore reducing the cost of steel produced.

This study has discuss extensively about this extra-ordinary assumption; however, the only purpose of this assumption is to simplify the accounting of energy and CO_2 emissions per tonne of steel produced; and removing the complexity of doing an energy optimization of the steel mill which tend to be very site specific conditions. It should be highlighted that one of the purpose of this study is to provide generic baseline information to estimate cost of CO_2 capture deployment in an integrated steel mill.

Nonetheless, this study has recommended that future study should remove this assumption. The cash flow analysis model developed for this study is capable to incorporate the export or import of energy into the steel mill.

(c.) Comments on the Assumptions used for the Air Separation Unit

- Experts have noted that assumption for energy consumption of the ASU is on the high side.

  The study assumed electricity consumption of 0.55 kWh/Nm^3 O_2 for the REFERENCE Case/ high purity O_2 for the OBF case; and 0.46 kWh/Nm^3 for low purity O_2 (95%, 5 bar$_a$) used by the OBF.

  Comments from Air Liquide and Air Products have recommended that for the REFERENCE case, the electricity consumption of 0.55 kWh/Nm^3 O_2 could be reduced to 0.48 kWh/Nm^3 O_2. On the other hand, significant difference has been noted for the low purity O_2 supplied to the OBF. Experts have recommended that a value of 0.33 kWh/Nm^3 O_2 as more appropriate that the assumed value of 0.47 kWh/Nm^3 used in this study.

  The authors have recognized this shortcoming and recommended that future study should pay attention in optimizing the ASU cycle to be used for the OBF case. Furthermore, it is also recommended to explore the use of Dual Purity ASU for the OBF case.

  Sensitivity analysis was made to roughly estimate the potential impact of the electricity consumption of the ASU to the breakeven price of the HRC. Tables 1 and 2 summarize the results of the sensitivity analysis.

Table 1: Impact of the Electricity Consumed by the ASU for the REFERENCE Case

	REFERENCE Steel Mill Base Case	REFERENCE Steel Mill with improved ASU
Electricity Consumed by the ASU	0.55 kWh/Nm^3 O_2	0.46 kWh/Nm^3 O_2
Specific Electricity Consumed by the Steel Mill	400.1 kWh/t HRC	389.2 kWh/t HRC
Natural Gas Consumed by the Steel Mill	0.8496 GJ/t HRC	0.7371 GJ/t HRC
Breakeven Price of HRC	US$ 575.23 /t HRC	US$ 573.99/t HRC

Table 2: Impact of the Electricity Consumed by the ASU for the OBF Case

	OBF Steel Mill Base Case	OBF Steel Mill with improved ASU
Electricity Consumed by the high purity O2 ASU	0.55 kWh/Nm^3 O_2	0.46 kWh/Nm^3 O_2
Electricity Consumed by the Low Purity O2 ASU	0.47 kWh/ Nm^3 O_2	0.33 kWh/Nm^3 O_2
Specific Electricity Consumed by the Steel Mill	573.4 kWh/t HRC	531.3 kWh/t HRC
Natural Gas Consumed by the Steel Mill	5.0454 GJ/t HRC	4.7778 GJ/t HRC
Breakeven Price of HRC	US$ 630.22 /t HRC	US$ 627.60/t HRC

- Consideration for the use of Two separate ASU producing two different purity specification

  Some experts have noted that the inclusion of two separate ASU's is hugely debatable due to the fact that integrated steel mill will require both high purity (for steelmaking) and low purity (for ironmaking) oxygen. This could increase CAPEX in terms of two separate set of pipe works, two set of storage bullets, etc…

  The authors may agree to this comment. Given the fact that the optimisation of the ASU has not be undertaken in this study. Critical to the deployment of OBF in integrated steel mill should also consider the interaction between a reliable supply of oxygen and operation of the OBF.

  It was recommended for future study that this should be given in more attention and more detail.

- Liquid Argon Sale

  Comments from the expert noted that the price for the Argon sold in this study is based on retail value therefore giving higher revenue. It should be noted that future study should factor in wholesale value which could provide a more realistic scenario for integrated steel mill with captive ownership of the ASU.

  Furthermore, it was also noted that liquid argon to sale is different between the REFERENCE and OBF cases, thus introducing a bias in the comparison. With a value of argon at 0.9299 US$/Nm^3, it is very likely that it penalize the OBF plant which is producing less argon ; therefore, it would be better to produce maximum argon from unit 3000 (even at a higher power consumption) but in this case we may favor too much the OBF plant ; an intermediate option would be to keep the same unit 1100 in both cases (at 1900 tpd O2 with argon production) and have a unit 3000 only for the additional oxygen (4100 – 1900 + 1200 = 3400 tpd O2 without argon production)

The authors have agreed to these comments. The current assumptions used in this study result to a lost of revenue of ~$10.8 million/y for the OBF case. It was recommended that future optimization of the ASU should factor in this consideration. It should also be highlighted that this is one of the site specific conditions (highly dependent on electricity price) that could impact economics of steel production.

(d.) Discussion on the assumption made for the OBF Case

Expert noted the difference between the technology choice selected by ULCOS and the current study. The Annex presents the key differences between OBF vs ULCOS BF.

In the course of this review, the following areas were discussed:

- The study selected an OBF which is nearly similar to the ULCOS BF v1, which is not the choice for the Florange Demonstration Project. Furthermore, they have noted the choice of using MDEA/Pz capture which ULCOS has noted to consume more energy as compared to the PSA option.

  The authors noted that the selection of the MDEA/Pz for CO_2 capture is not a recommendation as the best available technology for the OBF case. However, the selection is based on what data and cost information that is available in the open literature. MDEA/Pz is widely used in the separation of CO_2 from Natural Gas extraction. Performance are well documented. Cost data are readily available. Therefore this has been selected for this study in order to establish generic baseline cost information. It should be highlighted that selection of best technology for CO_2 capture is not the objective of this study.

- The study reported a BF productivity increase from 2.5 to 4.0 thm/m^3/d. Experts have noted that this could be optimistic.

  In the context of this discussion, it should be noted that this assumption is an important parameter in determining the hearth diameter of the BF. This assumption resulted to a reduction of diameter from 11m (REFERENCE Case) to 8.5m (OBF Case). The authors have noted that based on the calculation of the gas flow using the Ergun Equation, it is possible that productivity increase of 60% is achievable for this version of the OBF.

  Discussion on productivity is not straightforward, however, it should be noted that productivity is based on the gas flow through a bed of solids. Therefore, productivity is dependent on several factors which also include the assumption used in the coke reduction due to the top gas recycling. It is worthwhile to note that this calculation including the rate of coke reduction would require further validation in a large scale demonstration.

  As compared to the ULCOS v4 or v3, the carbon reduction assumed in this study is conservative at 17% (for ULCOS – v4 and v3 – they have estimated a ~24% carbon reduction).

Furthermore, the authors have noted that the assumption of 4.0 thm/m^3/d is comparable to the several operating BF today operating with very high O_2 enrichment (for example, Ijmuiden BF6 has achieved a productivity of 3.2 thm/m^3/d with hot blast oxygen enrichment of 32%).

(e.) Discussion on the steam consumption of the MDEA/Pz CO2 capture plant

Experts from ULCOS consortium has been critical with regard to the reported performance (i.e. steam demand of the reboiler) of the MDEA/Pz solvent. They believe that results presented are overly optimistic at 2.3 GJ/t CO_2. In this regard, IEAGHG consulted CSIRO (Australia) to provide an independent opinion regarding the results reported in this study. A detailed evaluation by CSIRO determined that the values reported for the reboiler duty are considered reasonable. From CSIRO's assessment and calculation, it was noted that reboiler duty could range between 2.5 and 2.7 GJ/t CO_2 depending on how the process is optimised. It was in their opinion that the value of 2.3 GJ/t CO_2 reported by SINTEF in this study has been optimised based on conventional configuration which are typically found in a natural gas treatment plant and value reported could be achievable for the given operating pressure. Furthermore, they have concluded that the lower value of 2.1 -2.2 GJ/t CO_2 could be achieved by using the split flow configuration which has been demonstrated to reduce energy consumption in pilot plant operated by CSIRO.

Furthermore, a sensitivity analysis has been made regarding the possible impact of the steam demand for solvent generation to the cost of steel produced. Figure 1 presents the results of this sensitivity analysis.

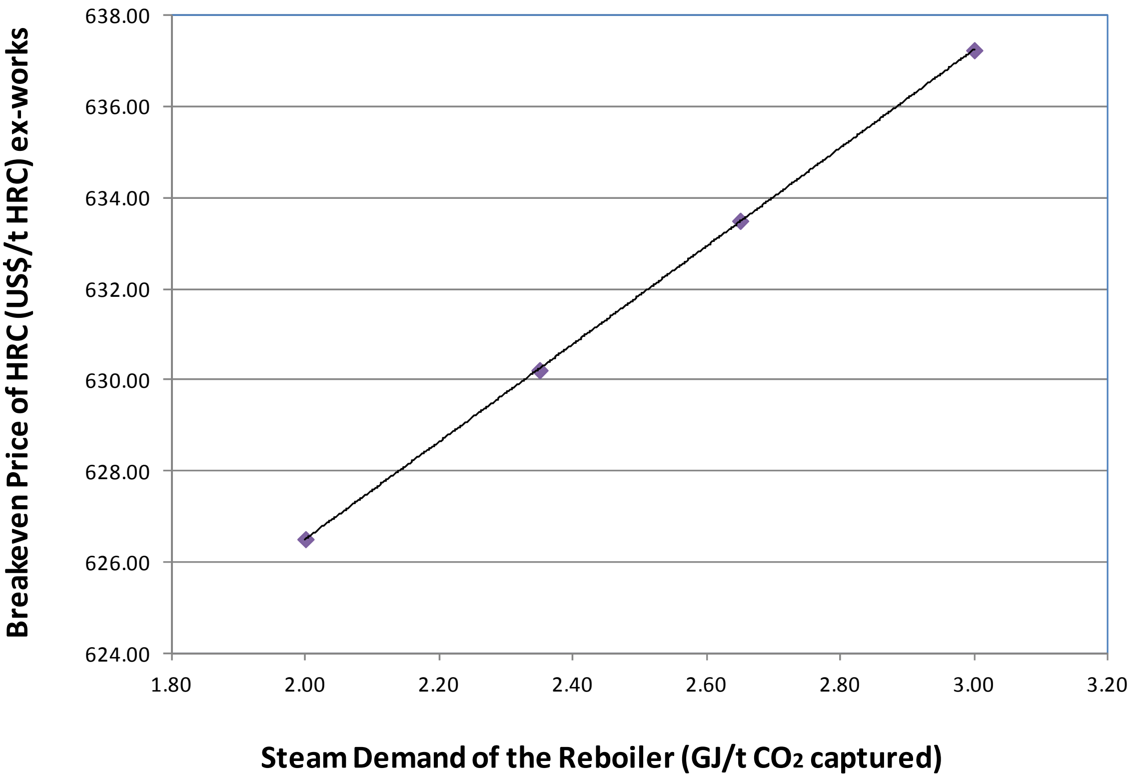


Figure 1: HRC Price Sensitivity to the Steam Demand of the CO_2 Capture plant

(f.) Discussion on the techno-economic calculation

Experts from ULCOS have noted the following:

- The cost calculations do not take on board all the uncertainties and variability that have been experienced in the last few years and which will be experienced in the future, volens nolens. The dispersion of possible prices for energy (especially coke in the steel case) and raw materials is much broader than what was assumed in the report. Moreover, it is rather meaningless to announce a cost of avoided CO_2 without specifying the values taken by these other parameters (foremost of which, again, is coke, but also electricity, natural gas, etc.): it is misleading to imply that there is a cost of avoided CO_2 for the steel sector, like the 60 €/t_{CO2} mentioned in the April 2012 version of the report. The real figure may be less or more, much more, and the uncertainty analysis does not explore this in a credible way.

In response to these comments, the authors agreed and would like to thank the experts for highlighting the importance of the sensitivity analysis. In this regard, we have incorporated sensitivity analysis of the coking coal and natural price in the study. The price range for coking coal has reflected the changes that were experienced in the past 10 years.

ANNEX

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Reviewers' comments on the IEA-GHG reports
"Assessing the potential of implementing CCS in an integrated steel mill",
volumes 1, 2 and 3

Jean-Pierre Birat, Jean Borlée, ArcelorMittal
Chris Treadgold, Bert Gols and Jan van der Steel, Tata Steel
Peter Sikström, LKAB
Kim Karsrud and Nils Edberg, SSAB

This review summarizes the comments made on the fly on the 3 reports, as they were communicated to us between October 2011 and April 2012. Many details were hopefully taken on board by the authors in real time and we only focus here on more general comments and issues. The present document will hopefully be included in the report.

The reviewers belong to the ULCOS consortium, led by ArcelorMittal. ULCOS is the only program in the steel sector, worldwide, addressing climate change mitigation in the near term and the CCS solution examined in the IEA reports is a mirror image of the ULCOS-BF technology. It thus seemed natural to prepare a common review document.

Our comments are the following:

1. the reports are easy to read and to check in details. The physics which they incorporate seems as good as can be. We wonder though why it is so detailed, as this kind of cost analysis is not usually reported so extensively. Moreover, given the level of details provided, the reader might be induced in taking the results and conclusions for granted, although they describe technology options which we question below.

2. regarding technology choices, we have a number of comments, which boil down to three points:

- the "reference" steel mill selected in the report is coherent and credible but represents a fairly conservative, middle of the road mill; moreover the perimeter of the steel mill does not match the choices made in previous published work (scope II not included, pellet and dolomite plant not included), etc. Energy and CO_2 emissions per ton of steel are thus on the high side and could fairly easily be improved, as is done in a large number of steel mills in Western Europe. In our own work (JP. Birat, JP. Lorrain, Y. de Lassat, The "CO_2 tool": CO_2 emissions and energy consumption of existing and breakthrough steelmaking routes, La Revue de Métallurgie-CIT, Sept. 2009, 325-336; JP. Birat, JP. Lorrain, Y. de Lassat, The « cost tool », La Revue de Métallurgie-CIT, Sept. 2009, 337-349), which you don't seem to have quoted, we described a more ambitious steel mill, closer to the state of the art (benchmark steel mill): the rationale of these publications was to incorporate as many energy savings technologies as makes sense in Western Europe up front and only afterwards to estimate what breakthrough technologies could bring in terms of further energy performance and CO_2 reduction.

  The difference between the energy and CO_2 ratios of the two reference steel mills range from 10 to 15%, with the reports' estimates on the higher side.

  The details of the differences are summarized in appendix I.

- the breakthrough steel mills that are examined in volumes 2 and 3 are quite different from the ULCOS Blast Furnace, although they may look superficially similar: to make ourselves perfectly clear, the solutions that the reports investigate fall broadly in the scope of ULCOS BF technologies, but the details selected do not match the elementary technologies chosen for the Florange demonstrator. We hope that this is made clear to all the readers, in a more explicit way than in the present version so that the conclusions reached cannot be taken by a casual reader as an illustration of what the ULCOS-BF demonstrator and more generally the ULCOS-BF technology will eventually deliver. The reader may also wonder why the reports chose these solutions rather than ULCOS' solutions, which have gone through a complex and detailed selection process: this should probably be explained somehow. Another point is that the level of technology incorporated in the breakthrough steel mill is not at the same level as in the reference mill (power plant, in particular). And, overall, the breakthrough steel mill is technologically optimistic, while the reference mill was pessimistic!

The difference between the energy and CO_2 ratios of the IEAGHG vs ULCOS mills ranges from 10 to 30%.

The details of the differences are summarized in appendix II.

- a major issue is related to uncertainties and sensitivity. Mirroring what chemical engineers usually claim, when they do a pre-FEED study, the report suggests a +/- 30% bracket range and this is also the bracket of exogenous parameters which is examined in the sensitivity analysis. A steel mill is not a chemical plant and metallurgical engineering is not chemical engineering. Moreover, there is NO experience on large scale implementation of the kind of breakthrough technologies that is discussed here, a situation which is quite different from the experience of the power industry.

It is therefore not right to believe that CCS can be handled in the same manner in the power and the industrial sectors, like steel: differences are very many, as we have very often pointed out (J.-P. Birat, Steel sectoral report, Contribution to the UNIDO roadmap on CCS, "Global Technology Roadmap for CCS in Industry" sectoral workshop, Abu Dhabi, 30 June-1 July 2010; http://www.unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Energy_Efficiency/CCS/Steel_sectoral_%20report.pdf; J.-P. Birat, Carbon dioxide (CO_2) capture and storage technology in the iron and steel industry, in Developments & innovation in carbon dioxide (CO_2) capture and storage technology, volume 1: C carbon dioxide (CO_2) capture, transport and industrial applications, M. Maroto-Valer, editor, Woodhead Publishing, 2010, 493-521).

The most efficient and economic technology to separate CO_2 from the top gas of an ULCOS-BF Blast Furnace is not amine scrubbing, as assumed by the report, but a PSA technology, complemented by further purification, for example a cryogenics unit. The cost structure of these technologies is completely different and this is another reason why the IEAGHG CCS solution is quite broadly unrelated to the ULCOS-BF technology.

3. regarding economic calculations:

- the cost calculations do not take on board all the uncertainties and variability that have been experienced in the last few years and which will be experienced in the future, volens nolens. The dispersion of possible prices for energy (especially coke in the steel case) and raw materials is much broader than what was assumed in the report. Moreover, it is rather meaningless to announce a cost of avoided CO_2 without specifying the values taken by these other parameters (foremost of which, again, is coke, but also electricity, natural gas, etc.): it is misleading to imply that there is a cost of avoided CO_2 for the steel sector, like the 60 €/t_{CO2} mentioned in the April 2012 version of the report. The real figure may be less or more, much more, and the uncertainty analysis does not explore this in a credible way.

- continuing on the comments of the previous section, the specific features of CCS for steel make estimating costs a very risky and non completely realistic endeavor! One important reason why the Florange demonstrator has been proposed to the NER-300 program is that we need large-scale experiments and lasting experience to reach a beilievable cost estimate. Present figures may be off by 100% or much more!

4. we had only limited time time, prior to the 12 May 2012 seminar, to examine and review volume 2. A quick check shows that the assumptions taken for MEA stripping (3 GJ/t_{CO2}) are overoptimistic and do not reflect the best state-of-the-art and likely energy consumption for a reasonable future.

5. we were quite interested by the level of analysis used to describe power generation based on steel process gas. However, given the very preliminary nature of the modeling of a BF with CCS, there is too much of it.

6. finally, the purpose of the study is expressed as aiming to help provide cost information, which does not exist today in the literature. What we want to stress, rather adamantly, is that the answers that the report provides are not contributing to this purpose in an obvious manner: the system modeled in this work is quite different, in very many details, from the process technologies that the ULCOS program is developing (the ULCOS program is the largest effort to develop these carbon-lean process solutions in the world) – with a gap of 30 to 40% in terms of energy or CO_2 reduction, a fairly large figure; moreover, the cost modeling does not reflect the range of uncertainties which come along with the published figures.

As a short summary of these comments, the IEAGHG report presents a version of CCS in the Steel sector which is clearly inspired by the ULCOS-BF technology, but is so different in so many details, that it does not seem relevant to describe the actual cost of a robust CCS solution. Why the authors have chosen to model this particular technology is hard to understand, given that the information related to what is being done in the ULCOS program is available openly.

The danger is that the casual reader will pick up the cost values reached at the end of the study and use them to evaluate CCS in the steel sector. Providing numbers, when these are very uncertain and the magnitude of the uncertainty is unknown, raises almost philosophical issues!

There is another important matter, which ought t be mentioned. There is today a huge gap between the need for a carbon-lean economy, as expressed by policy makers to respond to the vision of climate modelers, and the readiness of the world and especially of the economy to accommodate it: the present price of carbon in the ETS (6.6 €/t) is out of sync with the value needed to make CCS, in any context, economically viable. World governance will need to tackle this conundrum if CCS is even to become a solution to Climate Change.

As most of these comments have been addressed to the authors prior to the final edition of the report, we hope that they will have been taken on board in the final version of the report, which we did not see.

15 June 2012.

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Appendix I: comparison between the report baseline steel mill and the ULCOS benchmark Blast Furnace

Baseline BF
Scope & assumptions (metallurgical)

ArcelorMittal

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- Very efficient integrated plant
  - Lower RAR at BF (483 kg/thm)
  - PCI at BF: 193 kg/thm
  - TRT (Recovery Turbine at BF)
  - Less slag at BF and BOF
  - Higher product yield at HR
  - Less electricity at HR
  - More efficient ASU
- Pellet and burnt dolomite plants included

IEA GHG

- Typical (average) integrated plant
  - Higher RAR (501 kg/t = +4%)
  - PCI at BF: 152 kg/thm (-21%)
  - No TRT (+20 kWh/thm)
  - More slag at BF and BOF
  - Lower yield at HR (-3%)
  - +20 kWh/tHRC at HR (+5%)
  - +10% as kWh/t O2 at ASU

➔ Larger coke plant (+35%)

➔ More electricity consumed (+20%)

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Baseline BF
Scope & assumptions (overall energy)

ArcelorMittal

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- Power plant produces as much electricity as possible from the surplus of plant gases at ~36% efficiency

➔ Electricity import from the grid to balance steel plant needs:
33 kWh/t HRC at 370 g CO_2/kWh
= 12 kg CO_2/t HRC (Scope 2)

IEA GHG

- Power plant produces the whole electricity required by the steel plant

➔ Natural gas import to balance power plant needs:

- Base case (32% efficiency)
  75 kWh/t HRC at 650 g CO_2/kWh
  = 49 kg CO_2/t HRC
- Case 1a (37% efficiency)
  25 kWh/t HRC at 565 g CO_2/kWh
  = 15 kg CO_2/t HRC

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Baseline BF
Overall results

ArcelorMittal

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- Pellet and burnt dolomite plants included

  ➔ + 0.1 t CO_2/t HRC

IEA GHG

- +15 % (+ 88 kg/t HRC) coal input

  ➔ + 0.3 t CO_2/t HRC

- Higher electricity consumption compensated by more COG available

+0,2 t CO2/t HRC

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Baseline BF
Overall results

ArcelorMittal

	ulcos	IEA GHG	
CO_2 emissions (t CO_2/t HRC)	1.842 (scope 1 + 2)	Base case: 2.090 Case 1a: 2.056	+ 14% + 12%
Energy (GJ/t HRC)	18.6	Base case: 21.3 Case 1a: 20.7	+ 14% + 11%

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Appendix II: comparison between the report CCS steel mill and the ULCOS-BF process route

ULCOS-BF
Scope & assumptions (metallurgical)

ArcelorMittal

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- Very efficient WE integrated plant
  - …
- Pellet and burnt dolomite plants included
- TGR-BF V4
- BF productivity increase 25%
- With PSA+CPU capture

IEA GHG

- Typical (average) integrated plant
  - …
- TGR-BF V1
- BF productivity increase 60%
- With amine capture (aMDEA) with very optimistic steam consumption rate (2.3 GJ/t CO_2)*

* Similar plant in AM consumes close to 3 GJ/t CO_2

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ULCOS-BF
Scope & assumptions (overall energy)

ArcelorMittal

ulcos

- No power plant (no surplus of plant gases)

→ Full electricity import from the grid to balance steel plant needs: 547 kWh/t HRC at 370 g CO_2/kWh = 202 kg CO_2/t HRC (Scope 2)

→ Natural gas import to fulfil the heating demand (1.4 GJ/t HRC)

IEA GHG

- Boiler (fed with the surplus of plant gases + natural gas) to produce the steam required by the CO_2 scrubbing plant
- Power plant (NGCC at 57% efficiency) to produce the whole electricity required

→ Natural gas import to balance power plant needs: 573 kWh/t HRC at 370 g CO_2/kWh = 212 kg CO_2/t HRC

→ Natural gas import to fulfil the heating demand at boiler and plant (1.4 GJ/t HRC)

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ULCOS-BF
Overall results

ArcelorMittal

	ulcos	IEA GHG	
CO_2 produced (t CO_2/t HRC)	*1.660 (= 90% of BBF)*	*1.980 (= 96% of BBF)*	*+19%*
CO_2 emissions (t CO_2/t HRC)	0.899 (sc 1+2) (= 49% of BBF)	1.119 (= 54% of BBF)	+ 24%
CO_2 captured (t CO_2/t HRC)	0.760	0.860	+ 13%
Energy (GJ/t HRC)	16.9 (= 91% of BBF)	21.8 (= 103% of BBF)	+ 29%

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Synthesis Report:

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume I: Estimating the Cost of Hot Rolled Coil Production from an Integrated Steel Mill (Reference Case)

Project Partners:

Swedish Energy Agency   swerea MEFOS   ieaghg

SSAB   LKAB

Project Management, Implementation and Delivery:

swerea MEFOS   TATA STEEL

Issued by:

IEA Greenhouse Gas R&D Programme
Cheltenham, UK

November 2012

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The project – **"Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill"** was initiated by IEA Greenhouse Gas R&D Programme. In collaboration with Swerea MEFOS, this project was developed with an aim to provide a plant wide techno-economic assessment of an integrated steel mill with and without CO_2 capture.

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- Swedish Energy Agency
- LKAB
- SSAB
- Members of Swerea MEFOS

The project is managed by a Steering Committee whose members represent the different project partners mentioned above. This committee is chaired by Nils Edberg of SSAB.

The main work was done by Swerea MEFOS team – providing the relevant mass and energy balance information required for the techno-economic evaluation. The project is supported by TATA Steel Consulting - developing the cost estimate model and SINTEF Materials and Chemistry evaluating the CO_2 capture plant model.

IEA Greenhouse Gas R&D Programme would like to acknowledge the work done by the project team members from the following organisations:

- Swerea MEFOS (lead organisation)
- Tata Steel Consulting
- Sintef Materials and Chemistry

Disclaimer:

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume I: Estimating the Cost of Steel Production from an Integrated Steel Mill (Reference Case)

I N D E X

LIST OF ABBREVIATIONS

ASU	air separation unit (also known as oxygen plant)
BAT	best available technology
BF	blast furnace
BFG	blast furnace gas
BOF	basic oxygen furnace (also known LD or converter)
BOFG	basic oxygen furnace gas (also known as LDG or CG)
BOP	balance of plant
BOS	basic oxygen steelmaking
BREF	Best available technology reference document
BTX	benzene, toluene and xylene (also known as Benzole)
CAPEX	capital expenditure
CDQ	coke dry quenching
CG	converter gas (also known as BOFG or LDG)
COG	coke oven gas
De-S	desulphurised
dmtu	dry metric tonne unit
DRR	direct reduction rate
EAF	electric arc furnace
EBITDA	earnings before interest, tax, depreciation and amortisation
EOS	emission optimised sintering process
ESP	electrostatic precipitator
EU27	European Union (27 member countries)
FeMnC	ferromanganese carbide
FeSi75	ferromanganese silicon (at least 75% silica content)
GAN	gaseous nitrogen
GAR	gaseous argon
GBFS	granulated blast furnace slag
GGBFS	granulated ground blast furnace slag
GOX	gaseous oxygen
GTCC	gas turbine combined cycle
HM	hot metal (also known as pig iron)
HRC	hot rolled coil
HRM	hot rolling mill (also known as HSM)
HS	hot stove
HSM	hot strip mill
IEAGHG	IEA Greenhouse Gas R&D Programme
IPPC	integrated pollution prevention control
JCR	jumbo coke reactor (also known as SCS)
LAR	liquid argon
LDG	Lint-Donawitz gas (also known BOFG or CG)
LIN	liquid nitrogen
LM	ladle metallurgy
LOX	liquid oxygen
MAC	main air compressor
mtpy	million tonnes per year
NG	natural gas
NGCC	natural gas combined cycle
OBF	oxy-blast furnace (oxygen blown blast furnace)
OBF-PG	OBF processed gas

OBF-TG	OBF raw top gas
OHF	open hearth furnace
OPEX	operation expenditure
PCI	pulverized coal injection
PFD	process flow diagram
PFR kiln	parallel flow regenerative kiln
RAR	reducing agent rate
RHF	rotary hearth furnace
SCS	single chamber system (also known as JCR)
SCR	selective catalytic reactor (for NOx removal from flue gases)
SM	secondary metallurgy
SOACT	state of the art clean technology for steel production (REFERENCE Handbook)
tcs	tonne of crude steel
TGR	top gas recycle
thm	tonne of hot metal
tls	tonne of liquid steel
TRT	top gas recycle turbine
WBF	walking beam furnace

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume I: Estimating the Cost of Steel Production from an Integrated Steel Mill (Reference Case)

<u>**Section A**</u>

Introduction and Background

<u>**I N D E X**</u>

1. INTRODUCTION

The Executive Committee of IEA Greenhouse Gas R&D Programme (IEA GHG) has requested a study to be made evaluating the potential for CO_2 capture to reduce greenhouse gas emissions from an integrated steel mill and its associated cost.

In collaboration with Swerea MEFOS AB, this project was developed with co-funding support from the Swedish Energy Agency, SSAB, LKAB and Swerea MEFOS member companies. The project was initiated in January 2010.

Swerea MEFOS AB has retained the service of Corus Consulting PLC (now TATA Steel Consulting) to undertake the cost evaluation and financial modelling and also engaged SINTEF Materials and Chemistry to undertake the evaluation of post-combustion capture CO_2 modelling.

The primary goal of this project is to specify a **"REFERENCE"** integrated steel mill producing hot rolled coil and evaluate the cost and performance of the plant with and without CO_2 capture. It is important to note that "REFERENCE" Steel Mill specified for this study does not necessary employ every best available technology. It is presumed that any technology with minimal penetration or application to European Steel Mills will not be used.

The evaluation of the performance of the steel mill is focused on determining the direct CO_2 emissions of the different processes and evaluating the CO_2 avoidance cost for the "REFERENCE" Steel Mill without and with CO_2 capture. The mass and energy balances of the steel mill were calculated at a level of detail sufficient to estimate the cost of steel produced on with an accuracy of ±30%.

One of the aims of this study is to provide a clear methodology that provides the fundamental framework needed for evaluating the cost of steel production with and without CO_2 capture.

It should be emphasised that due to significant variations in steel production processes – as illustrated in this study, that the cost estimates presented in the report should not be quoted or used for comparison without careful consideration of the boundary limits and assumptions used.

This document is a synthesis of the Volume 1 report submitted by Swerea MEFOS to IEA Greenhouse Gas R&D Programme (IEA GHG) evaluating the cost of steel production from a reference integrated steel mill conceptually situated in the coastal region of Western Europe.

2. BACKGROUND

The iron and steel industry is one of the largest industrial sources of CO_2. Globally, it accounts for about 6% of anthropogenic CO_2 emissions from energy use.

Currently, two main processes dominate global steel production:

- the integrated steel mill in which steel is made by reducing iron ore in a blast furnace and subsequent processing in a primary steelmaking plant (BF-BOF Route); and
- the mini-mill in which steel is made by melting scrap steel or scrap substitutes in an electric arc furnace (EAF Route).

Globally, the production of steel from the BF–BOF route accounted for 65 - 69% in the past ten years. Within the EU27, the BF-BOF route accounted for 58% of steel production in 2008.

Alternative iron and steel making processes based on direct or smelting reduction technologies - such as COREX, FINEX, DRI, Midrex and many others - are also used to produce steel in various sites worldwide. Several of these technologies are commercially operated, however, they only account for a small share of steel produced globally. It is expected that steel production via the BF-BOF and EAF routes will still dominate steel production for several decades to come.

Current World Steel Association performance indicators are that 1.8 tonnes of CO_2 arises from the use of 20.8 GJ of energy per tonne of crude cast steel. However, there is wide variance in country by country data. It was widely reported that steel mills using the BF-BOF route emit between 1.6 and 2.2 t CO_2/tonne steel, whereas the EAF route using scrap metal emits 0.6 to 0.9 t CO_2/tonne steel and the EAF route using DRI emits 1.4-2.0 t CO_2/tonne steel[1].

To reduce CO_2 emissions from steel mills (specifically from Integrated Steel Mills) one of the leading options being considered by the iron and steel stakeholders is CO_2 capture and storage (CCS). Development of this technology for application in iron and steel production is still on-going (ref. ULCOS project or involvements of the World Steel Association CO_2 Breakthrough Programme).

This study is tasked to evaluate the cost and performance of a Reference Steel Mill (Base Case) without CO_2 capture, and three different scenarios from among the several options available for capturing CO_2 from an integrated steel mill.

3. PROJECT MANAGEMENT OVERVIEW

The study is managed by the Steering Committee whose members represent the project partners.

Members of the Steering Committee are:

- Nils Edberg, SSAB – Chairperson
- Camilla Axelsson, Swedish Energy Agency
- Helen Axelsson, Jernkontoret
- Kim Kaersrud, SSAB
- Anita Larsson, Swedish Energy Agency
- Stanley Santos, IEA Greenhouse Gas R&D Programme
- Peter Sikstrom, LKAB
- Jan Olov Wikstrom, Swerea MEFOS
- Guang Qing Zuo, LKAB

Any action required for the project is decided upon based on a consensus among all the members of the committee.

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[1] Note:

- Although the EAF route has lower CO_2 emissions, it should be emphasized that the two production routes (i.e. BF-BOF & EAF) are not comparable due to the differences in feedstock, in steel grade and other reasons.
- The very wide variation of the reported CO_2 emissions is due to the significant differences in the steel production process, raw material inputs, products (intermediate / by-products / finished) produced.
- Due to the multiple sources of CO_2 emissions from the different processes within the steel mill, it is noted that accounting of CO_2 emissions per tonnes of steel is not as straight forward as compared to accounting of power plant's CO_2 emissions from a single stack.

The project tasks are assigned to a project team whose members are:

- Lawrence Hooey (Swerea MEFOS) – Team Leader / Project Manager
- Axel Bodén (Swerea MEFOS)
- Mikael Larsson (Swerea MEFOS)
- Mikael Knights (Tata Steel Consulting)
- Jeremy Johns (Tata Steel Consulting)
- Vic Abraham (Tata Steel Consulting)
- Andrew Tobiesen (SINTEF Materials and Chemistry)
- Karl Anders Hoff (SINTEF Materials and Chemistry)
- Geir Haugen (SINTEF Materials and Chemistry)
- Steve Goldthorpe (IEA Greenhouse Gas R&D Programme)

4. OBJECTIVES OF THE STUDY

The project team was requested by the Steering Committee to specify and evaluate the cost and performance of an integrated steel mill producing 4 million tonnes of hot rolled coil per year. The "REFERENCE" integrated steel mill without CO_2 capture would be designed based on specifications typical to an average Western European Steel Mill.

Specifically, the study aims:

- To specify a conceptual "REFERENCE" steel mill typical to Western European configuration and evaluate the techno-economic performance of the integrated steel mill with and without CO_2 capture.

- To determine the techno-economic performance, CO_2 emissions and avoidance cost of the following cases:
    - A conceptual integrated steel mill typical to Western Europe as the "Base Case".
    - An end of pipe CO_2 capture using conventional MEA at two different levels of CO_2 capture rate
    - An Oxygen Blast Furnace (OBF) and using MDEA for CO_2 capture.

It should be noted that "REFERENCE" Steel Mill specified in this study is not necessarily the best performing steel mill which applies all the Best Available Technologies (BAT) that are commercially available. Nonetheless, this will be based on a common/typical configuration that could be found in many European steel mills.

5. SCOPE OF THE REPORT

The Volume 1 of this report presents the techno-economic analysis of the cost of steel production of a conceptual "REFERENCE" Integrated Steel Mill without CO_2 capture typical to Western Europe that produces 4 million tonnes of Hot Roll Coil (HRC) per year.

The main scope of Volume 1 is to define the assumptions used in the techno-economic evaluation of the study and to illustrate the main results of the study. These include description of:

- Plant location
- Boundary limit (Battery Limit)
- Raw materials, products and by-products

- Process description
- Material balances
- Process gas network
- CO_2 balance

The objective of Volume 1 of this report is to present and highlight the methodology of the Techno-Economic Evaluation, the key assumptions used to estimate CAPEX and OPEX and the key results of the study.

Finally, it should be noted that it is not the purpose of this synthesis report to present the full detailed engineering design and detailed description of the steel production processes nor the modelling approach of the mass and energy balance - as these are described in the main report presented by Swerea MEFOS [1].

6. NOTES TO THE READER

The intention of this study is to simulate the different techno-economic parameters of an average performing integrated steel mill. Therefore, it should be noted that the “REFERENCE” Steel Mill specified in this study is not necessarily to have the best performing steel mill that applies all the Best Available Technologies that are commercially available. Nonetheless, this will be based on a typical configuration that could be found in many European steel mills.

Finally, it is the intention of the authors to present every volumes of this report to be self containing. Therefore, all assumptions and the discussion of the background to them are presented in details in Volume 1. However, some of these discussions will be repeated within the text of Volumes 2 and 3 to ensure that these volumes could be read separately.

To summarise, Volume 1 of the report presents the design, assumptions, performance and economic details of a hypothetical steel mill which can be used as a basis to explore and comparing options for CO_2 emission reduction. Volume 2 of the report presents the analysis of a steel mill with conventional post-combustion capture options (i.e. capture of CO_2 from the different flue gases within the steel mill). Volume 3 presents an option where further efficiency could be gained through the use of novel technology using oxy-blast furnace with top gas recycle; that could improve the economics of the capture of CO_2 from an integrated steel mill.

7. REFERENCES

[1] Hooey, L., Boden, A., and Larsson, M. (2011). **“Assessing CO_2 Capture Application in Integrated Steel Plant – Reference Plant Design”.** *MEFOS Report – 560025*

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Section B

Design Basis, Assumptions and Methodology

INDEX

1. BOUNDARY LIMIT

The definition of the boundary (battery) limit of the integrated steel mill is essential to formulate a clear account of the overall energy requirements and direct CO_2 emissions per tonne of steel produced (For this study – this should define the total CO_2 emitted per tonne of hot rolled coil).

A schematic representation of the boundary limit, material inputs and outgoing products, by-products and waste is illustrated in Figure B-1. A full PFD diagram representing the Reference Steel Mill (Base Case) is presented in Figure B-2.

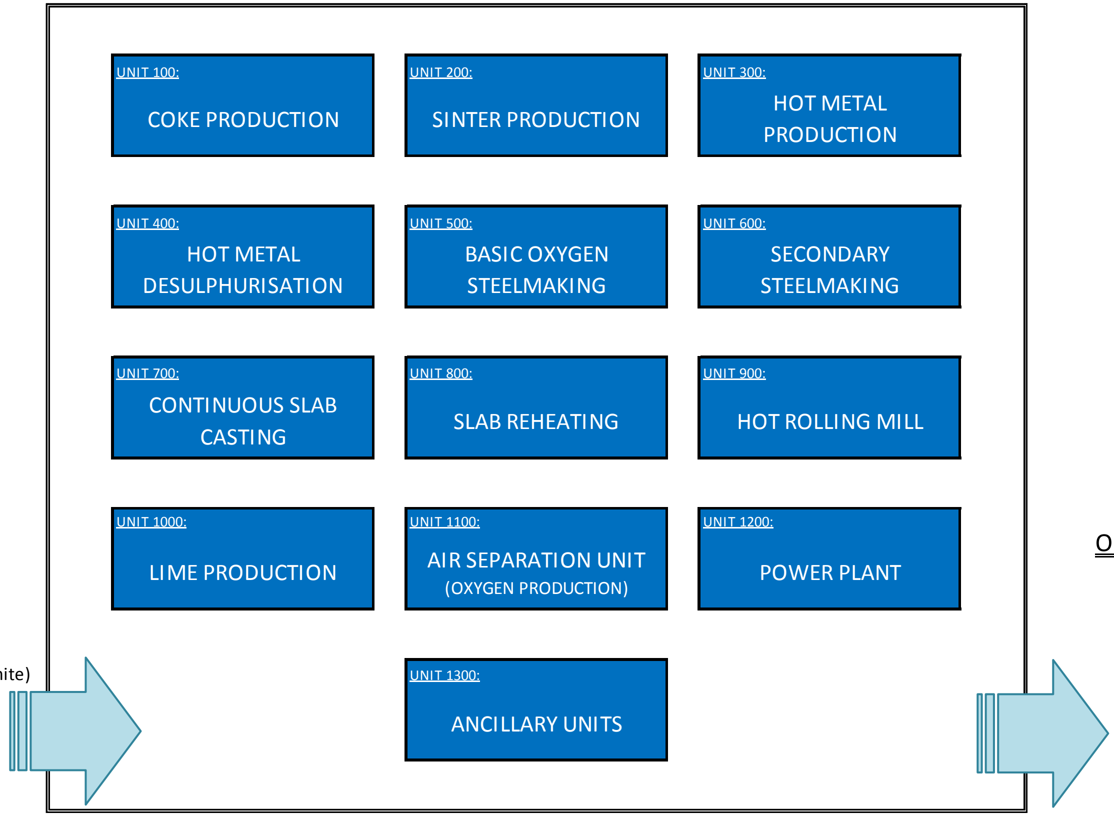
The steering committee agreed that the boundary limit should include the following unit processes:

- UNIT 100: Coke Plant
- UNIT 200: Sinter Plant
- UNIT 300: Blast Furnace and Hot Stoves (Iron Making Process)
- UNIT 400: Hot Metal Desulphurisation Plant
- UNIT 500: Basic Oxygen Steelmaking
- UNIT 600: Ladle Metallurgy
- UNIT 700: Continuous Casting
- UNIT 800: Reheating Furnace
- UNIT 900: Hot Rolling Mill
- UNIT 1000: Lime Plant
- UNIT 1100: Oxygen Plant (Air Separation Unit)
- UNIT 1200: Power Plant
- UNIT 1300: Ancillaries

Raw material handling, utilities, waste water treatment plant and other auxiliary equipment are assumed to be included in each unit.

INCOMING:

- Iron Ore Burdens (Fines, Lump & Pellet)
- Merchant Scrap
- Ferro Alloys (FeMnC, FeSi-75, Aluminium)
- Fluxes (Limestone, Quartzite, Olivine, CaC2, Burnt Dolomite)
- Coking Coal (Hard and Semi-Soft)
- PCI Coal
- Natural Gas
- Other Consummables and Additives



OUTGOING:

- Hot Rolled Coil
- Coking By-Products (Coal Tar, BTX and Sulphur)
- Slag (BF Granulated Slag, De-S Slag, BOF Slag, LM Slag)
- BF Sludge and Dust
- Liquid Argon

- Emissions (Flue Gases, Diffuse and Fugitive)
- Vent Gases (Waste Nitrogen and Oxygen)

Figure B-1: Schematic representation of the Boundary Limit of the REFERENCE Steel Mill. [1]

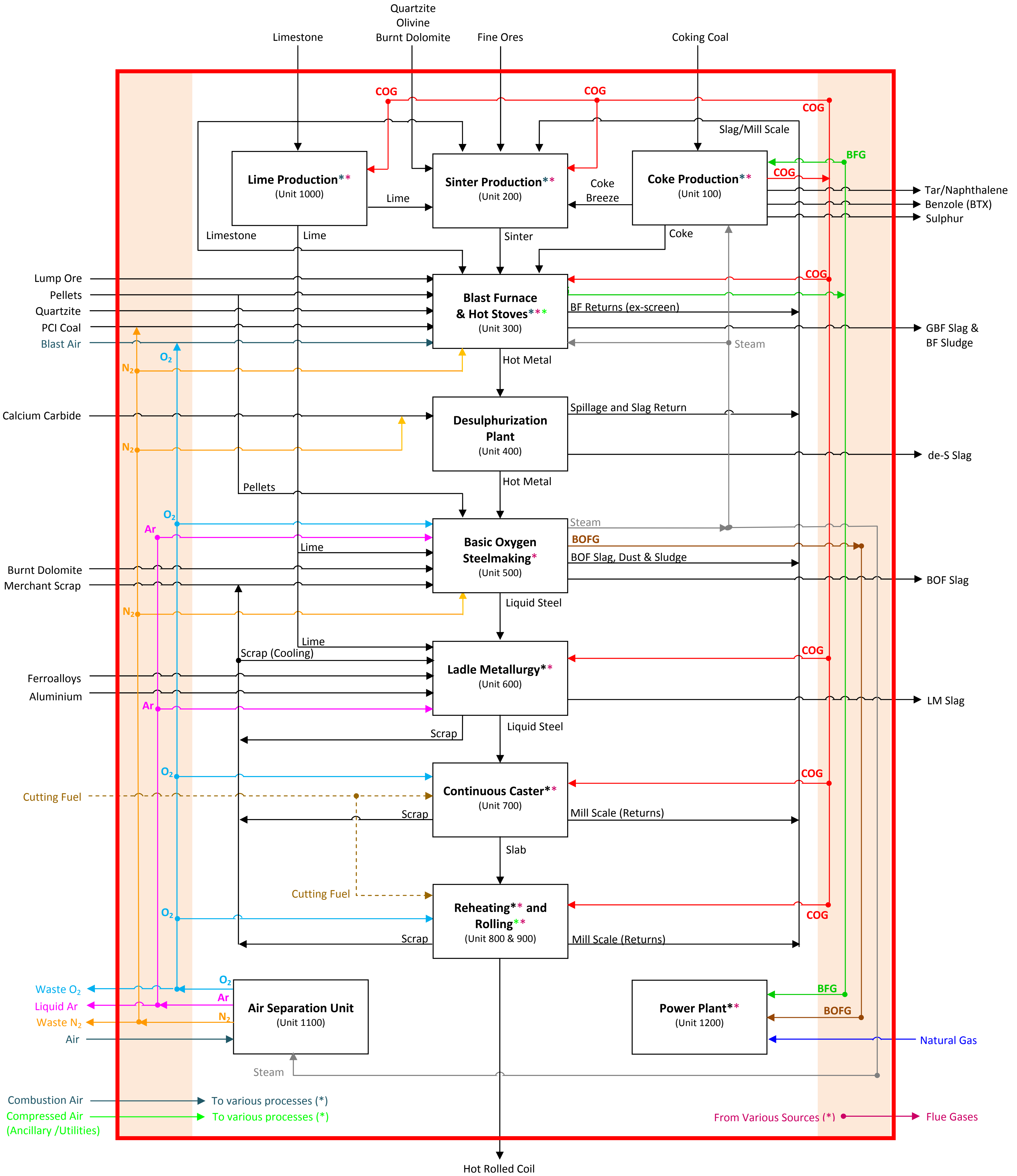


Figure B-2: Process Flow Diagram of the REFERENCE integrated steel mill without CO_2 capture [1]

The major raw materials for the steel production considered in the study are:

- Iron Ore Fines
- Iron Ore Pellets
- Lump Iron Ore
- Coking Coal
- PCI Coal
- Fluxes (Limestone, Quartzite, Olivine, Calcium Carbide, Burnt Dolomite)
- External Scrap (also referred to Merchant or Purchased Scrap)
- Ferro Alloys and Aluminium
- Natural Gas
- Other consumables (as specified in Section C).

The product and by-products that are sold outside the boundary limit include:

- Hot Rolled Coil
- Crude Tar
- Benzole
- Sulphur
- Granulated BF Slag
- BOS Slag (also referred to LD Slag)
- Argon

The site will be handling several intermediate products used in the production of steel and these include:

- Coke
- Sinter
- Lime
- Hot Metal
- Liquid Steel
- Slab

Materials that are accounted as waste that goes to the landfill are:

- BF Sludge
- de-S Slag
- BOS Slag (also referred to LD Slag)
- LM Slag (also referred to SM Slag)

Industrial gases and off-gases handled by the site include:

- Blast Furnace Gas (BFG)
- Basic Oxygen Furnace Gas (BOFG)
- Coke Oven Gas (COG)
- Oxygen
- Nitrogen
- Argon

Utilities that are available or produced within the boundary limit include:

- Steam
- Electricity
- Water (i.e. sea water, potable, machinery cooling water, condensates)

2. PLANT LOCATION AND LAYOUT

The steel mill is located along the Coastal Region of Western Europe. It should be noted that this location is representative of several integrated steel mills close to the Atlantic Coast of Europe.

The site is assumed to have:

- access to an existing port capable of handling all incoming raw materials
- access to natural gas via a pipeline connected to the main grid
- access to an existing rail line adjacent to the steel mill

It is assumed that the steel mill is situated where there are no exceptional ground conditions that would lead to higher than normal construction costs. It is also assumed to be close to a deep sea, thus limiting the length of the sea water cooling lines (both submarine and sea water pump discharge lines).

The site will have adequate road and rail networks for delivery of raw materials, intermediate and final products from stockyards to various points of the steel mill.

The site layout is shown in Figure B-3. This is only to illustrate the minimum land footprint required. It should be noted most steelworks have greater distances between individual processes.

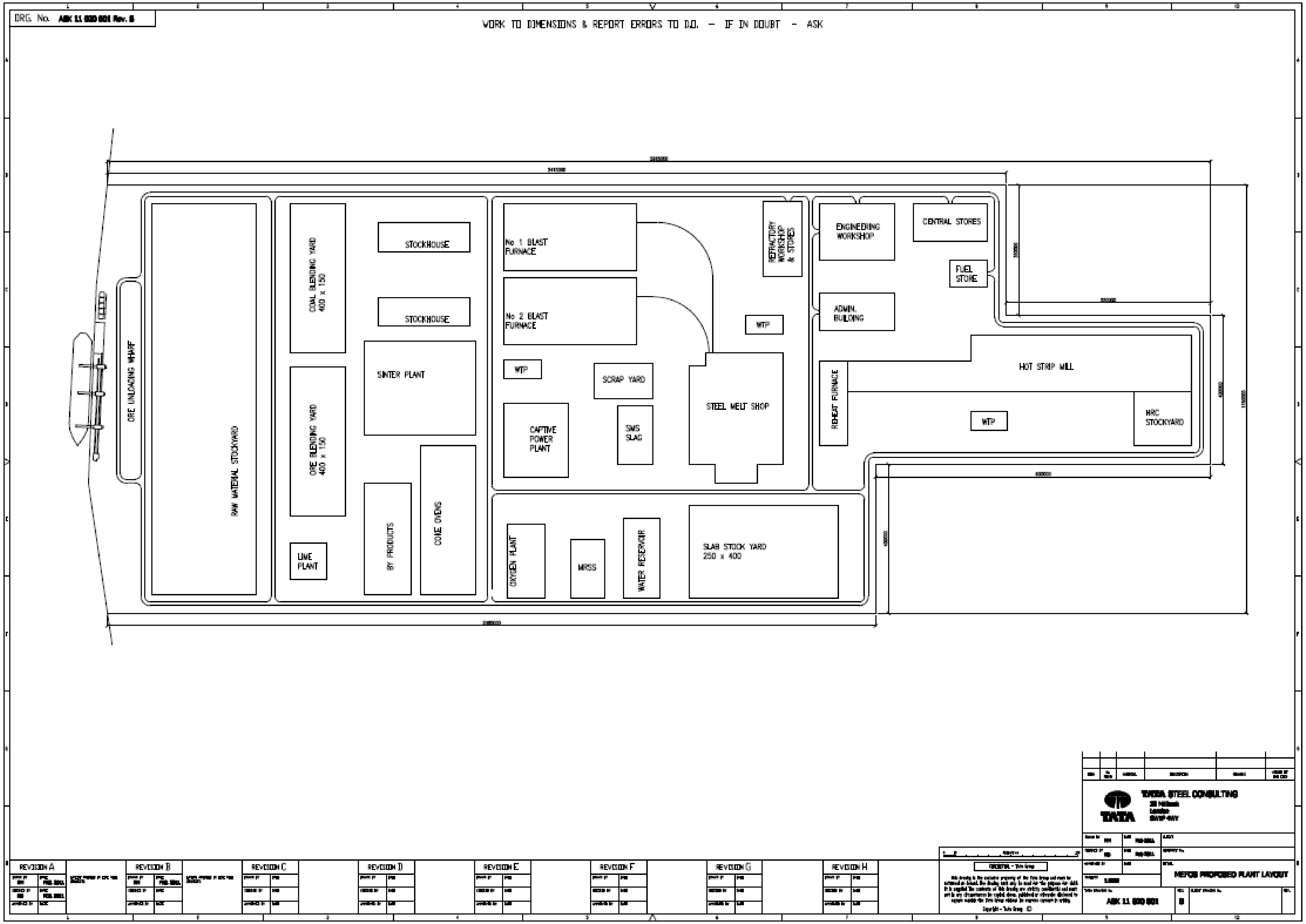


Figure B-3: Steelwork Site Layout [1]

3. GENERAL ASSUMPTIONS: REFERENCE STEEL MILL (BASE CASE)

The assumptions used to evaluate the "REFERENCE" integrated steel mill are summarized in this section. Other assumptions made which are specific to the different process units are presented in the methodology (Section B6).

3.1. Extra-Ordinary Assumptions

Some assumptions which are classified as extra-ordinary were used to simplify the accounting of the CO_2 emissions, the energy demand, and the cost of steel produced. It should be noted that these assumptions are only used to provide a clear illustration and to establish a comparable cost basis between steel mills with and without CO_2 capture.

It should be emphasized that these assumptions are very idealized and not intended to represent any actual integrated steel mills in operation. These are only used to simplify the accounting of energy imports and exports and the CO_2 emissions associated with these.

The steering committee agreed to the following extra-ordinary assumptions to be used in the study:

a) Only one type of steel product produced and sold.

   It was assumed in the study that a standard grade hot rolled coil will be the only main product to be sold outside the set boundary limit.

   It should be noted that typical integrated steel mills would produce several grades and forms of steel in a single site; and also have the possibility to sell semi-finished products like slab, beam or billet.

   Annual production of 4 million tonnes of hot rolled coil per year was assumed. This is agreed to represent typical capacity of European Integrated Steel Mills.

b) Plant ownership structure

   The study assumed captive ownership of the lime plant (UNIT 1000), oxygen plant (UNIT 1100) and power plant (UNIT 1200).

   In general, European integrated steel mills, do not own these plants. Electricity, industrial gases (O_2, Ar & N_2) and lime required by the steel mill are generally bought based on long term over the fence contracts and guarantees. CO_2 emissions from these facilities are typically not accounted for in the direct emissions of the integrated steel mill.

   However, directly or indirectly, these plants use the off-gases of the steel mill as their primary energy source. In order to simplify the accounting of the direct CO_2 emissions and cost evaluation without the consideration of the "CO_2 Emission Export", these plants were assumed to be included in the boundary limit and owned by the steel mill.

c) Balanced coke production

The study assumed that coke plant (UNIT 100) will produce lump coke and coke breeze that are sufficient for the demands of the steel mill – i.e. there will be no export or import of coke.

In general – coke is a tradable commodity and any surplus coke produced by an integrated steel mill is sold in the market. Typically, there is no integrated steel mill that will have coke production in balance with the steel mill's requirements.

d) Captive power plant – with balanced electricity production

The study assumed that all off-gas produced from the coke ovens (UNIT 100), blast furnaces (UNIT 300) and basic oxygen steel furnaces (UNIT 500) are recovered based on industry norms and are used within the steel mill. Any excess off-gases are delivered to the captive power plant as fuel.

The captive power plant is assumed to produce electricity that is only enough to supply the requirements of the whole steel mill as specified in the boundary limit. There will be no import or export of electricity.

The study assumed that only natural gas is imported into the boundary limit to supplement any fuel requirements that are not covered by the off-gas production. There will be no export of off-gases or other forms of energy (i.e. steam or hot water) outside the boundary limit.

In case that any surplus off gases is produced – it will be assumed to be flared. In addition to flared off-gases which are normal in any operating steel mills, all off-gases that are considered lost or not recovered will also be accounted for as "flared".

In reality the majority of Western European integrated steel mills do not own their power plant. Any excess off-gases produced from these steel mills are sold as fuel to a power plant or other users outside the steel mill complex. Delivery is via a pipeline based on an off take supply contract. The electricity required by the steel mill is generally bought from a power plant outside their steel mill complex based on a long term over the fence contract or is bought directly from the grid.

e) Other operating considerations

- CO_2 emissions resulting from manufacture of purchased pellets, burnt dolomites and merchant scrap will not be accounted as direct CO_2 emissions of the steel mill.

- Granulated BF Slag will not be given CO_2 emission credit – even if this could be considered as substitute clinker for the cement industry.

3.2. Key Assumptions

Key technical assumptions used to define the boundary conditions in determining the heat and mass balance are summarized below.

a) The steel mill is assumed to have access to natural gas delivered via pipeline.

b) Iron Ore Burden

The iron ore burden composition for the blast furnace was fixed in the study and this consisted of: (1.) Sinter ~70%w; (2.) Pellets ~22%w; and (3.) Lump ore ~8%w. This distribution is maintained constant over the economic life of the integrated steel mill.

The iron ore fines used to produce the sinter are assumed to be imported from Brazil (Hematite), Australia (Hematite & Goethite) and Sweden (Magnetite). The lump ore is from Australia; and the pellets are from Brazil.

In general, there are very wide variations in iron ore burden composition among the operating blast furnaces in Western Europe ranging from 100% pellet to 100% sinter. The burden chosen has been agreed among the members of the Steering Committee and accepted as representative ferrous burden of a typical European Steel Mill equipped with a sinter plant.

c) Coking Coal and Coke By-Products

The study assumed a By-Product Recovery Coking Plant with Coke Oven Gas, Crude Tar, Benzole and Sulphur as the only coking by-products produced by the "Reference" Steel Mill.

Based on industry norms the coke and coke by-products were specified according to the following yields (as %w of the input coking coal):

- Lump Coke 67.2%w
- Coke Breeze 10.6%w
- Coke Oven Gas (wet) 14.2%w
- Crude Tar 3.2%w
- Benzole 0.9%w
- Sulphur 0.2%w

However, it should be noted that the study did not provide a detailed mass balance for the coke by-product plant. Coke demand/coke rate was calculated from the Blast Furnace Model as briefly described in Section B6.3. Coking coal required is defined by the coke demand of the steel mill and typical coke yield reported by the industry.

It should be noted that it is very typical for steel mills to buy their coking coal from various sources and blend both high and low quality coking coal to the coke ovens (type of coking coal used is normally of several varieties unless it is being sourced from a single coal mine).

To represent the typical blends of high and low quality coking coal used in any steel mill, a proportion of 60%w hard coking coal and 40%w semi-soft coking coal was assumed. Both types of coking coal are imported from Australia. This distribution is maintained constant over the economic life of the integrated steel mill.

d) Key Ironmaking Operating Parameters

The following parameters were fixed to determine the overall iron ore requirements, sinter rate and coke rate of the blast furnace.

- PCI Coal Injection rate ~150 kg/thm

- Oxygen enrichment of the blast air 24%
- Slag rate ~280 kg/thm.
- Hot metal temperature set to 1470°C with hot metal Si and C content fixed at 0.5% and 4.7% respectively.

Hot Metal loss was fixed at ~1.9%Fe for the HM Desulphurisation Plant (UNIT 400).

e) Key Steelmaking Operating Parameters

The study assumed liquid steel production based on 2x 220 tonnes BOS Furnaces operating at 45 minutes per cycle, each equipped with waste heat boiler.

The following parameters were fixed to determine the amount of fluxes and additives needed for the steelmaking process.

- Total scrap rate ~190 kg/tls (with purchased scrap at ~116 kg/tls)
- Pellets for cooling ~5 kg/tls
- Burnt dolomite ~11 kg/tls
- Oxygen charged ~52 Nm^3/tls
- Slag rate ~113 kg/tls (with composition of the slag fixed)
- BOF gas recovery set at 75% of carbon recovery using a fixed gas composition.

Other operating considerations

- Continuous casting was assumed to have a slab yield of ~97%.
- Reheating and rolling mills was assumed to have steel recovery of ~95%.

f) Off-Gas Distribution

The composition of off gases obtained from the coke ovens, blast furnaces and basic oxygen furnaces were specified according to industry norms.

This study assumed the following utilisation of off-gases recovered for fuel:

- COG would supply fuel to the following:
  - coke plant (UNIT 100)
  - sinter plant (UNIT 200)
  - hot stoves (UNIT 300)
  - reheating furnace (UNIT 800) and
  - lime plant (UNIT 1000)

- BFG would supply fuel to the following:
  - hot stoves (UNIT 300) and
  - power plant (UNIT 1200)

- BOFG would supply fuel to the power plant (UNIT 1200).

The off-gas distribution will be maintained constant over the economic life of the REFERENCE Steel Mill.

4. DESIGN BASIS - SITE SPECIFIC CONDITIONS

4.1. Ambient Conditions

The average ambient conditions of the site were assumed as follows:

- Ambient Air Temperature 12°C
- Atmospheric Pressure 1.013 Bar
- Relative Humidity 80%

4.2. Raw Water

Raw water is obtained from the grid. This is normally treated and demineralised to the required standard for process water use and machinery cooling.

For machinery cooling, a maximum of 10°C rise was used during normal operation. It was assumed that a closed loop system was employed with sea water as the medium for cooling the machinery cooling water.

Raw Water

- Source: from grid
- Type : potable water
- Operating pressure at grade: 0.8 barg (min)
- Operating temperature : Ambient

Demineralised Water

- Type: treated water (mixed bed demineralization)
- Operating pressure at grade: 5.0 barg
- Operating temperature: Ambient
- Characteristics:
  - pH 6.5 to 7.0
  - Total dissolved solids (mg/kg) 0.1 max
  - Conductance at 25°C (μS) 0.15 max
  - Iron (mg/kg as Fe) 0.01 max
  - Free CO_2 (mg/kg as CO_2) 0.01 max
  - Silica (mg/kg as SiO_2) 0.015 max

4.3. Sea Water

Seawater used by the steel mill is normally for cooling duty using a once through cooling system. It is generally filtered and chlorinated to remove suspended solids and organic matter.

Sea Water

- Supply temperature:
  - average supply temperature: 12 °C
  - max allowed sea water temperature increase: 7 °C

- Other Data
  - Operating pressure at Users inlet: 0.9 barg
  - Max allowable ΔP for Users: 0.5 barg
  - Design pressure for Users: 4.0 barg
  - Design pressure for sea water line: 4.0 barg

- o Design temperature: 55 °C
- o Cleanliness Factor (for steam condenser): 0.9
- o Fouling Factor: 0.0002 h °C m^2/kcal

4.4. Steam

Steam is available for plant used at 8 Barg and 175^{o}C (saturated).

For the REFERENCE Steel Mill Base Case, it is verified that the steam produced from the basic oxygen steelmaking plant (UNIT 500) should deliver enough steam for the demand of the entire steel mill. Back up steam, if required, could be obtained by extracting low pressure steam from the captive power plant's steam turbine.

It should be noted that the Combined NH_3 cracker and Claus Plant should also produced a small amount of low to medium pressure steam which is not modelled in the study. However, it could be assumed that this will be used by the coke plant and will not be distributed to the works' steam network.

4.5. Electricity

The electricity required for the steel mill is produced from the captive power plant. It was assumed that the steel mill has access to the main grid to provide backup electricity.

Specification of the electricity grid of the steel mill is presented below.

- Voltage: 110kV
- Frequency: 50 Hz
- Fault Duty: 50 kA

5. DATABASE & ENERGY EFFICIENCY MANAGEMENT SELECTION

Swerea MEFOS used existing and newly developed Microsoft EXCEL based in-house mathematical models of individual processes to calculate the mass and energy balance of the iron and steel production.

The process models are calibrated and validated using data and information from different databases to reflect the typical configuration of a European Integrated Steel Mill.

5.1. Database

Various databases were used to calibrate the mathematical models. Some confidential databases were also used to validate the results of the model.

Databases and information used for this study include:

- Swerea MEFOS internal statistics (including confidential sources)
- Integrated Pollution Prevention and Control BREF Documents
    - o Iron and Steel Production [2, 3]
    - o Cement and Lime Production [4, 5]
    - o Ferrous Metal Processing [6]
- World Steel Association Reports [7, 8]
- SSAB EMEA Lulea Steel Mill data

- Other steel industry database
- VDEH Papers [9, 10]

5.2. Selection Criteria for Energy Efficiency Management

The study aims to develop a "REFERENCE" Integrated Steel Mill without CO_2 capture based on a typical average European Steel Mill configuration.

It should be noted that there are several commercially available technologies to improve energy efficiency which have been used in various steel mills [8, 11]. However, the adoption or penetration of these technologies varies from site to site. In cases ofwhere a technology penetration is low it is not be included in the model.

On the other hand, if energy recovery or energy saving technologies have been adopted widely or could be adopted easily then this will be included in the model.

For example –

- Technologies such as coke dry quenching for coke plant or top gas recycle turbine technology for energy recovery from blast furnaces are already widely used in several integrated steel mills worldwide. However, these technologies have very low penetration among European steel mills. Therefore these technologies were not included in the specification of the model.

- Energy recovery techniques such as the use of recuperators to recover heat from hot stoves and reheating furnace flue gases are widely or easily adopted in various European Steel Mills. Thus, this was included in the model. However, it should be noted that these technologies is not necessarily the best available technology for energy or heat recovery.

6. METHODOLOGY – MASS AND ENERGY BALANCE CALCULATION

6.1. Mass Balance Calculation

The primary purpose of the mass balance calculation was to evaluate the following:

- Material usage and product output for cost evaluation
- Iron balance for model calculation assumptions and result validation.
- Carbon balance for evaluation of CO_2 direct emissions of steel production.

Mass balances of each processes were first evaluated for the individual unit processes within the system boundary as shown in Figure B2 and these were then linked together to form one single model for the whole integrated steel mill.

The mass balance of each process was calculated based on steady state conditions or determined by using iron and steel production data from the industry. The mass balances of each species are reported based on mass flow rate per tonne of product of the process and mass flow rate per tonne of hot rolled coil produced.

6.2. Energy Balance Calculation

The energy balance of the integrated steel mill includes the accounting of:

- Electrical Energy Consumption

- Stream Enthalpy changes (Sensible Heat Energy)
- Chemical Energy (Oxidation and Reaction Energy)

Electrical Energy Consumption

The electrical energy consumption of each process was estimated using data reported in various industry databases as described in Section 6.1. This is normally reported as consumption per unit product of the plant or process. It was reviewed and validated to match the specified processes of the "REFERENCE" Steel Mill. In this study – this will be reported separately to the Sensible Heat and Chemical Energy.

Ideally, it is best to estimate the electrical consumption based on an actual audit of electricity demand of the machineries used by each plant or processes involved. However, this is out of the scope of this study.

Sensible Heat Energy and Chemical Energy

The study reported the energy flow of the process according to:

- **Sensible Energy** – This refers to the change in enthalpy in a stream between two points A and B. This is estimated from the flowrate, specific heat, phase condition and change in temperature. This will thus also account any latent heat released or absorbed due to phase change.

- **Oxidation Energy** – This refers to the heat of combustion or the lower heating value. This would be estimated by calculating the lower calorific value of converting all carbon, hydrogen, and sulphur to their complete oxidation state of CO_2, H_2O and SO_2.

- **Reaction Energy** – This refers to the heat of reaction involved in the reduction of iron and silicon, or calcination of limestone and other fluxes during the iron and steel making process.

The energy contents for streams are calculated for each unit and are carried through to the next stage. Recycled materials within the steel mill maintain their chemical energy – for example - limestone calcination in the case of slags and the reaction energy in the case of the recycling of internal scrap. Incoming non-fossil fuel containing materials such as the external scrap and ferroalloys are considered to have no reaction energy in order to make the system consistent with the assumption that they also do not enter the system with related CO_2 "backpacks". For sold slags, only the calcination energy to produce CaO from limestone is considered as chemical energy. Any other energy in waste materials is assumed to be zero. It should be noted that this assumption is not necessarily thermodynamically consistent but should simplify the reporting of the energy balance.

6.3. Limitations and Caveat

The modelling of the mass and energy balance for the blast furnace (UNIT 300) are reported in great detail in the work done by Hooey and co-workers [12]. However, the mass and energy balances of some processes are estimated from industry databases and other statistics. These processes are not evaluated to the same level of detail as the blast furnace operation.

The mass balance models for the other processes are developed only with sufficient accuracy to provide the mass flow rates needed as input for the cost estimation of iron and steel production.

7. PROCESS MODELLING – BRIEF DESCRIPTION

Swerea MEFOS used an existing model for blast furnace, and developed models for other processes using Microsoft EXCEL to evaluate a steady state mass and energy balance for individual processes. Some of the process models use simple performance equations utilizing data and information from industry databases as describe in Section B6.1. Each of these process models are then combined into one overall model and calibrated to reflect a typical European integrated steel mill.

It should be noted that in most cases, the individual process models have been previously validated using data from SSAB EMEA Luleå works and then adjusted to the reference plant conditions.

This section briefly described how individual process model were developed.

7.1. UNIT 100: Coke Production

The coke plant model is a steady state mass and energy balance consisting of the following calculations:

- Mass and Energy Balance of the coke oven under-firing heating system.
- Mass Balance for Coke and Coke By Product production
- Energy Content of the Coke and Coke By-Products.

The flue gas composition is determined by combined heat and mass balances using a fixed flame temperature, fuel gas composition and energy demand of the coking process.

It was assumed that a fixed percentage of the fuel gas for under-fire heating is provided by the Blast Furnace Gas and Coke Oven Gas. The composition of Coke Oven Gas was fixed according to industry norm. The composition of the Blast Furnace Gas was determined from the Blast Furnace Model.

The mass flow rate of the coking coal required is calculated from the coke demand of the Blast Furnace and the typical yield of coal to coke. The mass flow rate of the outgoing coke oven gas and by-products are specified according to the average yield reported by industry.

Energy content of the coals used in coking process is specified according to industry averages. The energy contained in the products (coke, coke oven gas and coke by-products) is calculated according to their low heating value (oxidation energy) using the specified composition.

Internal energy losses in raw gas, quenching of hot coke as well as the external loss of sensible heat of firing off-gas are taken from a balance of the SSAB coke plant [13].

7.2. UNIT 200: Sinter Production

The sinter plant model includes three sets of calculations:

- Accounting and distribution of revert materials to sintering, landfill or sales;
- Calculation of material demand in relation to the target basicity and MgO content of sinter;
- Calculation of sinter plant strand flue gas.

The accounting and distribution of revert materials are specified as a proportion of material to each destination set according to typical industry figures. The basicity, MgO content and oxidation degree of the sinter are fixed. The model adjusts the ores and flux additions within set ranges to meet the target basicity and MgO. Small additions of quartzite are added to achieve the desired basicity although this does not represent typical industrial practice. The final sinter composition is calculated from all incoming materials.

The sinter plant flue gas is calculated from a mass balance assuming combustion of a fixed coke breeze amount and ignition fuel per tonne sinter combined with fixed amount of incoming air and gasification of materials from the sintering process (i.e. water vapour and CO_2 from limestone).

The energy input via coke breeze, ignition energy and combustion of carbon contained in revert dusts are included in the total energy consumption however internal reactions are excluded. Enthalpy and temperature of the strand and cooler off-gas streams are estimated from reported values. The reaction energy carried by the sinter to the blast furnace in the sinter is calculated from the CaO content.

7.3. UNIT 300: Blast Furnace and Hot Stoves (Iron Making)

The iron making model consists of:

- Blast furnace model, and
- Hot stove model

The blast furnace model is an existing model developed by Hooey and co-workers [12]. This is the most complex model in the whole integrated steel mill model. It consists of a combined heat and mass balance of the blast furnace with specified shaft efficiency and reserve zone temperature according to the RIST diagram methodology.

Materials and energy balances are calculated in an iterative loop. The slag rate and basicity are fixed along with the hot metal temperature, hot metal composition and PCI coal injection rate. The model calculates the amount of required trim fluxes (quartzite and limestone) and overall iron ore required to meet the slag and hot metal target values.

In order to achieve the desired coke rate, the PCI rate and hot blast conditions are fixed and the shaft efficiency and thermal reserve zone temperature are adjusted. This calibrates the model to the correct efficiency. The energy balance is determined in the typical zones defined as above and below the thermal reserve zone temperature. Top gas composition and rate is calculated from the process balance. The overall energy requirements for the furnace are balanced iteratively by adjusting the coke rate.

The hot stove model is linked to the blast furnace model. It was assumed that blast furnace gas and coke oven gas will be used as the fuel to heat up the hot stoves.

The required blast temperature and volume is fixed by the blast furnace model. The heat losses per hour are fixed along with the oxygen content and temperature of the hot stove flue gas. The flame temperature for the hot stoves is constrained to a reasonable value higher than the hot blast temperature. The oxygen content in the flue gas is fixed and used to calculate incoming combustion air. A heat and mass balance iterates to solve for the volumes of combustion gas, with COG added if necessary to meet flame temperature requirements.

The energy balance is calculated for the hot stoves by linking the energy balance of the hot blast to the blast furnace model as discussed above.

7.4. UNIT 400: Hot Metal Desulphurisation

The hot metal desulphurization station covers the area from hot metal tapping to charging in the basic oxygen furnace. The hot metal desulphurisation model consists of the mass balance calculation based on estimating the desulphurisation reagent injection and metal spillage (refers to the loss of hot metal carried over in the slag during the skimming process).

The desulphurisation reagent addition is calculated using a statistical correlation used at SSAB EMEA in order to achieve 0.01%w S in hot metal to the basic oxygen furnace. Slag and spillage composition is calculated from estimated desulphurisation reagent addition and hot metal losses from spillage which is fixed. The temperature drop from the blast furnaces to basic oxygen furnaces is also fixed.

7.5. UNIT 500: Basic Oxygen Steelmaking

The Basic Oxygen Steelmaking model consists of:

- Mass and energy balance of the steelmaking process
- Calculation of the amount of BOF gas recovery
- Estimation of the steam production from waste heat boiler using the energy balance.

As the BOF operation is a batch process, the model calculates the mass balance of the process per charge. The mass balance model is calibrated using statistics from SSAB EMEA Works' BOFs. The final output assumes a steady state flow.

The slag rate and its composition, and charge weights of burnt dolomite, scrap, iron ore for cooling, oxygen, argon and nitrogen consumptions are fixed. The model calculates required lime addition based on the input materials and slag requirements. The carbon mass balance is based on all incoming materials and outgoing liquid steel. The BOF gas recovery is based on a fixed ratio of carbon recovery with a fixed gas composition defined according to industry norms.

The steam production was estimated from data reported from industry.

7.6. UNIT 600: Ladle Metallurgy (Secondary Steelmaking)

The ladle metallurgy model is a simple mass balance accounting for the addition of ferroalloys as well as a small loss in Fe. The ferroalloys used in this study are FeMnC and FeSi75 – which are typical alloys used in the production of standard grade steel. Aluminium is used to deoxidise the liquid steel. The amount of Ferroalloys, Aluminium used and %Fe loss to scrap are all fixed according to industry norms.

A small amount of oxygen and COG are consumed for ladle heating and argon is used for oxidation shielding and inert stirring. The amount of COG, oxygen, argon and electrode consumption are all estimated using average industry data.

7.7. UNIT 700: Continuous Casting

The continuous casting model is a simplified mass balance model with a specified yield for slab, internal scrap and mill scale. Minor consumption of COG, oxygen and argon are all accounted for in the study.

7.8. UNIT 800: Reheating Furnace

The reheat furnace model is designed to calculate the composition of the flue gas based on a fixed combustion energy demand and fuel. Either the flame temperature or oxygen content of the flue gas can be used to calculate the combustion air rate. The recuperator is set to a fixed combustion air output temperature. No iron losses are assumed, as all mill scales are accounted for in the operation of the hot rolling mills.

7.9. UNIT 900: Hot Rolling Mills

The rolling mill model is a simple mass balance based on a steel recovery yield from rolling and fixed amount of losses allocated to millscale and clippings. A small amount of oxygen used for cutting and scarfing were accounted for using data from industry databases.

Mill scale is returned to the sinter plant and clippings are returned to the BOF as internal scrap.

7.10. UNIT 1000: Lime Production

The lime kiln model is designed to calculate the flue gas composition based on required energy from combustion fuel per tonne lime and a defined exit gas temperature from the kiln.

The model is a mass and heat balance. Final flue gas composition is calculated from the mass balance of incoming limestone, fuel and air and outgoing lime. The quality of limestone and lime required are fixed according to typical quality used at integrated steelworks.

7.11. UNIT 1100: Oxygen Plant (Air Separation Unit)

The oxygen plant model is a simple mass balance based on fixed recoveries of oxygen and argon from air and their purity. Oxygen recovery is estimated at 96% and argon at 83%. Oxygen and Argon are supplied to the Steel Mill at purity of >99.9%

The minimum oxygen demand is calculated from the requirements of the blast furnace and various users of steelmaking processes. Due to fluctuating demand of oxygen and the favourable economics of argon production, the total production of oxygen is fixed at 110% of the total oxygen required by the steel mill. Excess oxygen produced is vented or lost, and these are accounted as flared.

The electrical consumption of the oxygen plant is estimated from industry reported data as a function of an overall O_2 production in kWh/Nm^3.

7.12. UNIT 1200: Power Plant

The power plant model is an electricity balance to calculate the minimum electricity demand of the steel mill and a heat and mass balance to calculate the fuel requirement and flue gas composition.

The power plant net output requirement is calculated from the electricity and steam demand of all the processes within the boundary of the integrated steel mill. The net electricity output from the power plant is estimated using a fixed net efficiency and load factor to meet the demand of the steel mill and this net output also includes a small amount of excess electricity production to represent system losses.

The amount of fuel required is estimated from the energy content of the Blast Furnace Gas and Basic Oxygen Steel Furnace Gas allocated to the power plant with Natural Gas as supplement to any deficit.

The calculation of final flue gas composition is based on fixed oxygen content in the flue gas and the combustion air required for complete combustion.

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Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume I: Estimating the Cost of Steel Production from an Integrated Steel Mill (Reference Case)

Section C

Specifications – Raw Materials, Products and Waste "REFERENCE" Integrated Steel Mill (Base Case)

I N D E X

1. INTRODUCTION

This section of the report provides the general information and assumptions used in establishing the operating parameters of the REFERENCE Steel Mill. These include the information regarding:

- Raw materials
- Energy and Reductants
- Products, Intermediate Products and By-Products
- Waste Materials for Disposal or Recycling

It should be noted that specifications reported in this section for all the energy, reductants, raw materials, products, by-products and waste are not the full assay normally required by the steel mill. However, the numbers provided should allow enough details for modelling of the mass and energy balance differences required for techno-economic evaluation.

2. ENERGY AND REDUCTANTS (EXTERNALLY SOURCED)

2.1. Coking Coal

Coking coal (also known as metallurgical coal) is the main raw material to produced coke and other coking by-products. The production of coke requires coal that agglomerates during an oxygen deficient decarbonisation process. The coke provides both the energy and reductant for the blast furnace. Furthermore, the coke used should possess enough strength to carry the top burden of the blast furnace and should have good porosity which is an important factor for development of a good permeable bed within the blast furnace.

Generally, coke producers use dozens of widely differing coals and employ many procedures to enhance the quality of the coke and to enhance the coke oven productivity and battery life. Typically, low and high quality coking coals are blended in the coal yard before being pushed into the coke ovens. The amount of low and high quality coking coal used is generally balanced between economics, availability and coke quality requirements.

For the purpose of this study – only two types of coking coal imported from Australia are used namely: hard coking coal (high quality coal) and semi-soft coking coal (lower quality coal) with an assumed average coking coal specification as presented below:

Table C-1: Specification of the Coking Coal

Dry Basis (%wt.)	Typical Range	Average (used in the study)
C	75 - 85	78.85
H	4 - 6	4.51
Fe	15 - 35	0.33
CaO	n.d.	0.05
MgO	n.d.	0.05
SiO_2	3 - 5	4.68
$Al2O_3$	1 - 3	2.10
Moisture	n.d.	8.00
LHV (MJ/kg) - dry	n.d.	31.10

2.2. PCI Coal

PCI Coal is one of the several injectants used in the blast furnace as auxiliary fuel and reductant, therefore reducing the amount of coke required. These injectants are introduced into the lower part of the blast furnace through lances projecting into the different tuyeres.

Typically, PCI coal as received by the steel mill is dried and pulverised in dryers to about 1% - 2% moisture. For this study, it was assumed that a low to medium volatile PCI coal from Australia is used. As received, the moisture of PCI coal is assumed to be around 8%. The specification of the PCI coal is presented in Table C-2.

Table C-2: Specification of the PCI Coal (after drying)

Dry Basis (%wt.)	Average (used in the study)
C	87.00
H	4.03
Fe	0.52
CaO	0.19
MgO	0.04
SiO_2	2.41
Al_2O_3	1.62
Moisture	1.00[1]
LHV (MJ/kg) - dry	33.37

2.3. Natural Gas

The study assumed that the integrated steel mill should have an access to a pipeline delivering natural gas with a specification similar to the natural gas from the southern part of Norwegian off-shore gas field. For the REFERENCE Steel Mill (Base Case), natural gas is consumed by the Power Plant (UNIT 1200) as supplementary fuel.

The specification of the natural gas is provided below:

Table C-3: Specification of the Natural Gas

Dry Basis (%vol.)	Average (used in the study)
CH_4	83.90
C_2H_6	9.20
C_3H_8	3.30
C_4H_{10}	1.20
C_5H_{12}	0.20
CO_2	1.80
N_2	0.40
LHV (MJ/Nm^3) - dry	40.64

[1] This number is based on the dried coal going into the blast furnace. The PCI coal received by the steel mill is assumed to have about 6-10% moisture.

3. RAW MATERIALS

3.1. Iron Ore – Fines, Lumps and Pellets

The main iron burdens used in the hot metal production worldwide are iron ores in the form of fines, lumps and pellets. Alternative iron burden such as scrap metal and hot briquetted iron are also used as iron input to blast furnaces but accounts for only a minority of iron production worldwide.

Iron ore fines are agglomerated in the Sinter Production Plant. Iron ore pellets are the product of a Pelletizing Plant using iron ore fines or concentrates, while lump iron ores are obtained directly from mines and can be used directly by the blast furnace without any ore preparation step (i.e. agglomeration). The amount of each type of iron ore used in a blast furnace is very site specific and dependent on economics and supply of the iron ore burden.

The study specified that the iron ore fines used in the Sinter Production (UNIT 200) are obtained from Australia (Hematite), Brazil (Hematite/Goethite) and Sweden (Magnetite). On the other hand, lump ore and pellets used in the Blast Furnace (UNIT 300) are delivered from Australia and Brazil respectively. Pellets are also used in the steel refining process as cooling medium. The specifications of these ores are summarised in Table C-4.

Table C-4: Specification of the Iron Ore Burden

Dry Basis (%wt.)	Iron Ore Fines			Lump Ore (Australia)	Pellets (Brazil)
	Hematite (Australia)	Hematite/Geothite (Brazil)	Magnetite (Sweden)		
Fe (Total)	66.2	57.95	69.77	61.00	65.50
CaO	0.05	0.28	0.42	0.30	1.80
MgO	0.06	0.18	0.45	0.20	1.20
Al_2O_3	0.87	1.91	0.17	2.76	0.60
SiO_2	2.58	5.02	1.15	8.38	2.80
Others[2]	Difference	Difference	Difference	Difference	Difference
Moisture	5.00	5.00	5.00	5.00	2.00

It should be noted that full assay of the iron ore also included specifications for FeO, Fe_xO_y, Mn, P, S, and other trace elements (i.e. zinc, vanadium, titanium, lead, et. al.). These elements and compounds are all accounted for and included in the model of the mass balance developed by Swerea MEFOS. Details of these trace elements are not reported because it is not relevant to the economic evaluation

3.2. Purchased Scrap and Ferroalloys

Purchased Scrap

Purchased scrap (also called merchant scrap) together with internally generated scrap from casting, reheating and rolling operations, and other steelmaking processes are used in the production of steel to supplement the liquid hot metal produced from the blast furnace. These scraps are charged into the basic oxygen furnace (UNIT 500) or used in the Secondary Metallurgy (UNIT 600). The amount of scrap charged in the steelmaking process is very site specific. This depends on the economics, availability and quality of the scrap collected. For simplification, it was assumed that

[2] Others include trace elements such as Ti, V, Mn, etc... that come together with the iron ore.

purchased scrap should have the same specification as internal scrap; and this is presented in Table C-5.

Table C-5: Specification of the Scrap Steel (External)

Dry Basis (%wt.)	Average (used in the study)
Fe[3]	98.89
C	0.11
Si	0.01
Others[4]	Difference

Ferroalloys and Aluminium

Ferro alloys generally used in the production of standard grade steel are ferromanganese and ferrosilicon. For this study the specifications of the Ferro alloys used are summarised in Table C-6.

Table C-6: Specification of the Ferroalloys

Dry Basis (%wt.)	FeMnC	FeSi-75
Fe	14.58	22.56
C	6.87	0.03
Si	0.11	76.61
Mn	78.27	0.01
Al	0.00	0.71
Others[3]	Difference	Difference

To reduce the oxygen content of the steel, aluminium is used and its specification is shown in Table C-7.

Table C-7: Specification of aluminium

Dry Basis (%wt.)	Average (used in the study)
Fe	0.67
Si	1.34
Mn	0.23
Al	96.30
Others[3]	Difference

3.3. Fluxes

Fluxes used in the iron and steelmaking process include:

- Limestone (Lime Production, Sinter Production and Blast Furnace)
- Quartzite (Sinter Production, Blast Furnace)
- Olivine (Sinter Production)
- Dolomite (Basic Oxygen Steelmaking Furnace)
- Calcium Carbide (Hot Metal Desulphurisation)

[3] External scrap comes in various forms and shape. Typically, Fe content should be in the range of 92 to 99%.
[4] Others include P, S, Cr, Nb, Ti, B, Ni, Cu, Pb, Zn, Mg, and other trace elements.

Limestone

Limestone is used as the main raw materials of the lime kilns (UNIT 1000) to produce lime which serves as the main fluxing agent for the steelmaking process (UNIT 500). Limestone is also used as fluxing agent in the Blast Furnace (UNIT 300) and a small portion is also added to the Sinter Production (UNIT 200) to manage the basicity of the resulting sinter.

High calcium limestone is required by the steel mill to produce the desired lime quality for the steelmaking process. Excellent quality limestone should contain at least greater than 52% CaO and less than 2% SiO_2. Generally, limestone is delivered to the site as pebbles. This is then crushed and milled according to the size required by the process.

Table C-8: Specification of Limestone

Dry Basis (%wt.)	Average (used in the study)
$CaCO_3$	94.20
CaO	1.20
$MgCO_3$	2.30
Al_2O_3	0.50
SiO_2	1.20
Fe (Total)	0.30
Others[5]	Difference
CO_2 (Total)	42.60
Moisture	1.00

Quartzite

Quartzite is used as fluxing agent to control the silica content of the sinter during sinter production (UNIT 200) and slag produced by the blast furnace (UNIT 300). This study assumed the quartzite delivered to the site is in sandy form and expected to have grain size between 100 and 400 microns. The chemical composition of the quartzite is assumed to be 98$\%_{wt}$ SiO_2 and 1.9% Al_2O_3 (dry basis) with moisture content of 1%.

Olivine

Olivine is used as fluxing agent to control the magnesium/silica content during sinter production (UNIT 200).

Table C-8: Specification of Olivine

Dry Basis (%wt.)	Average (used in the study)
MgO	47.90
CaO	0.20
Al_2O_3	0.48
SiO_2	41.60
Fe (Total)	5.70
Others[3]	Difference
Moisture	1.00

[5] Others include TiO_2, V_2O_5, P_2O_5, MnO, Na_2O, K_2O

Burnt Dolomite

Dolomitic lime (also called Burnt Dolomite) is charged with the burnt lime into the Basic Oxygen Furnace (UNIT 500). This is to saturate the slag with MgO, and reduce the dissolution of dolomite furnace refractories into the slag. It should be noted that the amount of burnt dolomite and burnt lime added to the Basic Oxygen Furnace (UNIT 500) strongly depends on experience and adjustments made by the steelmakers. These are based on observations of chemical attack of the slag on furnace refractories. Typically dolomitic lime contains about 36–42%w MgO and 55–59%w CaO. Table C-9 presents the specification of the Burnt Dolomite used in this study.

Table C-9: Specification of Burnt Dolomite

Dry Basis (%wt.)	Average (used in the study)
MgO	55.00
CaO	40.00
Al_2O_3	1.00
SiO_2	1.00
Fe (Total)	0.15
Others[6]	Difference
Moisture	1.00

Calcium Carbide

Calcium carbide is used as a desulphurisation agent for the Hot Metal from the Blast Furnace. In olden days, desulphurisation agent was added in the torpedo car and mixed while on it's way to the melt shop. Nowadays, a standalone Hot Metal Desulphurisation station is normally used. Other desulphurisation agents could be used – these include Mg powder, CaO, etc... Some HM Desulphurisation units even employ multi-chemicals injection systems.

For this study, it was assumed that only mono-injection using calcium carbide is used. The specification of the calcium carbide is presented in Table C-10.

Table C-10: Specification of Calcium Carbide

Dry Basis (%wt.)	Average (used in the study)
CaC_2	79.00
CaO	15.80
CaS	1.20
Al_2O_3	1.20
SiO_2	1.50
Fe (Total)	0.20
C (Residual)	1.00
Others[6]	Difference
Moisture	0.00

[6] Others include TiO_2, V_2O_5, P_2O_5, MnO, Na_2O, K_2O

4. PRODUCTS, INTERMEDIATE PRODUCTS AND BY-PRODUCTS

4.1. Hot Rolled Coil

The main product of the "REFERENCE" Steel Mill is a standard grade hot rolled coil. This study assumed a fixed production rate of 4 million tonnes per year. The chemical composition of the hot rolled coil is summarised in Table C-11.

Table C-11: Specification of the Hot Rolled Coil

Dry Basis (%wt.)	Average (used in the study)
Fe	98.73
C	0.12
Others[7]	Difference

The HRC produced from the finishing mill is directly transferred to the product stockyards ready for sale and delivery. Transport of finished goods is generally by rail. Hot Rolled Coil produced could be delivered in several sizes (thickness, width and length) dependent on the setting of the finishing mills. Thickness of the hot rolled coil could be in the range of 1 - 20mm; and width of 0.5 - 1.5m. Table C-12 presents dimensions of the hot rolled coil delivered by the "REFERENCE" Steel Mill which is a typical standard size sold in the market.

Table C-12: Dimension of the Hot Rolled Coil

Hot Rolled Coil	Dimension
Thickness	1.47 mm
Width	700 mm
Hot Rolled Coil (Inside Diameter)	762 mm
Hot Rolled Coil (Outside Diameter)	1000 mm
Tolerance (Inside Diameter)	+0 / -50 mm

4.2. Slab

Slab is the primary product of the continuous caster (UNIT 800) and could be a saleable product to other finishing mills outside the boundary limit if specified.

Typically slabs are rectangular (though sometimes trapezoidal, i.e. a tapered slab) with a dimension in the order of 250 mm thick, 5000 to 12000 mm long and 300 to 1500 mm wide. New technology based on continuous thin slab casting (not common in European steel mills) could produce slabs of the order of 50 mm thick.

The slab should have a similar chemical composition to the hot rolled coil as shown in Table C-11.

4.3. Liquid Steel

Liquid steel is the primary product of the basic oxygen furnace (UNIT 600). This is further refined in the Ladle metallurgy unit (UNIT 700) to provide the final liquid steel product. For higher grade steel, the liquid steel should undergo further processing (i.e. AOD or RH Degasser, etc...).

[7] Others are alloying materials added and other residual element.

The liquid steel produced by the Ladle Metallurgy (UNIT 700) should have a similar chemical composition to the hot rolled coil as shown in Table C-11.

Table C-13: Specification of the Liquid Steel

Dry Basis (%wt.)	Liquid Steel (after BOF)	Liquid Steel (after Ladle Metallurgy)
Fe	99.91	98.73
C	0.04	0.12
Others[8]	Difference	Difference

4.4. Hot Metal

Pig Iron is the main product of the blast furnace. In the liquid form the pig iron is generally referred to as hot metal. The chemical composition of pig iron can vary substantially from site to site, but it typically contains the following:

- Carbon 4.00 - 5.00%
- Silicon 0.30 - 1.50%
- Manganese 0.25 - 2.20%
- Phosphorous 0.04 - 0.20%
- Sulphur 0.03 - 0.80% (before desulfurization)
- Iron greater than 90%

Specification of the hot metal assumed for this study is presented below.

Table C-13: Specification of the Hot Metal

Dry Basis (%wt.)	Hot Metal (Before Desulphurisation)	Hot Metal (After Desulphurisation)
Fe	94.15	94.24
C	4.70	4.65
Si	0.50	0.49
Mn	0.27	0.27
Others	Difference	Difference

For this study, the sulphur content of the hot metal prior to desulphurisation is estimated at 0.032%. After desulphurisation, the sulphur content of the hot metal is reduced to less than 0.01%.

4.5. Sinter

Sinter is produced by agglomerating the iron ore fines with addition of fluxes and coke breeze. Slag from the Basic Oxygen Furnace (UNIT 600) and Desulphurisation Plant (UNIT 500) are also used as raw materials input along with other internally produced waste with high iron content (i.e. mill scale).

The specification of the Sinter varies depending on its input. Section D described the different material inputs used to produce the sinter. Table C-14 summarised the assumed composition.

[8] Others are alloying materials added and other residual element.

Table C-15: Specification of Sinter

Dry Basis (%wt.)	Average (used in the study)
Fe (Total)	57.88
CaO	9.40
MgO	1.50
Al_2O_3	1.04
SiO_2	5.23
Others[9]	Difference
Moisture	0.00

4.6. Coke and Coke Breeze

Lump coke produced by the coke plant (UNIT 100) is delivered to the Blast Furnace (UNIT 300); and the coke breeze (including Reclaimed Coke from BF undersized) is delivered to the Sinter Production (UNIT 200).

The chemical properties crucial to the quality of coke produced include - moisture, fixed carbon, ash, sulfur, phosphorus, and alkalis. For this study, the chemical composition of the coke produced by the Coke Plant (UNIT 100) is presented in Table C-16.

Table C-16: Chemical Composition of Coke (Lump & Breeze)

Dry Basis (%wt.)	Average (used in the study)
C	88.05
H	0.10
N	1.10
S	0.60
Fe	0.42
CaO	0.06
MgO	0.07
SiO_2	6.27
Al_2O_3	2.82
Alkalis (Na_2O & K_2O)	< 0.30
P	< 0.03
Moisture	4.00
Volatiles Matter	< 2.00
Ash	10.00
LHV (MJ/kg) - dry	29.01

The physical properties of the coke are measured based on how it would perform inside the blast furnace. These physical properties critical to determine coke qualities are:

- Coke Strength After Reaction (CSR) Index
- Coke Stability Index
- Cold Strength Index

It is expected that lump coke used in the Blast Furnace (UNIT 300) should have an average diameter of 45-55mm (covering > 80%). For this study, it was assumed that coke produced by the coke plant adheres to physical qualities required for large blast furnace operation.

[9] Others include other trace elements that are derived from the iron ore and fluxes.

4.7. Lime

The lime produced by the lime kilns (UNIT 1000) is mainly used as fluxing agent for the Basic Oxygen Furnace (UNIT 500), and some part of it is also used in the Sinter Production (UNIT 200).

The lime produced from the lime kiln (UNIT 100) should have a typical CaO content (total) of greater than 90%w and a residual CO_2 of about 2-3%w is expected for a PFR Lime Kiln operation. Chemical composition of the lime used for this study is presented in Table C-17.

Table C-17: Specification of Lime

Dry Basis (%wt.)	Average (used in the study)
$CaCO_3$	6.80
CaO	87.40
MgO	1.86
Al_2O_3	0.85
SiO_2	2.03
Fe (Total)	0.51
Others[10]	Difference
CO_2 (Total)	3.00
Moisture	0.00

4.8. Coal Tar, BTX and Sulphur

Coal Tar

Tar and naphthalene are produced as one of the many by-products of coke ovens. These are generally sold to chemical industries as raw materials. For this study, it is assumed that tar obtained from the Primary Cooler (UNIT 232), Tar Recovery Unit (UNIT 233) and Tar ESP (UNIT 234) are dehydrated and then mixed with the Naphthalene obtained from the BTX Distillation Unit (UNIT 275)and then sold as "Crude Tar".

For this study, it was assumed that the crude tar sold as by-product has an LHV of 42 MJ/kg (dry) and moisture content of 2.0%wt.

Benzene, Toluene and Xylene (BTX)

BTX (also called Benzole) is also derived as a by-product of the coke production. It is also sold to chemical industries as "Crude Benzole". Generally, the amount of Benzole that could be recovered varies from site to site dependent on the fuel composition and decarbonisation process of coking coal. Crude Benzole mainly contains Benzene, Toluene and Xylene, but other aromatic hydrocarbons (such as cresol, xylenol, pyridine, naphthalene, anthracene, etc…) could be included as minor components. The chemical composition (%wt.) of Crude Benzole typically contains the following:

- Benzene 55 - 65%
- Toluene 10 - 20%
- Xylene 5 - 10%
- Others Difference

For this study Crude Benzole is sold as by-product with an assumed LHV of 38 MJ/kg.

[10] Others include TiO_2, V_2O_5, P_2O_5, MnO, Na_2O, K_2O

Sulphur

Sulphur is one of the by-products of the Coke Production (UNIT 300) from its Combined Claus Plant and NH_3 Cracker (UNIT 360). The solid sulphur produced from the Claus unit is estimated to have an LHV of 9.3 MJ/kg. Typically, the sulphur sold as by-product has the following properties:

Table C-18: Sulphur Qualities

Sulphur	Quality
Status	Solid
Colour	Bright yellow
Purity	99.9% S (min.)
H_2S	< 10 ppm (max.)
Ash Content	< 0.05% (max.)
Carbonaceous Materials	< 0.05% (max)

4.9. Steel Mill Slag

The steel mill produces a variety of slags sold as by-products, recycled or discharged as waste. For this study the following slags were accounted for in the Techno-Economic Evaluation of the REFERENCE Steel Mill.

- Granulated BF Slag (GBF Slag)
- Hot Metal Desulphurisation Slag (De-S Slag)
- Basic Oxygen Furnace Slag (BOF Slag also known as LD Slag or BOS Slag)
- Ladle Metallurgy Slag (LM Slag also known as SM Slag)

Granulated Blast Furnace Slag (GBF Slag)

Granulated BF Slag is removed periodically from the Blast Furnace (UNIT 300) during the tapping or casting process. The liquid slag is then processed in a slag granulation plant were air is blown in to ensure that liquid slag introduced into a pool of water to cool and solidify emerges in granulated form. This slag consists of $CaO\text{-}MgO\text{-}SiO_2\text{-}Al_2O_3$ mixture in a glassy (amorphous) form. Chemical composition of the Granulated BF Slag is summarized in Table C-19.

Table C-19: Composition of Granulated BF Slag

Dry Basis (%wt.)	Average (used in the study)
Fe (Total)	0.30
CaO	42.21
MgO	7.63
Al_2O_3	10.33
SiO_2	36.71
Others	Difference
Moisture	12.00

Hot Metal Desulphurisation Slag (De-S Slag)

Slag derived from Hot Metal Desulphurisation (UNIT 400) is obtained by tilting the HM desulphurization ladle, scraping the slag from the top of the hot metal and pouring the collected slag in a slag pot. This slag is then processed to separate the metal and slag components.

Due to high sulphur content of the slag collected not all of the slag can be recycled. Part of the slag collected (around 63% in this study) is recycled to the sinter plant (UNIT 200) and the rest is disposed as waste. For simplification the study assumed the chemical composition of the recycled and disposed slag is of the same specification as shown in Table C-20.

Table C-20: Composition of De-S Slag

Dry Basis (%wt.)	Average (used in the study)
Fe (Total)	79.49
C (Total)	4.16
CaO	11.40
MgO	n.r.
Al_2O_3	n.r.
SiO_2	1.93
Others	Difference
Moisture	1.00

Basic Oxygen Furnace Slag (BOF Slag)

Basic Oxygen Furnace Slag (also known as BOS Slag or LD Slag) is formed during the blowing of oxygen and addition of fluxes. Part of the resulting slag is recycled back to the Sinter Plant (UNIT 200), and part of it is sold for agricultural applications and the unsold part is disposed as waste.

BOF Slag contains predominantly calcium ferrite with small amounts of free lime. Resulting slag at turndown in top-blown converters (BOF) has typical ranges: CaO (42 – 55 %), MgO (2 – 8 %), FeO (10 – 30 %), MnO (3 – 8 %), SiO_2 (10 – 25%), P_2O_5 (1 – 5%), Al_2O_3 (1 – 2 %) and S (0.1 – 0.3 %). For this study, Table C-21 summarizes the slag composition used in calculating heat and mass balances.

Table C-21: Composition of BOF Slag

Dry Basis (%wt.)	Average (used in the study)
Fe (Total)	20.00
CaO	50.74
MgO	5.47
Al_2O_3	0.56
SiO_2	9.45
Others	Difference
Moisture	1.00

Secondary Metallurgical Slag (SM Slag)

Ladle Metallurgy Slag (also known as SM Slag) is formed during the steel refining process. The resulting slag is generally disposed as waste due to its unstable slag chemistry and poor physical properties. Table C-22 presents the composition of the ladle slag used in the study.

Table C-22: Composition of Ladle Slag

Dry Basis (%wt.)	Average (used in the study)
Fe (Total)	1.08
CaO	62.46
MgO	n.r.
Al_2O_3	28.32
SiO_2	8.03
Others	Difference
Moisture	1.00

4.10. Off-Gases

Off-gases (also known as by-product gases or process gases) are produced from the coke production (UNIT 100), blast furnaces (UNIT 300) and basic oxygen furnaces (UNIT 500). These gases are collected in gas holders and distributed within the steel mill via its own gas pipeline network. The utilization of these off-gases varies from site to site. The manner in which these gases are recovered and utilized could significantly impact the CO_2 emissions of the integrated steel mill. If there is no demand for these gases, they are normally flared for safety reasons.

This section provides the specification of the cleaned (processed) Blast Furnace Gas, Coke Oven Gas and Basic Oxygen Furnace Gas used in this study.

In normal operation it is expected that the quality of the off-gases varies, depending on the process operation some of which is cyclic in nature. The specification presented in this study is based on typical average values reported by European steel mills.

Coke Oven Gas

For this study, the coke oven gas or COG is a medium CV fuel gas produced from the three coke oven batteries (UNIT 100). The gas from the coke oven is primarily processed to remove the tar, naphthalene, benzene/toluene/xylene (BTX), H_2S, ammonia and particulates as described in Section D. The fuel gas composition is summarized in Table C-23.

Table C-23: Specification of the Coke Oven Gas

Wet Basis (%vol.)	COG
CH_4	23.04
H_2	59.53
CO	3.84
CO_2	0.96
N_2	5.76
O_2	0.19
H_2O	3.98
Other HC	2.69
LHV (MJ/Nm^3) - wet	17.33

Blast Furnace Gas

Blast furnace gas or BFG is a low CV by-product gas produced by the blast furnace (UNIT 300). This gas is primarily cleaned to remove the particulates. The specification of the blast furnace gas used in this study is presented below. Note that the gas sent to other users is the same composition apart from its water content.

Table C-24: Specification of the Blast Furnace Gas

Wet Basis (%vol.)	BFG to Hot Stove	BFG to Other Users
H_2	3.59	3.63
CO	22.10	22.34
CO_2	21.86	22.10
N_2	48.24	48.77
H_2O	4.21	3.15
LHV (MJ/Nm^3) - wet	3.18	3.21

Basic Oxygen Furnace Gas

Basic Oxygen Furnace Gas or BOFG (also known as BOS Gas, LD Gas or Converter Gas) is a medium CV by-product gas produced by the basic oxygen furnace (UNIT 600). This gas is primarily cleaned to remove the particulates. The specification of the BOF gas used in this study is presented below.

Table C-24: Specification of the Basic Oxygen Furnace Gas

Wet Basis (%vol.)	BOFG
H_2	2.64
CO	56.92
CO_2	14.44
N_2	13.83
H_2O	12.16
LHV (MJ/Nm^3) - wet	7.47

4.11. Oxygen, Nitrogen and Argon

Oxygen, nitrogen and argon are all produced from the Air Separation Unit (UNIT 1100). All gases will be available as either liquid or gaseous products at required delivery pressure. Table C-25 summarized the product specifications of the oxygen, nitrogen and argon from the ASU.

Table C-25: Specification of the Oxygen, Nitrogen and Argon

	Oxygen	Nitrogen	Argon
Main Product	Gaseous Oxygen (GOX)	Gaseous Nitrogen (GAN)	Gaseous Argon (GAR) Liquid Argon (LAR)
Purity	99.9%	99.98%	99.99%
Delivery Pressure	7 Bar and 31 Bar	7 Bar and 21 Bar	7 Bar and 31 Bar
Product Sale	-	-	Liquid Argon (LAR)

4.12. Steam

The whole steel mill has an access to steam at 9 bar_a and 175^oC. The steam is supplied mainly from the waste heat boilers installed at the Basic Oxygen Furnace (UNIT 600). Back up steam could be extracted from the power plant (UNIT 1200).

4.13. Electricity

The electricity required for the steel mill is produced from the captive power plant (UNIT 1200). As backup, it was assumed that electricity could be bought from the grid. Typical steel mills either import or export electricity dependent on the supply and demand of the off-gases from the different processes of the steel mill. Seldom does a steel mill have a balanced supply of electricity (i.e. supply = demand). For simplicity in a CO_2 emissions audit, it is assumed in this study that electricity produced from the captive power plant is balanced.

Specification of the Electricity produced by the captive power plant is presented below.

- Nominal Power Output: 215 MWe
- Voltage: 110 kV
- Frequency: 50 hz
- Fault Duty: 50 kA

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume I: Estimating the Cost of Steel Production from an Integrated Steel Mill (Reference Case)

Section D

Process Overview & Specifications
"REFERENCE" Integrated Steel Mill (Base Case)

I N D E X

1. INTRODUCTION

1.1. Reference Integrated Steel Mill (Base Case) – Process Overview

The study assumed a “REFERNECE” integrated steel mill situated in the Coastal Region of the Western Europe producing 4 million tonnes of hot rolled coil per year.

The REFERENCE Steel Mill consists of the following processes:

- Unit 100: Coke Production — based on 3 batteries of coke ovens
- Unit 200: Sinter Production — based on a single train fixed bed sintering machine
- Unit 300: Hot Metal Production — based on 2 trains of blast furnaces
- Unit 400: Hot Metal Desulphurisation — based on 2 stations of HM desulphurisation
- Unit 500: Primary Steelmaking — based on 2 trains of basic oxygen furnace
- Unit 600: Secondary Steelmaking — based on 2 stations of ladle metallurgy process
- Unit 700: Continuous Casting — based on 2 trains of double strand slab casters
- Unit 800: Slab Reheating — based on 2 furnaces per line of HSM
- Unit 900: Hot Rolling Mills — based on 2 lines of hot strip mills (HSM)
- Unit 1000: Lime Production — based on 2 trains of PFR lime kiln
- Unit 1100: Oxygen Production — based on 1 train of Air Separation Unit
- Unit 1200: Electricity Production — based on 1 captive power plant
- Ancillaries, off-sites, utilities and balance of plant

This section of the report aims to provide the following information: (a.) study specification, (b.) process flow diagram and mass balance; and (c.) utilities consumption (electricity, steam and water).

Detailed description of the process and some relevant energy saving measures are presented in the Swerea MEFOS report [1], IEA CCC report on CO_2 reduction in iron and steel industry [2], and Synthesis Report (Supplementary Volume – Process Description).

1.2. Process Flow Diagram and Mass Balance

The process flow diagrams (PFD) and the mass balances (MB) of the 12 major processes relevant to the production of hot rolled coil are presented in this section of the report which forms the basis of the techno-economic evaluation.

The mass balance was evaluated using the Energy and Mass Balance Model (Massmod) developed by Swerea MEFOS as briefly described in Section B and in Reference [3].

1.3. Process Nomenclature and Units Arrangement

With reference to the different PFD presented in this section, the list below gives the arrangements and nomenclatures used for each processes.

- Unit 100: Coke Production
    - 105: Coal Handling and Blending Facility
    - 110: Coke Oven Batteries
    - 120: Coke Quenching
    - 125: Coke Screening
    - 130: COG Cooling and Tar Separation

- 131: Primary Gas Cooler
- 132: Tar ESP
- 133: Tar Recovery Unit and Tar Dehydrator
- 140: Naphthalene Scrubber
- 150: H_2S and NH_3 Scrubber
- 155: H_2S and NH_3 Stripper
- 160: Combine Claus Plant and NH_3 Cracker
- 170: BTX Scrubber
- 175: BTX Distillation
- 180: Gas Exhauster and Gas Holder

- Unit 200: Sinter Production
  - 210: Raw Materials Handling and Blending Station
  - 220: Sinter Plant
  - 230: Gas Cleaning (from Sinter Strand) – Fabric Filter and ESP
  - 240: Sinter Crusher, Cooler and Screening
  - 250: Gas Cleaning (from Sinter Cooler) - ESP

- Unit 300: Hot Metal Production
  - 310: Raw Materials Handling, Blending and Feeding
  - 320: Blast Furnace
  - 330: BF Slag Granulation Plant
  - 340: Hot Stoves
  - 350: Recuperators
  - 360: Main Air Compression Plant
  - 370: BF Gas Cleaning - Cyclone and Scrubber
  - 380: Gas Holder
  - 1310: PCI Coal Preparation (Coal Mill) and Drying – part of ancillary unit

- Unit 400: Hot Metal Desulphurisation
  - 410: Hot Metal Desulphurisation Station
  - 420: Slag & HM Spillage Processing Unit

- Unit 500: Primary Steelmaking
  - 510: Basic Oxygen Furnace
  - 520: Slag Processing Unit
  - 530: Gas Recovery Hood and Waste Heat Boiler
  - 540: BOF Gas Cleaning – Cyclone and Scrubber
  - 550: Gas Holder

- Unit 600: Secondary Steelmaking (Ladle Metallurgy)
  - 610: Ladle Station

- Unit 700: Continuous Casting
  - 710: Continuous Slab Caster

- Unit 800 & 900: Reheating and Rolling Mills
  - 810: Reheating Furnaces
  - 820: Recuperators
  - 910: Hot Rolling Mill

- Unit 1000: Lime Production
    - 1010: Lime Kiln
    - 1020: Gas Cleaning – ESP
    - 1030: Screening

- Unit 1100: Air Separation Unit
    - 1110: Main Air Compressor
    - 1120: Air Pre-Cooling and Treatment
    - 1130: Main Heat Exchanger and Cryogenic Separation Plant
    - 1140: Liquid Product Storage
    - 1150: Product Evaporation and Compression Plant

- Unit 1200: Captive Power Plant
    - 1210: Boiler Island
    - 1220: Steam Turbine Island
    - 1230: Electricity Generator

2. UNIT 100: COKE PRODUCTION

2.1. Study Specification

The REFERENCE Steel Mill's coke production is based on 3 batteries of by-product recovery coke ovens equipped with 48 ovens per batteries (144 ovens in total). The total charge volume is ~45m^3. The coke is quenched in wet quenching towers designed to achieve minimal emissions. Total production per year is about 1.63 million tonnes (both lump coke and coke breeze combine). Coking by-products recovered include coke oven gas, crude tar, BTX and sulphur.

Coke oven gas and blast furnace gas are used as fuel to heat up the oven.

A detailed description of the coking process is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-1 summarises the specification of the coke production of the reference steel mill.

2.2. PFD and Mass Balance

Figure D-1 presents the process flow diagram of the coke production of the integrated steel mill (Reference Case). Table D-2 presents a summary of the mass balance for the coke production of the steel mill – reference case. Furthermore, below is the list of other users of coke oven gas within the REFERENCE Steel Mill not specified in any PFDs presented in this section of the report.

	Attached Unit	Nm^3 COG/t HRC
Torpedo heating	300: Hot Metal Production	1.10
Ignition, BF flare	300: Hot Metal Production	1.10
Ladle heating	500: BOF Steelmaking	10.86
Ignition, BOF flare	500: BOF Steelmaking	1.10

2.3. Utilities Consumption (Electricity, Steam and Make-Up Water)

The coke production requires about 35.0 kWh/t coke (14.3 kWh/t HRC or 57,068.15 MWh/y).

The major electricity consumers of the coke production consist of:

- Gas exhausters
- Combustion air blowers,
- Flue gas ID fans,
- Various pumps,
- Various electric motors for drives of conveyors, rail car, etc...

The overall steam requirement of the coke production is about 150 kg/t coke. Major users of steam include the H_2S and NH_3 strippers (Unit 155), reboiler of the BTX still (Unit 175) and the tar dehydrator (Unit 133). It is assumed that the steam is supplied from the waste heat boiler of steelmaking process (Unit 500). Whilst the small amount of steam generated by the waste heat boilers of the Combined Claus Plant and NH_3 Cracking (Unit 160) is used as supplement to the coke production requirement.

The coke production should require make up water for process used of 2,931,317 m^3 per year. The largest water consumer is the coke wet quenching unit (Unit 120).

Table D-1: General Information – Study Specification (Unit 100: Coke Production)

Description	Summary - Relevant Specifications	
No. of Coke Oven Batteries Total No. of Ovens Total Charge Volume	3 (each battery consists of 48 ovens) 144 45 m^3	
Coking Coal (dry) • Hard Coking Coal • Semi-Soft Coking Coal COG Consumption (wet) BFG Consumption (wet) Steam Consumption (9 bar_a, sat.) Electricity Consumption COG Export (wet)	1285.2 kg/t coke (2.10 Mt/y) 771.1 kg/t coke 514.1 kg/t coke 112.6 Nm^3/t coke 450.4 Nm^3/t coke 150.0 kg/t coke 35.0 kWh/t coke 327.0 Nm^3/t coke	523.8 kg/t HRC 314.3 kg/t HRC 209.5 kg/t HRC 45.9 Nm^3/t HRC 183.6 Nm^3/t HRC 61.1 kg/t HRC 14.3 kWh/t HRC 133.3 Nm^3/t HRC
Total Coke Production (dry) • BF Coke • Coke Breeze Crude Tar / Naphthalene (dry) Benzene, Toluene, Xylene (dry) Sulphur (dry)	1000.0 kg/t coke (1.63 Mt/y) 863.7 kg/t coke (1.41 Mt/y) 136.3 kg/t coke (0.22 Mt/y) 41.1 kg/t coke 12.1 kg/t coke 3.0 kg/t coke	407.6 kg/t HRC 352.0 kg/t HRC 55.6 kg/t HRC 16.8 kg/t HRC 4.9 kg/t HRC 1.2 kg/t HRC

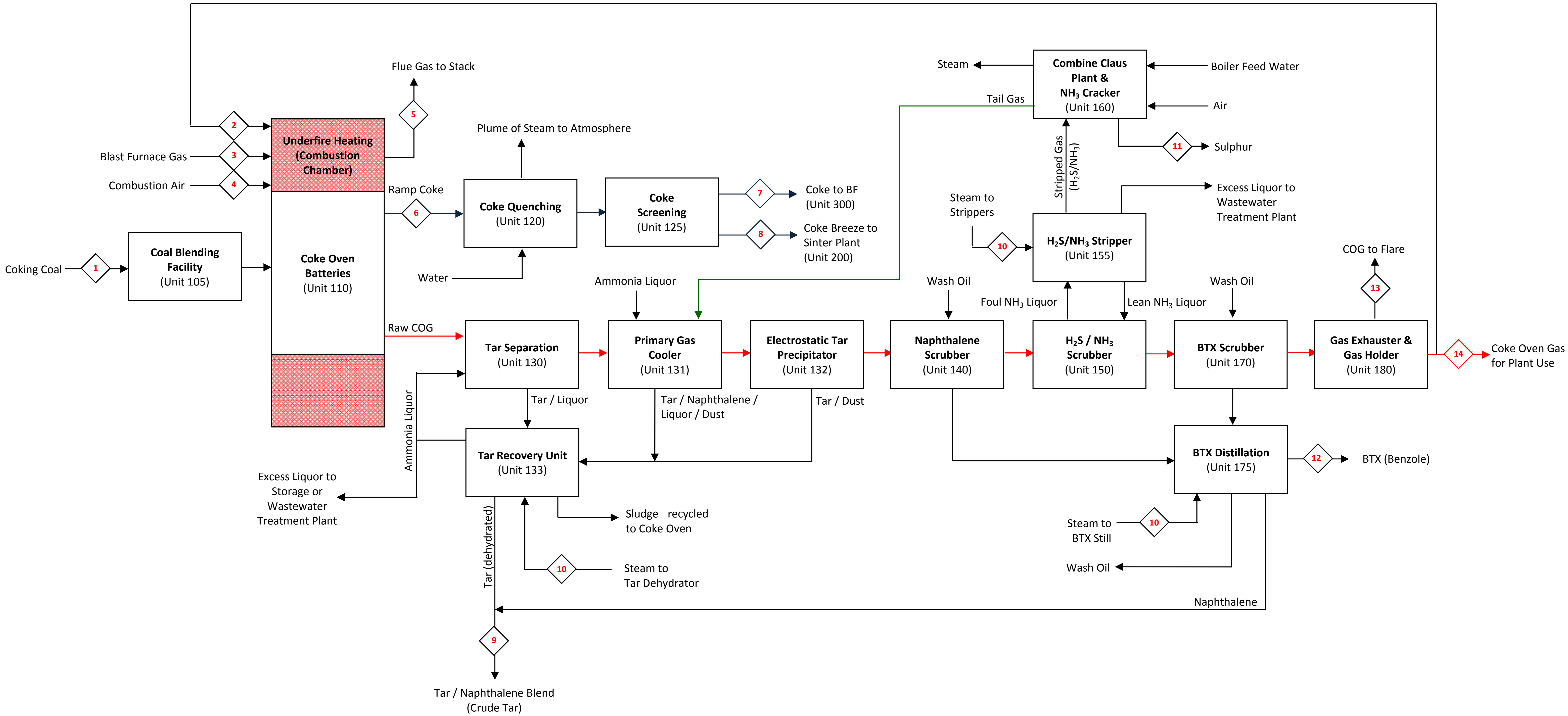

Figure D-1: PFD of the coke production (Unit 100)

Table D-2: Mass Balance (Unit 100: Coke Production)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Stream		**Coking Coal**	**COG to Underfire Heating**	**BFG**	**Combustion Air**	**Flue Gas**	**Ramp Coke**	**Coke to BF**	**Coke to Sinter**	**Crude Tar & Napthalene**	**Steam to Various Users**	**Sulphur**	**BTX (Benzole)**	**COG to flare**	**COG to Users**
Total Mass Flow (wet)	**t/y**	**2,277,702**	**79,713**	**992,429**	**2,402,783**	**3,474,968**	**1,698,457**	**1,466,917**	**231,540**	**68,449**	**244,578**	**4,937**	**19,729**	**7,321**	**231,457**
Total Mass Flow (dry)	**t/y**	**2,095,486**	**73,838**	**973,827**	**2,386,050**	**3,246,484**	**1,630,519**	**1,408,241**	**222,278**	**67,080**	**244,578**	**4,937**	**19,729**	**6,782**	**214,400**
Specific Mass Flow (wet)	kg/t coke	1396.9	48.9	608.7	1473.6	2131.2	1041.7	899.7	142.0	42.0	150.0	3.0	12.1	4.5	142.0
Specific Mass Flow (dry)	kg/t coke	1285.2	45.3	597.2	1463.4	1991.1	1000.0	863.7	136.3	41.1	150.0	3.0	12.1	4.2	131.5
Pressure	Bara	amb.	1.11	1.11	amb.	1.03	amb.	amb.	amb.	amb.	9.01	amb.	amb.	1.11	1.11
Temperature	oC	12	29	25	12	250	25	25	25	12	175	12	12	29	29
Phase		solid	gas	gas	gas	gas	solid	solid	solid	liquid	gas	solid	liquid	gas	gas
Solid Composition (dry basis)															
Fe	%wt.	0.33	-	-	-	-	0.42	0.42	0.42	-	-	-	-	-	-
C	%wt.	78.85	-	-	-	-	88.05	88.05	88.05	-	-	-	-	-	-
H	%wt.	4.51	-	-	-	-	0.10	0.10	0.10	-	-	-	-	-	-
CaO	%wt.	0.05	-	-	-	-	0.06	0.06	0.06	-	-	-	-	-	-
MgO	%wt.	0.05	-	-	-	-	0.07	0.07	0.07	-	-	-	-	-	-
SiO2	%wt.	4.68	-	-	-	-	6.27	6.27	6.27	-	-	-	-	-	-
Al2O3	%wt.	2.10	-	-	-	-	2.82	2.82	2.82	-	-	-	-	-	-
Moisture (wet basis)	%wt.	8.0	-	-	-	-	4.0	4.0	4.0	2.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/t coke	-	112.60	450.4	1149.74	1619.34	-	-	-	-	-	-	-	10.34	326.96
Average MW			9.7	30.3	28.7	29.5					18.0			9.7	9.7
Gas Composition (wet basis)															
CH4	%v.	-	23.04	-	-	-	-	-	-	-	-	-	-	23.04	23.04
Other HC (Average MW = C2.5H5)	%v.	-	2.69	-	-	-	-	-	-	-	-	-	-	2.69	2.69
H2	%v.	-	59.53	3.63	-	-	-	-	-	-	-	-	-	59.53	59.53
CO2	%v.	-	0.96	22.10	-	14.77	-	-	-	-	-	-	-	0.96	0.96
CO	%v.	-	3.84	22.34	-	-	-	-	-	-	-	-	-	3.84	3.84
O2	%v.	-	0.19	-	20.72	5.00	-	-	-	-	-	-	-	0.19	0.19
N2	%v.	-	5.76	48.77	78.17	69.47	-	-	-	-	-	-	-	5.76	5.76
H2O	%v.	-	3.98	3.15	1.11	10.76	-	-	-	-	100.00	-	-	3.98	3.98

3. UNIT 200: SINTER PRODUCTION

3.1. Study Specification

The model for the reference case has assumed that the sinter production is equipped with a single train sintering machine with an annual production of 4.45 million tonnes sinter. This is equipped with raw materials handling (comprising different feed hoppers) and blending station (mixing drum), sinter strand, flue gas cleaning based on ESP and fabric filter, sinter crusher and rotary cooler, hot and cold screens, and off-gas cleaning consisting of ESP.

The sinter strand is a standard travelling grate equipped with an ignition furnace consisting of roof burners fired with coke oven gas as primary fuel and natural gas as back-up fuel. The sinter strand is assumed to have a grate area estimated at 410 m^2 with 90% utilization at 35 t/(m^2-24h).

A full description of the sinter process is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-3 summarises the specification of the sinter production of the reference steel mill.

3.2. PFD and Mass Balance

Figure D-2 presents the process flow diagram of the sinter production of the integrated steel mill (Reference Case). Table D-4 presents a summary of the mass balance for the sinter production of the integrated steel mill – reference case.

3.3. Utilities Consumption (Electricity and Make-Up Water)

The sinter production requires about 32.0 kWh/t sinter (35.6 kWh/t HRC or 142,257.88 MWh/y).

The major power consumers of the sinter production process consist of:

- combustion air blowers,
- sinter off-gas exhaust fans,
- dust collection FD fans,
- cooling fans,
- electric motors for drives of crusher, conveyors, mixing drums, etc...

The major process water consumer is at the mixing and granulation drum. It was estimated that the total process water used is about 1,324,616 m^3 per year.

Table D-3: General Information – Study Specification (Unit 200: Sinter Production)

Description	Summary - Relevant Specifications	
No. of Sinter Plant Grate Area Type of Sinter Cooler Flue Gas Clean Up Sinter Basicity (Ratio of CaO/SiO_2)	1 (Standard Travelling Grate) 410 m^2 with 90% utilization at 35 t/(m^2-24h). Rotary Cooler ESP and fabric filter 1.80	
Coke Breeze (dry) COG Consumption (wet) Electricity Consumption	50.0 kg/t sinter 4.2 Nm^3/t sinter 32.0 kWh/t sinter	55.6 kg/t HRC 4.6 Nm^3/t HRC 35.6 kWh/t HRC
Sinter(dry) Iron Ore Fines (dry) • Hematite (Brazil) • Hematite/Goethite (Australia) • Magnetite (Sweden)	1000.0 kg/t sinter (4.45 Mt/y) 792.3 kg/t sinter (3.52 Mt/y) 657.6 kg/t sinter 79.3 kg/t sinter 55.5 kg/t sinter	1111.4 kg/t HRC 880.5 kg/t HRC 730.8 kg/t HRC 88.1 kg/t HRC 61.6 kg/t HRC

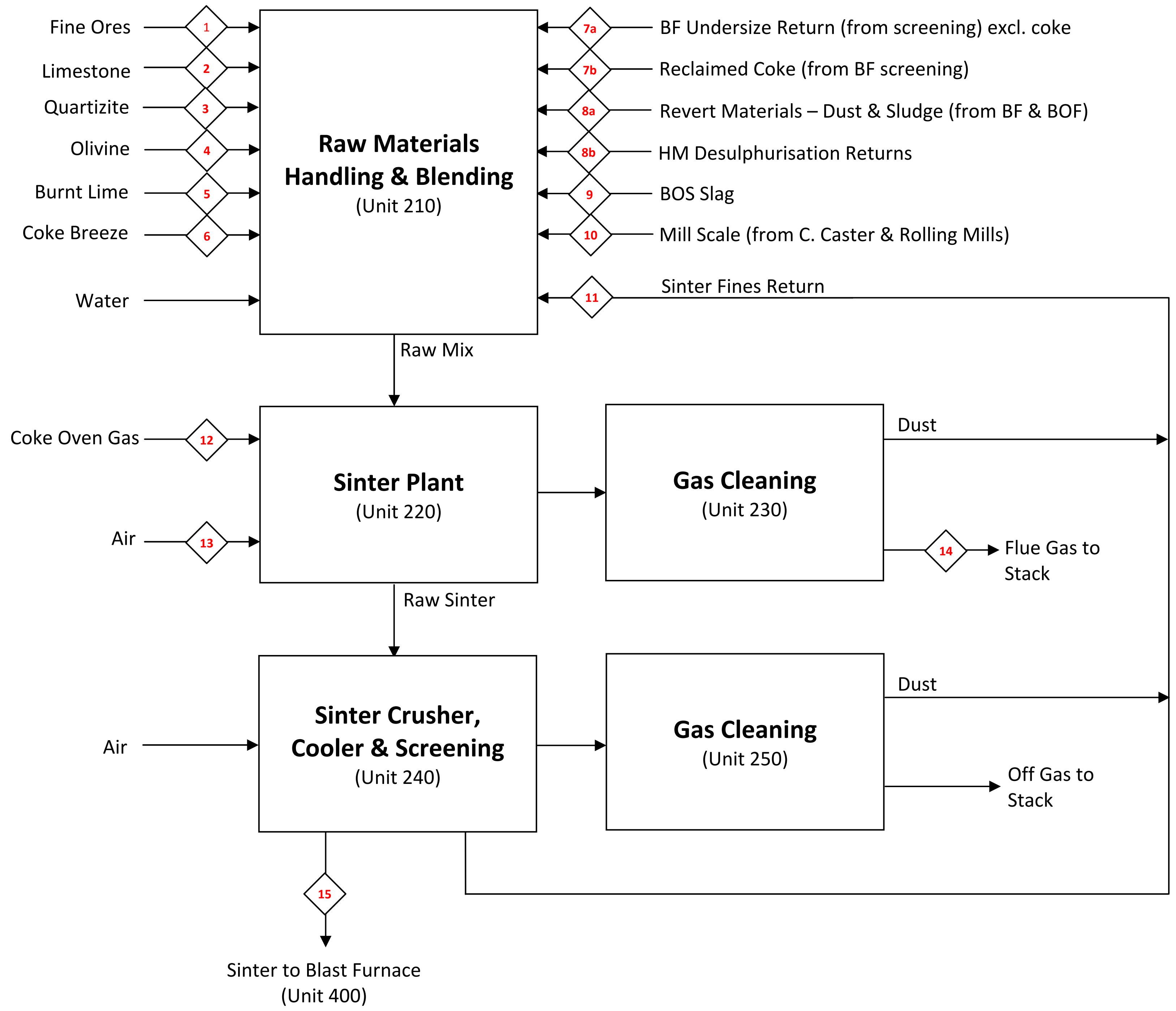

Figure D-2: PFD of the sinter production (Unit 200)

Table D-4: Mass Balance (Unit 200: Sinter Production)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stream		**Iron Ore Fines**	**Limestone**	**Quartzite**	**Olivine**	**Lime**	**Coke Breeze**	**BF Undersize**	**Revert Materials**	**BOS Slag**	**Mill Scale**	**Sinter Fines Return**	**COG**	**Combustion Air**	**Flue Gas**	**Sinter to BF**
Total Mass Flow (wet)	**t/y**	**3,707,389**	**523,103**	**53,886**	**91,261**	**44,456**	**231,540**	**93,796**	**255,479**	**138,275**	**97,131**	**1,111,390**	**8,000**	**12,645,530**	**1,818,115**	**4,445,559**
Total Mass Flow (dry)	**t/y**	**3,522,020**	**517,872**	**53,347**	**90,349**	**44,456**	**222,278**	**90,795**	**220,398**	**136,893**	**96,159**	**1,111,390**	**7,530**	**12,557,468**	**1,737,452**	**4,445,559**
Specific Mass Flow (wet)	kg/t sinter	834.0	117.7	12.1	20.5	10.0	52.1	21.1	57.5	31.1	21.8	250.0	1.8	2844.5	409.0	1000.0
Specific Mass Flow (dry)	kg/t sinter	792.3	116.5	12.0	20.3	10.0	50.0	20.4	49.6	30.8	21.6	250.0	1.7	2824.7	390.8	1000.0
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	1.11	amb.	1.03	amb.
Temperature	oC	12	12	12	12	12	12	12	12	12	12	80	25	12	120	45
Phase		solid	solid	solid	solid	solid	solid	solid	solid	solid	solid	solid	gas	gas	gas	solid
Solid Composition (dry basis)																
Fe	%wt.	65.62	0.30	-	5.70	0.51	0.42	42.01	54.80	20.00	70.00	57.84	-	-	-	57.84
C	%wt.	-	-	-	-	-	88.05	27.51	14.18	-	-	-	-	-	-	-
H	%wt.	-	-	-	-	-	0.10	-	-	-	-	-	-	-	-	-
CO2 (resiudual)	%wt.	-	42.60	-	-	3.00	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	0.10	54.00	-	0.20	91.26	0.06	1.73	10.22	50.72	0.72	9.45	-	-	-	9.45
MgO	%wt.	0.10	1.10	-	47.90	1.86	0.07	0.56	2.34	5.47	0.07	1.50	-	-	-	1.50
SiO2	%wt.	2.72	1.20	98.00	41.60	2.03	6.27	6.76	2.22	9.45	0.84	5.25	-	-	-	5.25
Al2O3	%wt.	0.93	0.50	1.90	0.48	0.85	2.82	1.87	0.60	0.56	0.16	1.04	-	-	-	1.04
Moisture (wet basis)	%wt.	5.0	1.0	1.0	1.0	-	4.0	3.2	13.7	1.0	1.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/t sinter	-	-	-	-	-	-	-	-	-	-	-	4.18	2219.33	2388.41	-
Average MW													9.7	28.7	28.0	
Gas Composition (wet basis)																
CH4	%v.	-	-	-	-	-	-	-	-	-	-	-	23.24	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	-	-	-	-	-	-	-	-	2.71	-	-	-
H2	%v.	-	-	-	-	-	-	-	-	-	-	-	60.05	-	-	-
CO2	%v.	-	-	-	-	-	-	-	-	-	-	-	0.97	-	4.81	-
CO	%v.	-	-	-	-	-	-	-	-	-	-	-	3.87	-	0.74	-
O2	%v.	-	-	-	-	-	-	-	-	-	-	-	0.19	20.72	14.90	-
N2	%v.	-	-	-	-	-	-	-	-	-	-	-	5.81	78.17	72.65	-
H2O	%v.	-	-	-	-	-	-	-	-	-	-	-	3.15	1.11	6.90	-

4. UNIT 300: HOT METAL PRODUCTION

4.1. Study Specification

The hot metal production of the REFERENCE integrated steel mill is designed based on 2 trains of blast furnace each producing around 1.98 Mt/y of hot metal (providing a total of 3.97 Mt/y). Each blast furnace is equipped with 3 hot stoves operating in staggered configuration. The main air compression that provides the blast air to the hot stove is electrically driven. Hot metal produced by the blast furnace is transferred to the Hot Metal Desulphurisation stations via pre-heated torpedo cars. The slag produced by the blast furnace is processed in a conventional wet slag granulation plant.

The blast furnace has a hearth diameter of 11 meter and a working volume of ~2750 m^3. The charging of the raw materials to the blast furnace is based on a bell less top technology. The blast furnace is equipped with PCI injection delivering coal at a rate of ~152 kg dry coal/thm. Blast furnace gas and coke oven gas are used as fuel to heat up the hot stoves. Hot blast air used by the blast furnace has oxygen added to enrich it to 24% O_2. Blast furnace gas collected is cleaned using a cyclone and wet scrubber system before being distributed to the different users (hot stove heating, coke oven under-fire heating, and power plant) within the steel mill.

A full description of the hot metal production process is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-5 summarises the specification of the hot metal production of the reference steel mill.

4.2. PFD and Mass Balance

Figure D-3 presents the process flow diagram of the hot metal production of the integrated steel mill (Reference Case). Table D-6 presents a summary of the mass balance for the hot metal production of the integrated steel mill – reference case.

4.3. Utilities Consumption (Electricity, Steam and Make-Up Water)

The hot metal production requires about 98.8 kWh/thm (98.1 kWh/t HRC or 392,205.88 MWh/y). Additional 4.9 kWh/thm (4.8 kWh/t HRC or 19,272.00 MWh/y) of electricity is required to supply 44.1 Nm^3/thm (43.8 Nm^3/t HRC) of compressed air to the slag granulation plant.

The major power consumers of the hot metal production process consist of:

- Main air compressors – BF blowers (69 kWh/thm)
- Dust collection FD fans (cast houses),
- Water pumps (cooling water and slag granulation plant),
- ID fans (slag granulation plant, coal drying, hot stoves, etc...),
- Electric motors for drives of conveyors, feeders, PCI coal milling, torpedo cars, etc...

The overall steam requirement of the hot metal production is about 8 kg/thm (@ $9bar_a$, sat.). This is added to the hot blast air to achieve the target blast moisture content. It is assumed that the steam is supplied from the waste heat boiler of steelmaking process (Unit 500).

The major process water consumers are the slag granulation plant and BF cooling water (make up). It was estimated that the total process water used is about 3,483,639 m^3 per year (also to include water requirements of Unit 400: HM desulphurisation plant).

Table D-5: General Information – Study Specification (Unit 300: Hot Metal Production)

Description	Summary - Relevant Specifications	
No. of Blast Furnace	2 (Each having a hearth diameter of 11 m & working volume of 2750 m^3)	
No. of Hot Stoves	6 (Each BF is equipped with 3 hot stoves with a central recuperator)	
No. of Main Air Compressors	2 (Each BF has 1 Axial Air Compressor ~250,000 Nm^3/h @ 3.8 Bara)	
Main Air Compressors Drive	Electrically Driven	
PCI Coal Injection Facility	Yes – with 1x PCI Coal Drying/Milling & 2x Injection Facilities	
Off-Gas Clean Up	2 trains of cyclone and wet scrubber (1 per BF)	
No. of Casthouses	2 (1 per BF with 2 operating tapholes for hot metal and slag withdrawal)	
No. of Slag Granulation Plant	2 (1 per BF – equipped with slag dewatering facility)	
Hot Metal Transfer Mode	Via Torpedo Cars to HM Desulphurisation Stations (Unit 400)	
BF Iron Burden Distribution (dry)	Sinter (70%w.), Pellets (22%w.), Lump (8%w.)	
Sinter Basicity (CaO/SiO_2 Ratio)	1.80	
Reducing Agent Rate – RAR (dry)	507 kg/thm	
Blast Volume (wet)	1053 Nm^3/thm	
Blast Pressure	3.8 Bara	
Blast Temperature	1118^{o}C	
Blast O_2 Enrichment	24%v.	
Blast Moisture	16 g/Nm^3(dry)	
Hot Metal Temperature	1470^{o}C	
Hot Metal Carbon Content (dry)	4.7%w.	
Hot Metal Silicon Content (dry)	0.5%w.	
Slag Rate (dry)	280 kg/thm	
Slag Basicity (CaO/SiO_2 Ratio)	1.15	
Top Pressure	2.4 Bara	
Top Gas Temperature	140^{o}C	
PCI Coal (dry)	152.0 kg/thm	150.8 kg/t HRC
Lump Coke (dry)	354.8 kg/thm	352.1 kg/t HRC
COG Consumption – hot stoves (wet)	7.2 Nm^3/thm	7.2 Nm^3/t HRC
COG Consumption – PC drying (wet)	1.4 Nm^3/thm	1.4 Nm^3/t HRC
BFG Consumption – hot stoves (wet)	479.2 Nm^3/thm	475.4 Nm^3/t HRC
Steam Consumption (9 bar_a, sat.)	8.0 kg/thm	7.9 kg/t HRC
Electricity Consumption - HM Prod.	98.8 kWh/thm	98.1 kWh/t HRC
Electricity Consumption - Ancillary	4.9 kWh/thm	4.8 kWh/t HRC
BFG Export (wet)	1119.3 Nm^3/thm	1110.6 Nm^3/t HRC
Hot Metal (dry)	1000.0 kg/thm (3.97 Mt/y)	992.2 kg/t HRC
Sinter(dry)	1120.1 kg/thm	1111.4 kg/t HRC
Lump Ore (dry)	125.3 kg/thm	124.3 kg/t HRC
Pellets (dry)	351.8 kg/thm	349.0 kg/t HRC
Granulated Slag (dry)	280.0 kg/thm	277.8 kg/t HRC

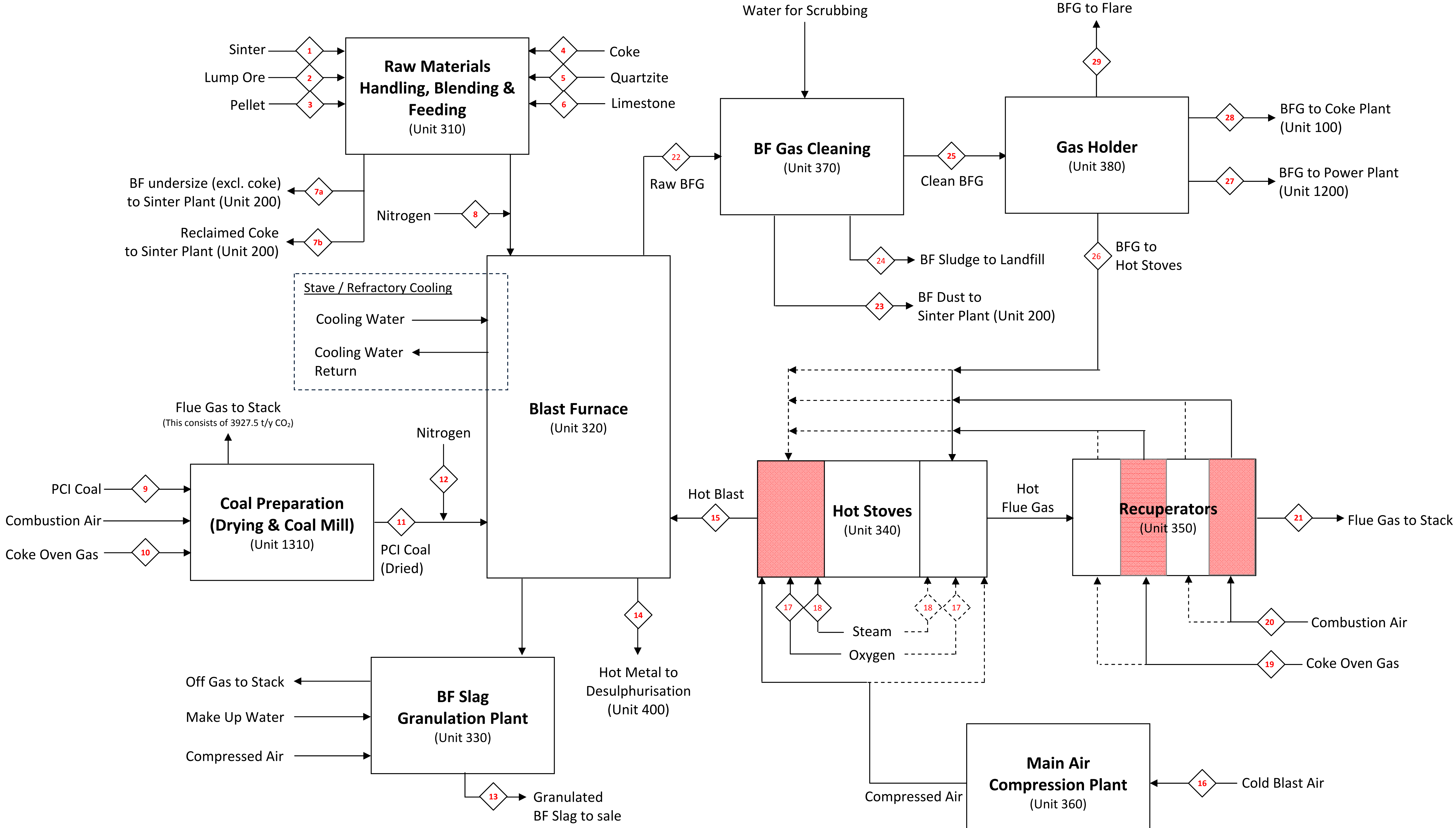

Figure D-3: PFD of the hot metal production (Unit 300)

Table D-6: Mass Balance (Unit 300: Hot Metal Production)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stream		**Sinter**	**Lump Ore**	**Iron Ore Pellets**	**Coke**	**Limestone**	**Quartzite**	**BF Undersize**	**N2 to RM Feeder (Top)**	**PCI Coal to Dryer**	**COG to Dryer**	**PCI Coal (dried)**	**N2 to PCI**	**BF Granulated Slag**	**Hot Metal**	**Hot Blast**
Total Mass Flow (wet)	**t/y**	**4,445,559**	**523,304**	**1,424,671**	**1,466,917**	**53,027**	**43,564**	**93,814**	**9,923**	**655,708**	**2,394**	**609,344**	**14,884**	**1,262,786**	**3,968,756**	**5,363,687**
Total Mass Flow (dry)	**t/y**	**4,445,559**	**497,139**	**1,396,178**	**1,408,241**	**52,497**	**43,129**	**90,795**	**9,923**	**603,251**	**2,254**	**603,251**	**14,884**	**1,111,252**	**3,968,756**	**5,296,779**
Specific Mass Flow (wet)	kg/thm	1120.1	131.9	359.0	369.6	13.4	11.0	23.6	2.5	165.2	0.6	153.5	3.8	318.2	1000.0	1351.5
Specific Mass Flow (dry)	kg/thm	1120.1	125.3	351.8	354.8	13.2	10.9	22.9	2.5	152.0	0.6	152.0	3.8	280.0	1000.0	1334.6
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	amb.	6.01	amb.	amb.	amb.	21.01	amb.	amb.	3.81
Temperature	oC	45	12	12	25	12	12	12	60	12	25	120	60	12	1470	1118
Phase		solid	solid	solid	solid	solid	solid	solid	gas	solid	gas	solid	Gas	solid	liquid	gas
Solid & Liquid Composition (dry basis)																
Fe	%wt.	57.88	61.00	65.50	0.42	0.30	-	42.01	-	0.52	-	0.52	-	0.30	94.15	-
C	%wt.	-	-	-	88.05	-	-	27.51	-	87.00	-	87.00	-	-	4.70	-
H	%wt.	-	-	-	0.10	-	-	-	-	4.03	-	4.03	-	-	-	-
Si	%wt.	-	-	-	-	-	-	-	-	-	-	-	-	-	0.50	-
CO2 (residual)	%wt.	-	-	-	-	42.60	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	9.40	0.30	1.80	0.06	54.00	-	1.73	-	0.19	-	0.19	-	42.21	-	-
MgO	%wt.	1.50	0.20	1.20	0.07	1.10	-	0.56	-	0.04	-	0.04	-	7.63	-	-
SiO2	%wt.	5.23	8.38	2.80	6.27	1.20	98.00	6.76	-	2.41	-	2.41	-	36.71	-	-
Al2O3	%wt.	1.04	2.76	0.60	2.82	0.50	1.90	1.87	-	1.62	-	1.62	-	10.33	-	-
Moisture (wet basis)	%wt.	-	5.0	2.0	4.0	1.0	1.0	3.2	-	8.0	-	1.0	-	12.0	-	-
Specific Vol. Flow (wet)	Nm3/thm	-	-	-	-	-	-	-	2.00	-	1.40	-	3.00	-	-	1052.68
Average MW									28.0		9.66		28.0			28.8
Gas Composition (wet basis)																
CH4	%v.	-	-	-	-	-	-	-	-		23.24	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	-	-	-	-	-		2.71	-	-	-	-	-
H2	%v.	-	-	-	-	-	-	-	-		60.05	-	-	-	-	-
CO2	%v.	-	-	-	-	-	-	-	-		0.97	-	-	-	-	-
CO	%v.	-	-	-	-	-	-	-	-		3.87	-	-	-	-	-
O2	%v.	-	-	-	-	-	-	-	0.02		0.19	-	0.02	-	-	24.13
N2	%v.	-	-	-	-	-	-	-	99.98		5.81	-	99.98	-	-	73.88
Ar	%v.	-	-	-	-	-	-	-	-		-	-	-	-	-	-
H2O	%v.	-	-	-	-	-	-	-	-		3.15	-	-	-	-	1.99

Table D-6: Mass Balance (Unit 300: Hot Metal Production) – cont'd.

		16	17	18	19	20	21	22	23	24	25	26	27	28	29
Stream		**Cold Blast (Air)**	**O2**	**Steam**	**COG to Hot Stove**	**Combustion Air to Hot Stove**	**Flue Gas from Hot Stove**	**Raw BFG (Top Gas)**	**BF Dust to Sinter Plant**	**BF Sludge to Landfill**	**Clean BFG (Total)**	**BFG to Hot Stove**	**BFG to Power Plant**	**BFG to Coke Plant**	**Flared BFG**
Total Mass Flow (wet)	**t/y**	**5,060,744**	**271,438**	**31,568**	**12,336**	**1,820,735**	**4,390,757**	**8,724,518**	**59,531**	**17,639**	**8,668,140**	**2,557,673**	**5,012,625**	**992,397**	**122,228**
Total Mass Flow (dry)	**t/y**	**5,025,502**	**271,438**	**31,568**	**11,611**	**1,808,056**	**4,231,961**	**8,505,664**	**59,531**	**15,875**	**8,505,664**	**2,493,264**	**4,918,668**	**973,795**	**119,937**
Specific Mass Flow (wet)	kg/thm	1275.1	68.4	8.0	3.1	458.8	1106.4	2198.4	15.0	4.4	2184.2	644.5	1263.1	250.1	30.8
Specific Mass Flow (dry)	kg/thm	1266.3	68.4	8.0	2.9	455.6	1066.4	2143.2	15.0	4.0	2143.2	628.2	1239.4	245.4	30.2
Pressure	Bara	amb.	11.01	9.01	1.11	1.11	1.11	2.41	amb.	amb.	1.11	1.11	1.11	1.11	1.11
Temperature	oC	12	60	175	25	41	140	140	12	12	25	30	25	25	25
Phase		gas	gas	gas	gas	gas	gas	gas	solid	solid	gas	gas	gas	gas	gas
Solid & Liquid Composition (dry basis)															
Fe	%wt.	-	-	-	-	-	-	-	26.10	37.70	-	-	-	-	-
C	%wt.	-	-	-	-	-	-	-	47.03	23.69	-	-	-	-	-
H	%wt.	-	-	-	-	-	-	-	0.43	-	-	-	-	-	-
Si	%wt.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2 (residual)	%wt.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	-	-	-	-	-	-	-	6.00	6.18	-	-	-	-	-
MgO	%wt.	-	-	-	-	-	-	-	1.23	1.71	-	-	-	-	-
SiO2	%wt.	-	-	-	-	-	-	-	4.93	4.61	-	-	-	-	-
Al2O3	%wt.	-	-	-	-	-	-	-	1.98	1.90	-	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	-	-	-	-	0.0	10.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/thm	994.88	47.90	-	7.21	357.95	780.41	1633.97	-	-	1616.30	479.05	934.68	185.05	22.79
Average MW		28.7	32.0	18.0	9.7	28.7	31.8	30.2			30.3	30.2	30.3	30.3	30.3
Gas Composition (wet basis)															
CH4	%v.	-	-	-	23.24	-	-	-	-	-	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	2.71	-	-	-	-	-	-	-	-	-	-
H2	%v.	-	-	-	60.05	-	-	3.59	-	-	3.63	3.59	3.63	3.63	3.63
CO2	%v.	-	-	-	0.97	-	27.30	21.86	-	-	22.10	21.86	22.10	22.10	22.10
CO	%v.	-	-	-	3.87	-	-	22.10	-	-	22.34	22.10	22.34	22.34	22.34
O2	%v.	20.72	99.90	-	0.19	20.72	0.80	-	-	-	-	-	-	-	-
N2	%v.	78.17	0.01	-	5.81	78.17	65.52	48.25	-	-	48.77	48.24	48.77	48.77	48.77
Ar	%v.	-	0.09	-	-	-	-	-	-	-	-	-	-	-	-
H2O	%v.	1.11	-	100.00	3.15	1.11	6.38	4.20	-	-	3.15	4.21	3.15	3.15	3.15

5. UNIT 400: HOT METAL DESULPHURISATION

5.1. Study Specification

The study assumed the hot metal desulphurisation station reducing hot metal sulphur content from ~0.032%w. to less than 0.01%w. based on mono-reagent injection using CaC_2. The process is not expected to be energy intensive; nonetheless, best practice in place is aimed to achieve energy efficiency by reducing hot metal spillage to minimum during slag skimming, and reducing hot metal temperature drop during hot metal transfer.

The study assumed 1.9% hot metal loss and a temperature drop of 110°C (from BF tapping to BOF charging). Metal spillage and slag are combined in the slag processing unit of which 37% is returned to the sinter plant and 63% sent to landfill.

A full description of the hot metal desulphurisation process is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-7 summarises the specification of the hot metal production of the reference steel mill.

5.2. PFD and Mass Balance

Figure D-4 presents the process flow diagram of the hot metal desulphurisation unit of the integrated steel mill (Reference Case). Table D-8 presents a summary of the mass balance for the hot metal desulphurisation unit of the integrated steel mill – reference case.

5.3. Utilities Consumption (Electricity and Make-Up Water)

The electricity consumption for the hot metal desulphurisation has been accounted for in the Hot Metal Production (Unit 300).

The major power consumers of the hot metal desulphurisation process consist of:

- CaC_2 storage, preparation, injection facilities,
- Off-gas ID fans,
- Electric motors for drives used in the ladle transfer car, slag skimmers, slag pot, gantry, etc...

The major water user for this process is the slag and HM spillage processing unit. The overall water consumptions were accounted for in the Hot Metal Production (Unit 300).

Table D-7: General Information – Study Specification (Unit 400: HM Desulphurisation)

Description	Summary - Relevant Specifications	
No. of HM Desulphurisation Station Desulphurisation Reagent Reagent Injection Carrier Gas Off-Gas Clean Up Hot Metal Loss Hot Metal Temperature Drop Sulphur Content	2 stations (including slag and spillage processing unit) Mono-injection system using CaC_2 Nitrogen De-dusting Equipment (i.e. Cyclone) 1.9% 110°C < 0.01%w.	
Electricity Consumption	Accounted for in Unit 300	-
De-S Hot Metal (dry) Hot Metal from BF (dry)	1000.0 kg/t de-S HM (3.89 Mt/y) 1019.1 kg/t de-S HM (3.97 Mt/y)	973.6 kg/t HRC 992.2 kg/t HRC

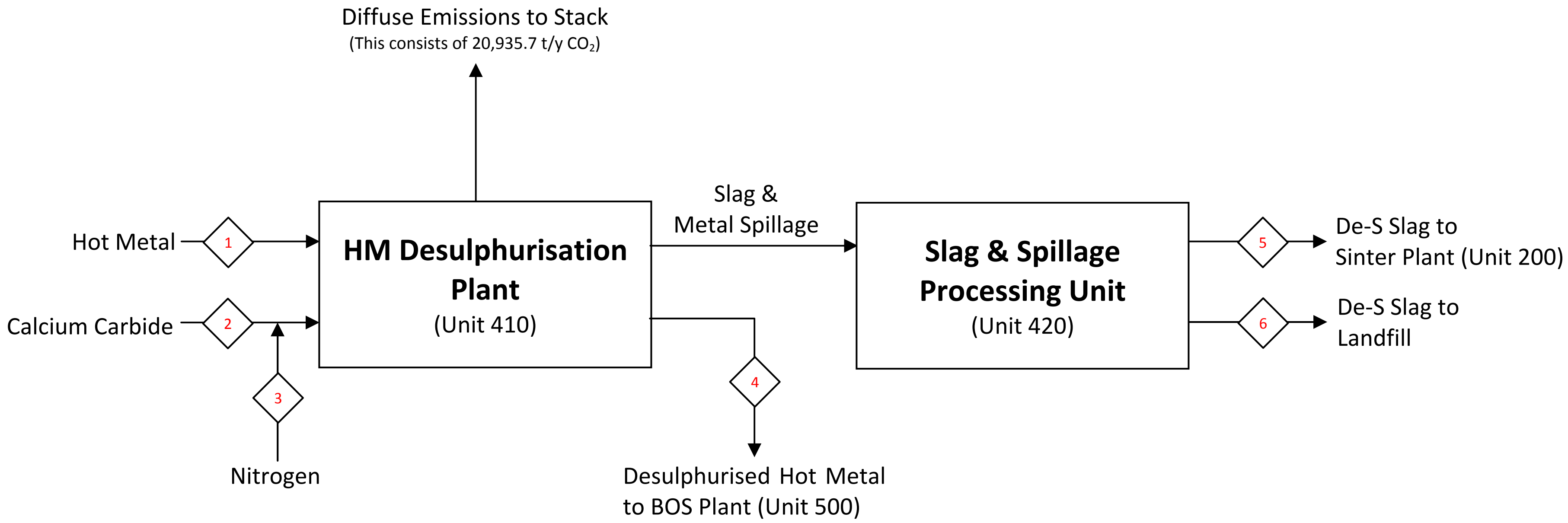

Figure D-4: PFD of the hot metal desulphurisation (Unit 400)

Table D-8: Mass Balance (Unit 400: Hot Metal Desulphurisation)

		1	2	3	4	5	6
Stream		**Hot Metal from BF**	**Calcium Carbide**	**N2 to CaC2 Feed**	**De-S Hot Metal**	**De-S Slag to Landfill**	**De-S Slag to Sinter**
Total Mass Flow (wet)	**t/y**	**3,968,756**	**12,710**	**715**	**3,894,263**	**53,604**	**31,482**
Total Mass Flow (dry)	**t/y**	**3,968,756**	**12,710**	**715**	**3,894,263**	**53,068**	**31,167**
Specific Mass Flow (wet)	kg/thm (de-S)	1019.1	3.3	0.2	1000.0	13.8	8.1
Specific Mass Flow (dry)	kg/thm (de-S)	1019.1	3.3	0.2	1000.0	13.6	8.0
Pressure	Bara	amb.	amb.	21.01	amb.	amb.	amb.
Temperature	oC	1470	12	60	1360	12	12
Phase		liquid	solid	gas	liquid	solid	solid
Solid & Liquid Composition (dry basis)							
Fe	%wt.	94.15	0.20	-	94.24	79.49	79.49
C	%wt.	4.70	1.00	-	4.65	4.16	4.16
Si	%wt.	0.50	-	-	0.49	-	-
CaC2	%wt.	-	79.00	-	-	-	-
CaS	%wt.	-	1.20	-	-	n.r.	n.r.
CaO (incl. carbonates)	%wt.	-	15.80	-	-	11.40	11.40
MgO	%wt.	-	-	-	-	-	-
SiO2	%wt.	-	1.50	-	-	1.93	1.93
Al2O3	%wt.	-	1.20	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	-	1.0	1.0
Specific Vol. Flow (wet)	Nm3/thm (de-S)	-	-	0.15	-	-	-
Average MW				28.0			
Gas Composition (wet basis)							
O2	%v.	-	-	0.02	-	-	-
N2	%v.	-	-	99.98	-	-	-
H2O	%v.	-	-	-	-	-	-

6. UNIT 500: BASIC OXYGEN STEELMAKING PLANT

6.1. Study Specification

The primary steelmaking of the REFERENCE integrated steel mill is based on 2 trains of Basic Oxygen Furnace having a capacity of 220 tonnes per vessel. Each of the converter furnaces is equipped with a suppressed combustion off-gas recovery hood and waste heat boilers to recover the BOF gas and produce the steam required by the steel mill.

The BOF operation is assumed to have a scrap rate of ~190 kg/tls, which comprises 73 kg/tls supplied from internal scrap; and 117 kg/tls from external source. Oxygen injection rate of about 52 Nm^3/tls is required to reduce the carbon content of the hot metal. A small amount of pellets are used coolant. Lime and burnt dolomite are used as fluxes. The total processing time per charge is about 45 minutes.

It was assumed that 75% of the carbon is recovered in the off-gas whilst the unrecovered off-gases are flared. The off-gas is cleaned via a cyclone, wet scrubber and wet ESP. Dust and sludge collected are recycled to the sinter plant (Unit 200).

28% of the slag produced from the BOF operation is recycled to the Sinter Plant (Unit 200); 46% of slag is sold as liming materials (i.e. agricultural application) and the remaining 26% of the slag produce is sent to landfill.

A full description of the basic oxygen steelmaking is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-9 summarises the specification of the basic oxygen steelmaking operation of the reference steel mill.

6.2. PFD and Mass Balance

Figure D-5 presents the process flow diagram of the primary steelmaking of the integrated steel mill (Reference Case). Table D-10 presents a summary of the mass balance for the primary steelmaking of the integrated steel mill – reference case.

6.3. Utilities Consumption (Electricity, Steam and Make-Up Water)

The basic oxygen steelmaking requires about 20.0 kWh/tls (21.6 kWh/t HRC or 86,466.53 MWh/y).

The major power consumers of the basic oxygen steelmaking process consist of:

- BOF gas exhauster (radial fans)
- Pumps (water scrubbing, boiler feed water, and condensates),
- Electric motors for drives of converter's gantry machine, conveyors, scrap charging equipment, slag pot, transfer car, etc...

It is assumed that the steam at 70.6 kg/tls (9 bara, sat.) is produced from the waste heat boilers of the steelmaking process (Unit 500) to satisfy the steam demand of the whole steel mill.

The major process water consumers are the make-up water of the waste heat boilers, cooling/scrubbing water for gas clean up and slag processing unit. It was estimated that the total process water used is about 1,673,679 m^3 per year (also includes water requirements of the ladle metallurgy).

Table D-9: General Information – Study Specification (Unit 500: BOF Steelmaking)

Description	Summary - Relevant Specifications	
No. of Basic Oxygen Furnace	2 converter furnaces – top blowing with inert gas bottom stirring	
Off-gas recovery	Each furnace are equipped w/ suppressed combustion BOFG recovery	
Waste Heat Boiler	Yes (1 per BOF – providing 9 Bara saturated steam)	
Off-Gas Clean Up	2 trains of cyclone, wet scrubber and wet ESP (1 per BOF)	
Scrap Rate (dry)	190.0 kg/tls	
Oxygen Consumption	52.0 Nm^3/tls	
Flux Consumption	75.7 kg/tls (lime and burnt dolomite – including lime splashing)	
Slag Rate (dry)	113.1 kg/tls (28% to Sinter Plant, 46% to Sale, and 26% to Landfill)	
Dust and Sludge (dry)	30.0 kg/tls	
Electricity Consumption	20.0 kWh/tls	21.6 kWh/t HRC
Steam Export (9 bara, sat.)	70.6 kg/tls	76.3 kg/t HRC
BOFG Export (wet)	81.8 Nm^3/tls	88.4 Nm^3/t HRC
Liquid Steel (dry)	1000.0 kg/tls (4.32 Mt/y)	1080.8 kg/t HRC
Hot Metal (dry)	900.8 kg/tls (3.97 Mt/y)	992.2 kg/t HRC
Merchant Scrap (dry)	116.9 kg/tls	126.4 kg/t HRC
Internal Scrap (dry)	73.1 kg/tls	79.0 kg/t HRC
Pellets (dry)	5.0 kg/tls	5.4 kg/t HRC

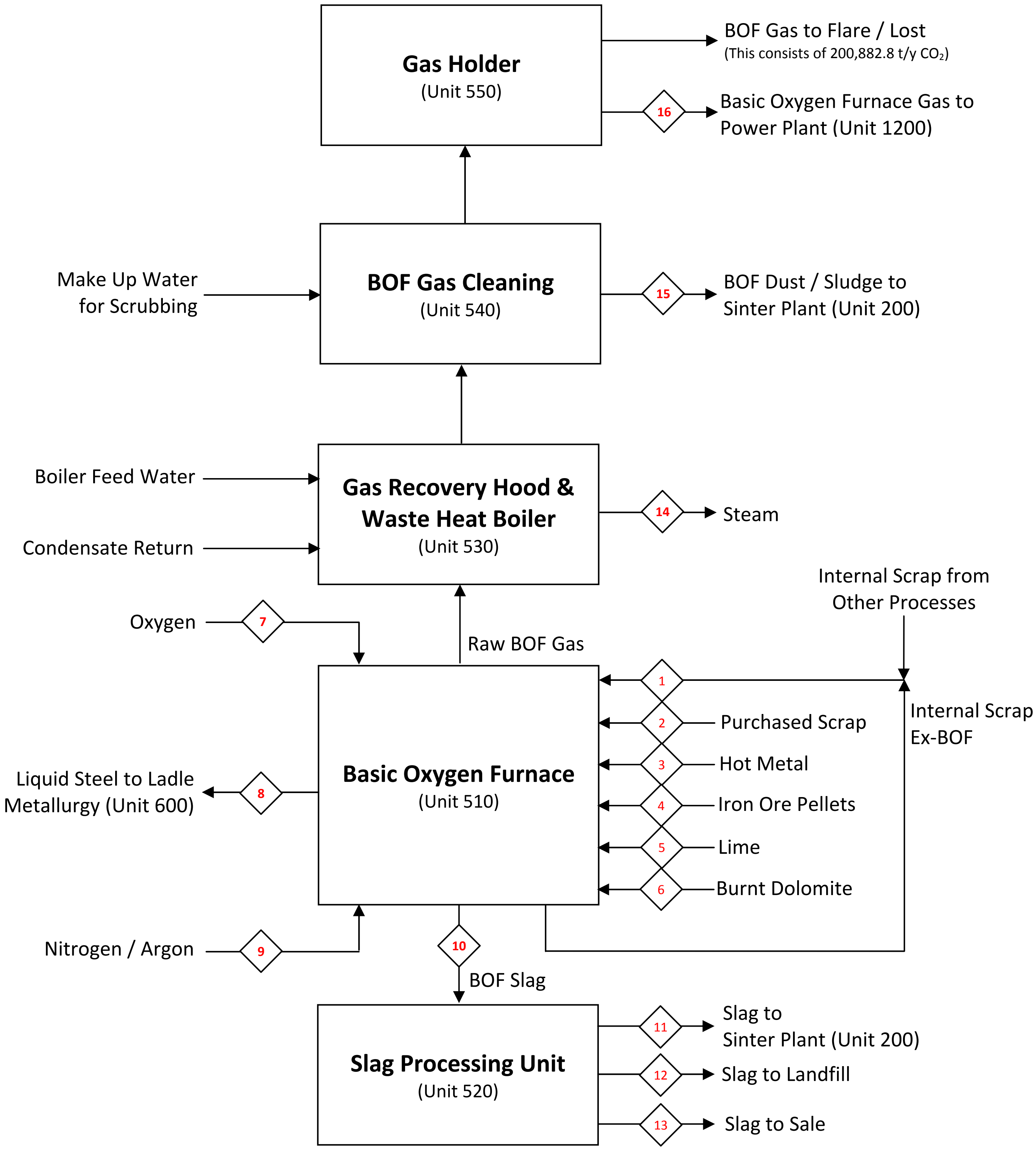

Figure D-5: PFD of the basic oxygen steelmaking plant (Unit 500)

Table D-10: Mass Balance (Unit 500: BOS Plant)

		1	2	3	4	5	6	7	8	9a	9b	10	11	12	13	14	15	16
Stream		**Internal Scrap to BOF**	**Purchased Scrap**	**De-S Hot Metal**	**Iron Ore Pellets (Cooling)**	**Lime**	**Burnt Dolomite**	**O2**	**Liquid Steel**	**N2**	**Ar**	**BOF Slag**	**Slag to Sinter Plant**	**Slag to Landfill**	**Slag to Sale**	**Steam**	**BOF Dust & Sludge to Sinter Plant**	**BOF Gas to Power Plant**
Total Mass Flow (wet)	**t/y**	**315,940**	**505,492**	**3,894,263**	**21,983**	**280,230**	**47,640**	**318,514**	**4,323,327**	**1,638**	**3,348**	**493,859**	**138,275**	**128,408**	**227,175**	**305,283**	**169,174**	**448,173**
Total Mass Flow (dry)	**t/y**	**315,940**	**505,492**	**3,894,263**	**21,544**	**280,230**	**47,164**	**318,514**	**4,323,327**	**1,638**	**3,348**	**488,920**	**136,893**	**127,124**	**224,903**	**305,283**	**129,700**	**413,619**
Specific Mass Flow (wet)	kg/tls	73.1	116.9	900.8	5.1	64.8	11.0	73.7	1000.0	0.4	0.8	114.2	32.0	29.7	52.5	70.6	39.1	103.7
Specific Mass Flow (dry)	kg/tls	73.1	116.9	900.8	5.0	64.8	10.9	73.7	1000.0	0.4	0.8	113.1	31.7	29.4	52.0	70.6	30.0	95.7
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	31.01	amb.	21.01	21.01	amb.	amb.	amb.	amb.	9.01	amb.	1.11
Temperature	oC	12	12	1360	12	40	12	60	1672	60	60	12	12	12	12	175	12	50
Phase		solid	solid	solid	solid	solid	solid	gas	Gas	gas	gas	solid	solid	solid	solid	gas	solid	gas
Solid & Liquid Composition (dry basis)																		
Fe	%wt.	98.89	98.89	94.24	65.50	0.51	0.15	-	99.91	-	-	20.00	20.00	20.00	20.00	-	62.04	-
C	%wt.	0.11	0.11	4.65	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-
Si	%wt.	0.01	0.01	0.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2 (residual)	%wt.	-	-	-	-	3.00	2.00	-	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	-	-	-	1.80	91.26	40.00	-	-	-	-	50.72	50.72	50.72	50.72	-	11.87	-
MgO	%wt.	-	-	-	1.20	1.86	55.00	-	-	-	-	5.47	5.47	5.47	5.47	-	3.42	-
SiO2	%wt.	-	-	-	2.80	2.03	-	-	-	-	-	-	-	-	-	-	-	-
Al2O3	%wt.	-	-	-	0.60	0.85	-	-	-	-	-	-	-	-	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	2.0	-	1.0	-	-	-	-	1.0	1.0	1.0	1.0	-	23.3	-
Specific Vol. Flow (wet)	Nm3/tls	-	-	-	-	-	-	51.59	-	0.30	0.43	-	-	-	-	-	-	81.75
Average MW								32.0		28.0	39.9					18.0		28.4
Gas Composition (wet basis)																		
H2	%v.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.64
CO2	%v.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.44
CO	%v.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	56.92
O2	%v.	-	-	-	-	-	-	99.90	-	0.02	0.01	-	-	-	-	-	-	-
N2	%v.	-	-	-	-	-	-	0.01	-	99.98	-	-	-	-	-	-	-	13.83
Ar	%v.	-	-	-	-	-	-	0.09	-	-	99.99	-	-	-	-	-	-	-
H2O	%v.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	12.16

7. UNIT 600: LADLE METALLURGY (SECONDARY STEELMAKING)

7.1. Study Specification

The secondary steelmaking of the REFERENCE integrated steel mill is based on 2 stations of ladle metallurgy (with heat size up to ~250 ton per ladle). The final chemistry of the liquid steel is adjusted by addition of ferroalloys (FeMnC and FeSi-75), and aluminium is used to remove the oxygen content of the liquid steel. The secondary steelmaking of the REFERENCE integrated steel mill is not equipped with vacuum degassers or other additional steel refinement steps. The temperature of the liquid steel is controlled and maintained by electric arc heating. Furthermore, ladle pre-heating using COG and oxygen is employed to minimise the heating duty of the electrode therefore reducing electricity consumption. Argon is used for purging, oxidation shielding and inert stirring. A small amount of scrap is used for cooling (temperature moderation duty).

A full description of the ladle metallurgy is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-11 summarises the specification of the ladle metallurgy operation of the reference steel mill.

7.2. PFD and Mass Balance

Figure D-6 presents the process flow diagram of the secondary steelmaking process of the integrated steel mill (Reference Case). Table D-12 presents a summary of the mass balance for the secondary steelmaking process of the integrated steel mill – reference case.

7.3. Utilities Consumption (Electricity, Steam and Make-Up Water)

The ladle metallurgy would require about 25.0 kWh/tls - refined (27.2 kWh/t HRC or 108,630.71 MWh/y).

The major power consumers of the ladle metallurgy process consist of:

- AC/DC converters & voltage transformers (electric arc heating),
- ID fans (ladle's off-gas exhauster),
- Pumps (cooling water – ladle roof and slag processing unit),
- Electric motors for drives of conveyors, gantry machine, alloy charging machine, slag pot, ladle transfer car, etc...

The major process water consumer is the quenching water of the slag processing unit. The total water requirement for the ladle metallurgy has been accounted for in the Basic Oxygen Steelmaking Process (Unit 500).

Table D-11: General Information – Study Specification (Unit 600: Ladle Metallurgy)

Description	Summary - Relevant Specifications	
No. of Ladle Metallurgy Station Fe loss to internal scrap Oxygen Consumption Flux Consumption Slag Rate (dry)	2 stations – based on ladle transfer cars configuration. 9.9 kg/tls – refined (1%). 2.1 Nm^3/tls – refined 5.0 kg/tls – refined (lime – including lime splashing) 7.9 kg/tls – refined (100% to Landfill)	
COG Consumption (pre-heating) Electricity Consumption	0.9 Nm^3/tls - refined 25.0 kWh/tls – refined	0.9 Nm^3/t HRC 27.2 kWh/t HRC
Liquid Steel from Ladle (dry) Liquid Steel from BOF (dry) Cooling Scrap (dry) Internal Scrap to BOF (dry) Ferroalloys (dry) • FeMnC (dry) • FeSi-75 (dry) • Aluminium (dry)	1000.0 kg/tls - refined (4.35 Mt/y) 995.0 kg/tls – refined (4.32 Mt/y) 1.0 kg/tls – refined 9.9 kg/tls - refined 11.0 kg/tls – refined 3.0 kg/tls – refined 1.5 kg/tls – refined	1086.3 kg/t HRC 1080.8 kg/t HRC 1.1 kg/t HRC 10.8 kg/t HRC 11.9 kg/t HRC 3.3 kg/t HRC 1.6 kg/t HRC

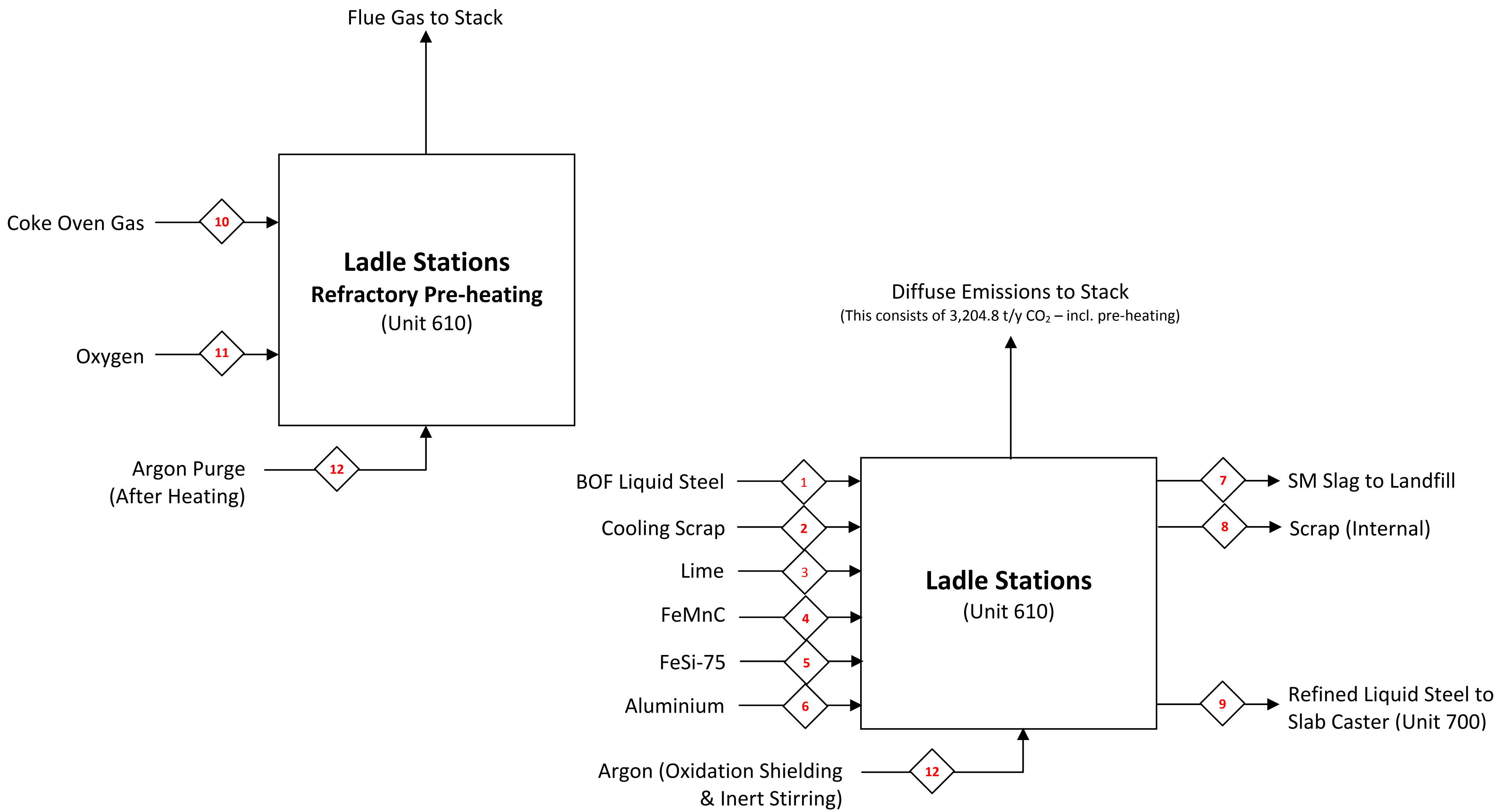

Figure D-6: PFD of the ladle metallurgy (Unit 600)

Table D-12: Mass Balance (Unit 600: Ladle Metallurgy)

		1	2	3	4	5	6	7	8	9	10	11	12
Stream		**Liquid Steel from BOF**	**Scrap (Cooling)**	**Lime**	**FeMnC**	**FeSi-75**	**DeOx. Aluminium**	**LM Slag to Landfill**	**Scrap to BOF**	**Liquid Steel from LM**	**COG**	**O2**	**Ar**
Total Mass Flow (wet)	**t/y**	**4,323,327**	**4,345**	**21,726**	**47,798**	**13,036**	**6,518**	**34,760**	**43,233**	**4,345,228**	**1,607**	**13,030**	**2,232**
Total Mass Flow (dry)	**t/y**	**4,323,327**	**4,345**	**21,726**	**47,798**	**13,036**	**6,518**	**34,412**	**43,233**	**4,345,228**	**1,512**	**13,030**	**2,232**
Specific Mass Flow (wet)	kg/tls (ladle)	995.0	1.0	5.0	11.0	3.0	1.5	8.0	9.9	1000.0	0.4	3.0	0.5
Specific Mass Flow (dry)	kg/tls (ladle)	995.0	1.0	5.0	11.0	3.0	1.5	7.9	9.9	1000.0	0.3	3.0	0.5
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	1.11	31.01	21.01
Temperature	oC	1672	12	40	12	12	12	12	12	1531	25	60	60
Phase		liquid	solid	Solid	solid	Solid	solid	solid	solid	liquid	gas	gas	gas
Solid & Liquid Composition (dry basis)													
Fe	%wt.	99.91	98.89	0.51	14.58	22.56	0.67	1.08	98.89	98.73	-	-	-
C	%wt.	0.04	0.11	-	6.87	0.03	-	-	0.11	0.12	-	-	-
Si	%wt.	-	0.01	-	0.11	76.61	1.34	-	0.01	-	-	-	-
Mn	%wt.	-	0.10	-	78.27	0.01	0.23	-	0.10	-	-	-	-
Al	%wt.	-	-	-	-	0.71	96.30	-	-	-	-	-	-
CO2 (residual)	%wt.	-	-	3.00	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	-	-	91.26	-	-	-	62.46	-	-	-	-	-
MgO	%wt.	-	-	1.86	-	-	-	-	-	-	-	-	-
SiO2	%wt.	-	-	2.03	-	-	-	8.03	-	-	-	-	-
Al2O3	%wt.	-	-	0.85	-	-	-	28.32	-	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	-	-	-	1.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/tls (ladle)	-	-	-	-	-	-	-	-	-	0.86	2.10	0.29
Average MW											9.7	32.0	39.9
Gas Composition (wet basis)													
CH4	%v.	-	-	-	-	-	-	-	-	-	23.24	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	-	-	-	-	-	-	2.71	-	-
H2	%v.	-	-	-	-	-	-	-	-	-	60.05	-	-
CO2	%v.	-	-	-	-	-	-	-	-	-	0.97	-	-
CO	%v.	-	-	-	-	-	-	-	-	-	3.87	-	-
O2	%v.	-	-	-	-	-	-	-	-	-	0.19	99.90	0.01
N2	%v.	-	-	-	-	-	-	-	-	-	5.81	0.01	-
Ar	%v.	-	-	-	-	-	-	-	-	-	-	0.09	99.99
H2O	%v.	-	-	-	-	-	-	-	-	-	3.15	-	-

8. UNIT 700: CONTINUOUS CASTING

8.1. Study Specification

The study assumed that the continuous casting of the REFERENCE integrated steel mill is based on the operation of 2 trains of slab casting machine, each equipped with a tundish feeding liquid steel into two moulds (twin strand). The moulds are cooled with water and air where liquid steel solidifies and forms the slab. The resulting slabs are cut using oxygen torches. To maintain the temperature of the liquid steel in the tundish, COG is used as fuel for heating.

The study also assumed that 25.8 kg/t slab (~2.6%) is lost as scrap, and 8.7 kg/t slab (~0.9%) is lost as mill scale. The scrap is recycled back to the BOF (Unit 500); whilst the mill scales are recycled back to the sinter plant (Unit 200).

A full description of the continuous casting is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-13 summarises the specification of the continuous casting operation of the reference steel mill.

8.2. PFD and Mass Balance

Figure D-7 presents the process flow diagram of the slab production of the integrated steel mill (Reference Case). Table D-14 presents a summary of the mass balance for the slab production of the integrated steel mill.

8.3. Utilities Consumption (Electricity and Make-Up Water)

The slab casting operation would require about 10.3 kWh/t slab (10.9 kWh/t HRC or 43,452.28 MWh/y).

The major power consumers of the continuous casting process consist of:

- Pumps for cooling water,
- FD fans for combustion air,
- Stack Exhaust ID fans,
- Electric motors for drives of casting and rolling machine, ladle transfer car, tundish operation, gantry machine, etc...

The major process water consumers are the water used for cooling the moulds and the secondary cooling system. The total water requirement for the continuous casting was reported as 3,655,576 m^3 per year.

Table D-13: General Information – Study Specification (Unit 700: Continuous Casting)

<table>
<tr><th>Description</th><th colspan="2">Summary - Relevant Specifications</th></tr>
<tr><td>No. of Continuous Casting
Fe loss to internal scrap
Fe loss to mill scales
Oxygen Consumption</td><td colspan="2">2 trains of twin strand slab casting machines (Vertical Bending Type)
25.8 kg/t slab (2.6%).
8.7 kg/t slab (0.9%).
2.1 Nm^3/t slab</td></tr>
<tr><td>COG Consumption (pre-heating)
Electricity Consumption</td><td>1.1 Nm^3/t slab
10.3 kWh/t slab</td><td>1.1 Nm^3/t HRC
10.9 kWh/t HRC</td></tr>
<tr><td>Slab (dry)
Liquid Steel from Ladle (dry)</td><td>1000.0 kg/t slab (4.21 Mt/y)
1032.0 kg/t slab (4.35 Mt/y)</td><td>1052.6 kg/t HRC
1086.3 kg/t HRC</td></tr>
</table>

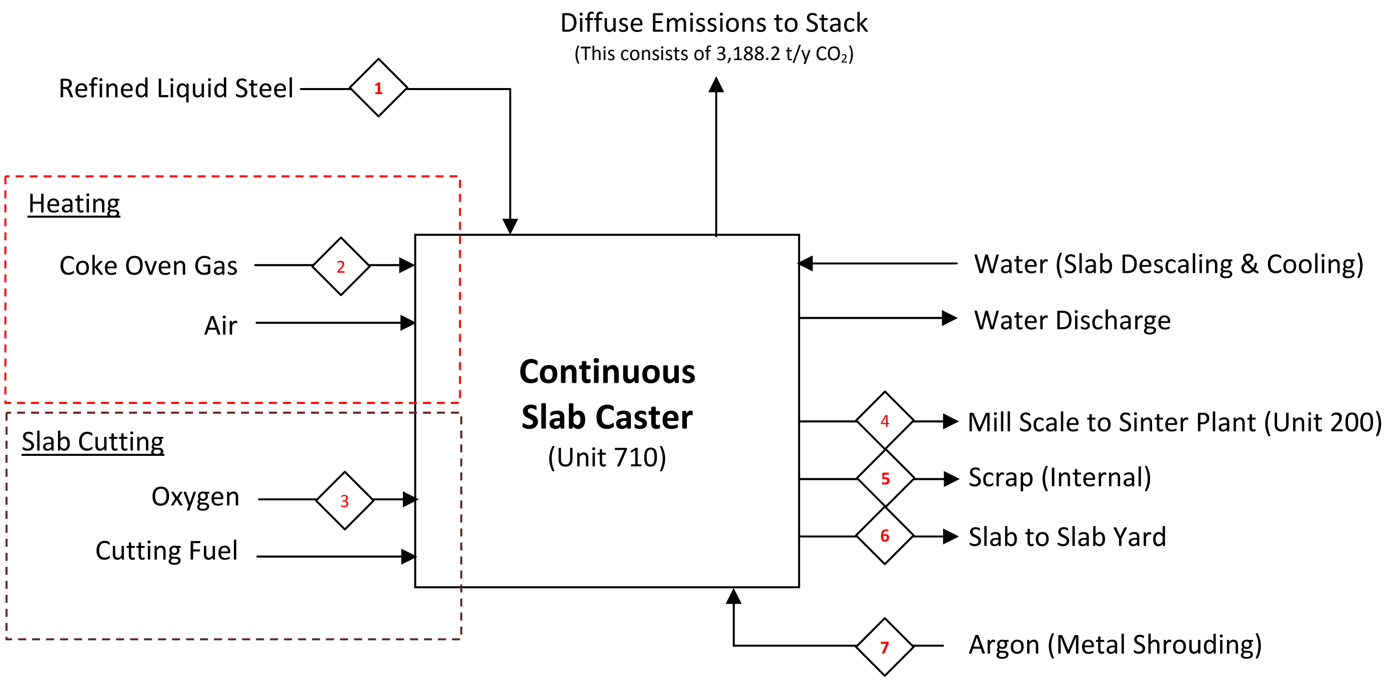

Figure D-7: PFD of the Continuous Casting (Unit 700)

Table D-14: Mass Balance (Unit 700: Continuous Casting)

		1	2	3	4	5	6	7
Stream		**Liquid Steel from LM**	**COG**	**O2**	**Mill Scales to Sinter**	**Scrap to BOF**	**Slab to Reheating Furnace**	**Ar**
Total Mass Flow (wet)	**t/y**	**4,345,228**	**1,934**	**12,409**	**37,144**	**108,631**	**4,210,526**	**774**
Total Mass Flow (dry)	**t/y**	**4,345,228**	**1,820**	**12,409**	**36,772**	**108,631**	**4,210,526**	**774**
Specific Mass Flow (wet)	kg/t slab	1032.0	0.5	2.9	8.8	25.8	1000.0	0.2
Specific Mass Flow (dry)	kg/t slab	1032.0	0.4	2.9	8.7	25.8	1000.0	0.2
Pressure	Bara	amb.	1.11	31.01	amb.	amb.	amb.	21.01
Temperature	oC	1531	25	60	12	12	25	60
Phase		liquid	Gas	gas	solid	solid	solid	gas
Solid & Liquid Composition (dry basis)								
Fe	%wt.	98.73	-	-	70.00	98.73	98.73	-
C	%wt.	0.12	-	-	-	0.12	0.12	-
Moisture (wet basis)	%wt.	-	-	-	1.0	-	-	-
Specific Vol. Flow (wet)	Nm3/t slab	-	1.07	2.06	-	-	-	0.10
Average MW			9.7	32.0				39.9
Gas Composition (wet basis)								
CH4	%v.	-	23.24	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	2.71	-	-	-	-	-
H2	%v.	-	60.05	-	-	-	-	-
CO2	%v.	-	0.97	-	-	-	-	-
CO	%v.	-	3.87	-	-	-	-	-
O2	%v.	-	0.19	99.90	-	-	-	0.01
N2	%v.	-	5.81	0.01	-	-	-	-
Ar	%v.	-	-	0.09	-	-	-	99.99
H2O	%v.	-	3.15	-	-	-	-	-

9. UNIT 800 & 900: REHEATING AND HOT ROLLING MILL

9.1. Study Specification

REFERENCE Steel Mill is evaluated based on 2 lines of Reheating and Rolling Mills producing 4 million tonnes of hot rolled coils per year. Each line of Hot Rolling Mills comprises: walking beam furnaces (total of 4 furnaces); roughing mills (total of 2 roughing mills); finishing mills (total of 6 finishing mills); coilers (total of 3 coilers).

Coke Oven Gas is used to heat the reheating furnace with natural gas as back up fuel. The reheating furnace is equipped with recuperators to preheat the combustion air.

The rolling mills employ the use of oxyfuel firing to oxidise slab surface irregularities to form mill scales. After this, the slab undergoes descaling to remove the scales. The study assumes that 14.8 kg/t HRC (~1.5%) is lost as mill scales. Roughing and finishing mills involve the width reduction, slitting, trimming and cutting of the coil. The study assumes 42.1 kg/t HRC (~4.2%) is lost as scrap during the rolling process. The mill scales are recycled back to the sinter plant (Unit 200); whilst scrap is recycled back to the BOF (Unit 500).

A full description of the Reheating and Rolling Mills is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-15 summarises the specification of the continuous casting operation of the reference steel mill.

9.2. PFD and Mass Balance

Figure D-8 presents the process flow diagram of the reheating and rolling mills of the integrated steel mill (Reference Case). Table D-16 presents a summary of the mass balance for the reheating and rolling mills of the integrated steel mill – reference case.

9.3. Utilities Consumption (Electricity and Make-Up Water)

The reheating and rolling mills would require 105.3 kWh/t HRC (421,052.63 MWh/y).

The major power consumers of the reheating and rolling mills consist of:

- Combustion air blowers
- FD fans (reheating furnaces),
- ID fans (flue gas – reheating furnaces)
- Pumps (cooling water – reheating and rolling mills),
- Compressed air (rolling mills),
- Electric motors for drives of reheating furnace skids, conveyors, gantry machine, roughing mills, finishing mills, coilers etc...

The major process water consumer is the make-up water for cooling duties. The total water requirements for both reheating and rolling mills are estimated at 8,000,000 m^3 per year.

Table D-15: General Information – Study Specification
(Unit 800 & 900: Reheating & Hot Rolling Mills)

Description	Summary - Relevant Specifications	
No. of Reheating Furnaces Heat Recovery System Fuel Energy Requirements Rolling Mills Fe loss to internal scrap Fe loss to mill scales Oxygen Consumption	4 (2 walking beam furnaces per line of rolling mill) 2 recuperators (1 per line to preheat combustion air) 1438 MJ/t slab reheated (1514 MJ/t HRC) 2 lines (2x Roughing Mills, 6x Finishing Mills and 3x Coilers) 42.1 kg/t HRC (4.2%). 14.8 kg/t HRC (1.5%). 2.6 Nm^3/t HRC	
COG Consumption (Reheating) Electricity Consumption	84.3 Nm^3/t HRC 105.3 kWh/t HRC	- -
Hot Rolled Coil (dry) Slab (dry)	1000.0 kg/t HRC (4.00 Mt/y) 1052.6 kg/t HRC (4.21 Mt/y)	- -

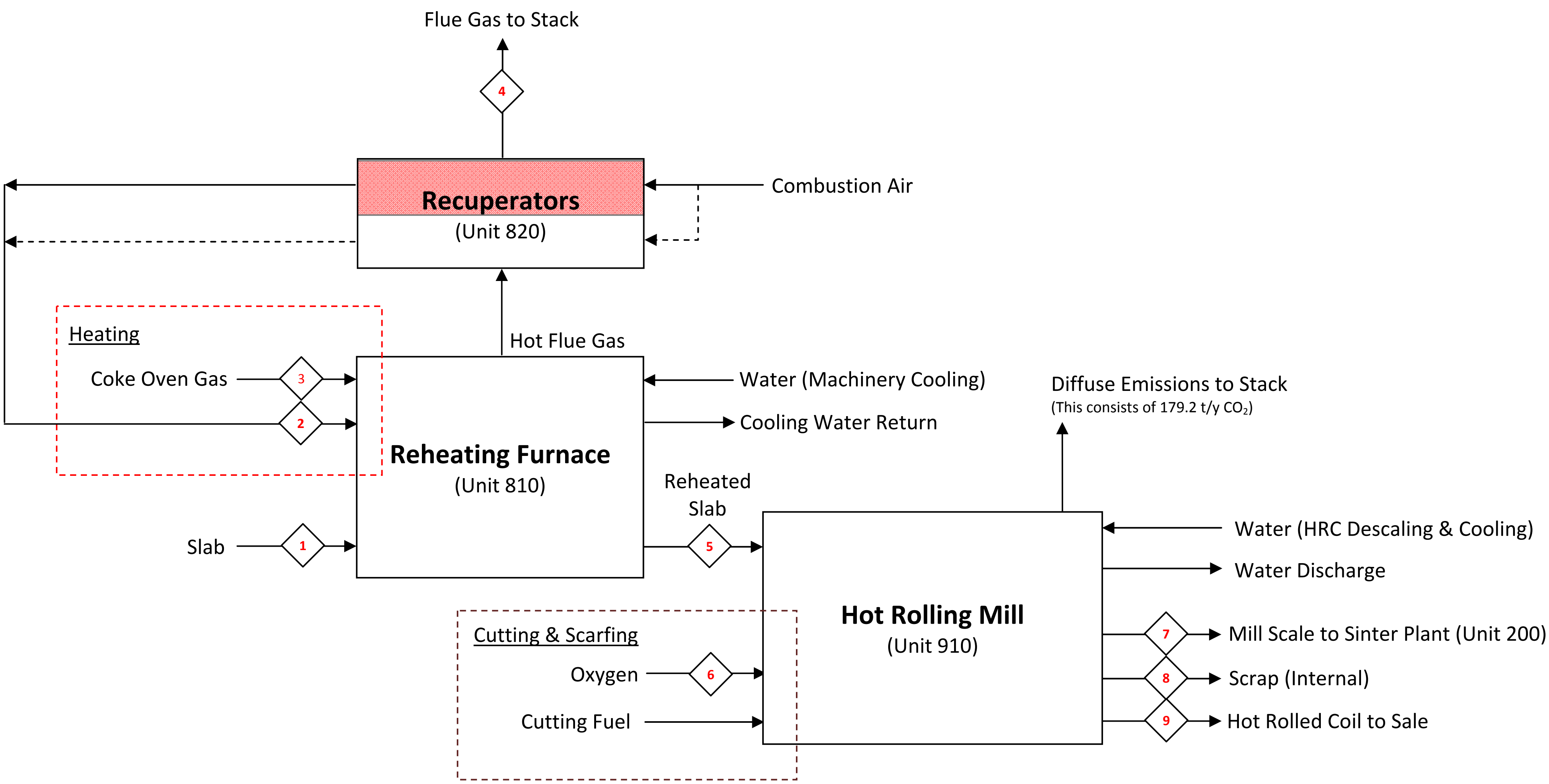

Figure D-8: PFD of the hot strip mill (Unit 800 & 900)

Table D-16: Mass Balance (Unit 800 & 900: Reheating and Rolling Mill)

		1	2	3	4	5	6	7	8	9
Stream		**Slab to Reheating Furnace**	**Combustion Air**	**COG (Reheating Furnace)**	**Flue Gas (Reheating Furnace)**	**Reheated Slab**	**O2 to HRM**	**Mill Scale to Sinter**	**Internal Scrap to BOF**	**HRC to Sale**
Total Mass Flow (wet)	**t/y**	**4,210,526**	**2,985,364**	**145,313**	**3,130,752**	**4,210,526**	**15,031**	**59,987**	**168,421**	**4,000,000**
Total Mass Flow (dry)	**t/y**	**4,210,526**	**2,964,574**	**136,772**	**2,794,253**	**4,210,526**	**15,031**	**59,387**	**168,421**	**4,000,000**
Specific Mass Flow (wet)	kg/t HRC	1052.6	746.3	36.3	782.7	1052.6	3.8	15.0	42.1	1000.0
Specific Mass Flow (dry)	kg/t HRC	1052.6	741.1	34.2	698.6	1052.6	3.8	14.8	42.1	1000.0
Pressure	Bara	amb.	1.11	1.11	1.03	amb.	21.01	amb.	amb.	amb.
Temperature	oC	25	400	25	500	1200	60	12	12	12
Phase		solid	gas	gas	gas	solid	gas	solid	solid	solid
Solid & Liquid Composition (dry basis)										
Fe	%wt.	98.73	-	-	-	98.73	-	70.00	98.73	98.73
C	%wt.	0.12	-	-	-	0.12	-	-	0.12	0.12
Moisture (wet basis)	%wt.	-	-	-	-	-	-	1.0	-	-
Specific Vol. Flow (wet)	Nm3/t HRC	-	582.30	84.29	640.23	-	2.63	-	-	-
Average MW			28.7	9.7	27.4		32.0			
Gas Composition (wet basis)										
CH4	%v.	-	-	23.24	-	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	2.71	-	-	-	-	-	-
H2	%v.	-	-	60.05	-	-	-	-	-	-
CO2	%v.	-	-	0.97	4.59	-	-	-	-	-
CO	%v.	-	-	3.87	-	-	-	-	-	-
O2	%v.	-	20.72	0.19	7.20	-	99.90	-	-	-
N2	%v.	-	78.17	5.81	71.86	-	0.01	-	-	-
Ar	%v.	-	-	-	-	-	0.09	-	-	-
H2O	%v.	-	1.11	3.15	16.34	-	-	-	-	-

10. UNIT 1000: LIME PRODUCTION

10.1. Study Specification

The lime production of the REFERENCE Integrated Steel Mill is based on 2 trains of PFR lime kilns producing 346.4 kt/y of burnt lime (of which 87% is consumed by the steelmaking process – BOF and LM and 13% consumed by the sinter plant). The study assumed that the lime produced has a residual CO_2 of ~3%. COG is used as fuel for the lime kiln with natural gas as back up fuel.

The lime kiln employs low NOx burner (fuel lance heating) technologies and is equipped with fabric filters to reduce dust emissions.

A full description of the lime kiln is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-17 summarises the specification of the lime kiln operation of the reference steel mill.

Table D-17: General Information – Study Specification (Unit 1000: Lime Production)

Description	Summary - Relevant Specifications	
No. of lime kilns Residual CO_2 (dry)	2 trains of Parallel Flow Regenerative (PFR) Kilns 3%	
COG Consumption (pre-heating) Electricity Consumption	200.2 Nm^3/t lime 30.0 kWh/t lime	17.3 Nm^3/t HRC 2.6 kWh/t HRC
Lime(dry) • Lime to BOF/LM (dry) • Lime to Sinter Plant (dry) Limestone (dry)	1000.0 kg/t lime (0.34 Mt/y) 871.7 kg/t lime 128.3 kg/t lime 1690.0 kg/t lime (0.59 Mt/y)	86.6 kg/t HRC 75.5 kg/t HRC 11.1 kg/t HRC 146.4 kg/t HRC

10.2. PFD and Mass Balance

Figure D-9 presents the process flow diagram of the lime production of the integrated steel mill (Reference Case). Table D-18 presents a summary of the mass balance for the lime production of the integrated steel mill – reference case.

10.3. Utilities Consumption (Electricity and Make-Up Water)

The lime production would require 30.0 kWh/t lime (2.6 kWh/t HRC or 10,392.36 MWh/y).

The major power consumers of the lime production process consist of:

- Combustion air blowers
- FD fans (cooling)
- ID fans (flue gas)
- Electric motors for drives of conveyors, raw materials handling, screening, etc...

Lime production of the REFERENCE Steel Mill is not a major water consumer as there is no hydrated lime produced on site.

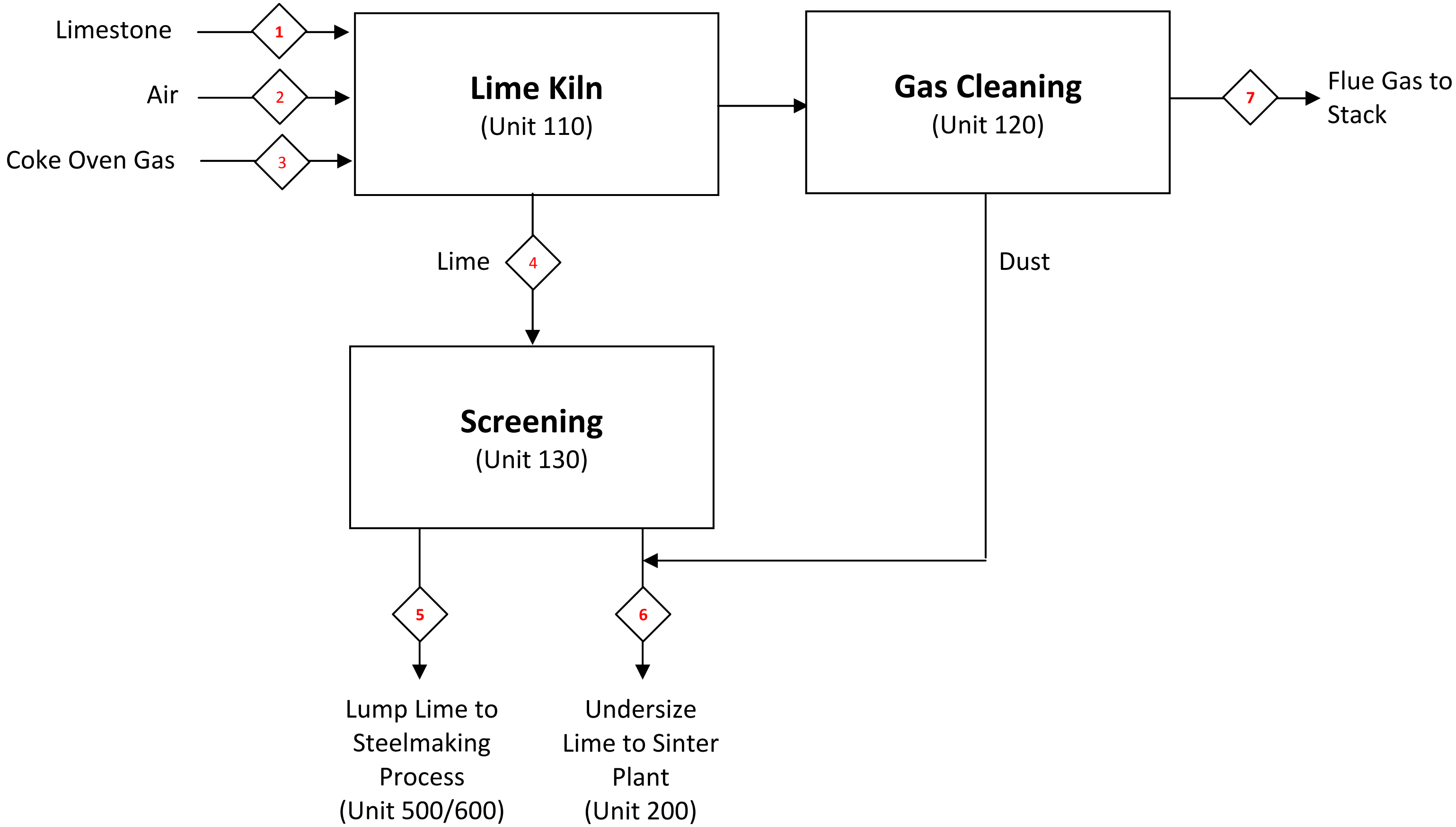

Figure D-9: PFD of the Lime Production (Unit 1000)

Table D-9: Mass Balance (Unit 1000: Lime Production)

		1	2	3	4	5	6	7
Stream		**Limestone**	**Air**	**COG**	**Lime (Total)**	**Lime to BOF & LM**	**Lime to Sinter**	**Flue Gas**
Total Mass Flow (wet)	**t/y**	**591,361**	**736,814**	**29,889**	**346,410**	**301,956**	**44,454**	**1,011,785**
Total Mass Flow (dry)	**t/y**	**585,447**	**731,683**	**28,132**	**346,410**	**301,956**	**44,454**	**935,796**
Specific Mass Flow (wet)	kg/t lime	1707.1	2127.0	86.3	1000.0	871.7	128.3	2920.8
Specific Mass Flow (dry)	kg/t lime	1690.0	2112.2	81.2	1000.0	871.7	128.3	2701.4
Pressure	Bara	amb.	1.03	1.11	amb.	amb.	amb.	1.03
Temperature	oC	12	12	25	40	40	40	130
Phase		solid	gas	gas	solid	solid	solid	gas
Solid & Liquid Composition (dry basis)								
Fe	%wt.	0.30	-	-	0.51	0.51	0.51	-
CO2 (residual)	%wt.	42.60	-	-	3.00	3.00	3.00	-
CaO (incl. carbonates)	%wt.	54.00	-	-	91.26	91.26	91.26	-
MgO	%wt.	1.10	-	-	1.86	1.86	1.86	-
SiO2	%wt.	1.20	-	-	2.03	2.03	2.03	-
Al2O3	%wt.	0.50	-	-	0.85	0.85	0.85	-
Moisture (wet basis)	%wt.	1.0	-	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/t lime	-	1659.51	200.20	-	-	-	2169.76
Average MW			28.7	9.7				30.2
Gas Composition (wet basis)								
CH4	%v.	-	-	23.24	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	2.71	-	-	-	-
H2	%v.	-	-	60.05	-	-	-	-
CO2	%v.	-	-	0.97	-	-	-	19.41
CO	%v.	-	-	3.87	-	-	-	-
O2	%v.	-	20.72	0.19	-	-	-	7.77
N2	%v.	-	78.17	5.81	-	-	-	60.24
H2O	%v.	-	1.11	3.15	-	-	-	12.58

11. UNIT 1100: AIR SEPARATION UNIT (OXYGEN PLANT)

11.1. Study Specification

The oxygen plant (or Air Separation Unit - ASU) of the REFERENCE integrated steel mill is evaluated based on a captive single ASU train with a design capacity of 1900 tpd O_2 delivering around 693,464 t/y gaseous O_2 and 6,355 t/y gaseous Ar to the steel mill; and selling 26,865 t/y liquid Ar to the market.

The oxygen delivered to the steel mill will have 99.9% purity and be available at pressure of 13 bara and 37 bara. Argon and nitrogen supplied to the steel mill will have 99.99% and 99.98% purity respectively and are available at 7 bara and 25 bara. Liquid argon will also have a purity of 99.99%.

Steam at 0.16 MJ/Nm^3 total O_2 is required for product re-gasification and TSA regeneration. Hydrogen is used for purification of the crude argon however, this is not accounted for in this study. System losses and buffer requirements for oxygen supply to cover for disruption and uneven demand were also accounted for in this study (9%wt. of total O_2 production).

A full description of the air separation plant is presented in the Synthesis Report (Supplementary Volume – Process Description). Table D-19 summarises the specification of the captive air separation unit of the reference steel mill.

11.2. PFD and Mass Balance

Figure D-10 presents the process flow diagram of the oxygen production of the integrated steel mill (Reference Case). Table D-20 presents a summary of the mass balance for the oxygen production of the integrated steel mill – reference case.

11.3. Utilities Consumption (Electricity and Steam)

The air separation unit would require 0.55 kWh/Nm^3 O_2 (385.2 kWh/t O_2, 66.8 kWh/t HRC or 267,104.18 MWh/y).

The major power consumers of the oxygen production process consist of:

- Main air compressor
- Booster compressor
- Product compressors
- Expanders (electricity credit)
- Cooling water pumps

Steam (9 bara and sat.) requirement for the air separation unit is about 0.06 kg/Nm^3 O_2 (7.3 kg/t HRC). It is expected that this will be supplied by the waste heat boilers installed at the BOF steelmaking process (Unit 500).

Water consumption by the air separation unit is considered minimal therefore it is not reported in this study.

Table D-19: General Information – Study Specification (Unit 1100: Oxygen Production)

Description	Summary - Relevant Specifications	
No. of ASU	1 train of ASU @ 1900 tpd O_2 (GOX, GAN, GAR, LAR)	
Main Products	Gaseous O_2, N_2, Ar and Liquid Ar (with Liquid O_2 as buffer)	
Argon Purification Unit	via H_2 catalytic combustion (De Oxo Process)	
Annual Oxygen Production (Total)	485,643,965 Nm^3/y (693,464 t/y)	
Annual Liquid Argon to Sale	15,073,913 Nm^3/y (28,886 t/y)	
Steam Requirements	0.06 kg/Nm^3 O_2	
Purity (Delivery Pressure)		
• Gaseous O_2	99.90% (13 bar_a & 37 bar_a)	
• Gaseous N_2	99.98% (7 bar_a & 25 bar_a)	
• Gaseous Ar	99.99% (25 bar_a)	
Product Recovery Rate		
• O_2	96%	
• Ar	83%	
Steam Consumption (9 bar_a, sat.)	0.06 kg/Nm^3 O_2	7.3 kg/t HRC
Electricity Consumption	0.55 kWh/Nm^3 O_2	66.8 kWh/t HRC
Oxygen (Total Produced)	1.000 Nm^3 O_2/Nm^3 O_2 (Total)	121.4 Nm^3 O_2/t HRC
• O_2 to BF Hot Stoves	0.391 Nm^3 O_2/Nm^3 O_2 (Total)	47.5 Nm^3 O_2/t HRC
• O_2 to BOF	0.459 Nm^3 O_2/Nm^3 O_2 (Total)	55.8 Nm^3 O_2/t HRC
• O_2 to Ladle Metallurgy	0.019 Nm^3 O_2/Nm^3 O_2 (Total)	2.3 Nm^3 O_2/t HRC
• O_2 to Continuous Casting	0.018 Nm^3 O_2/Nm^3 O_2 (Total)	2.2 Nm^3 O_2/t HRC
• O_2 to Hot Rolling Mills	0.022 Nm^3 O_2/Nm^3 O_2 (Total)	2.6 Nm^3 O_2/t HRC
Liquid Argon to Sale	0.031 Nm^3 Ar/Nm^3 O_2 (Total)	3.8 Nm^3 Ar/t HRC

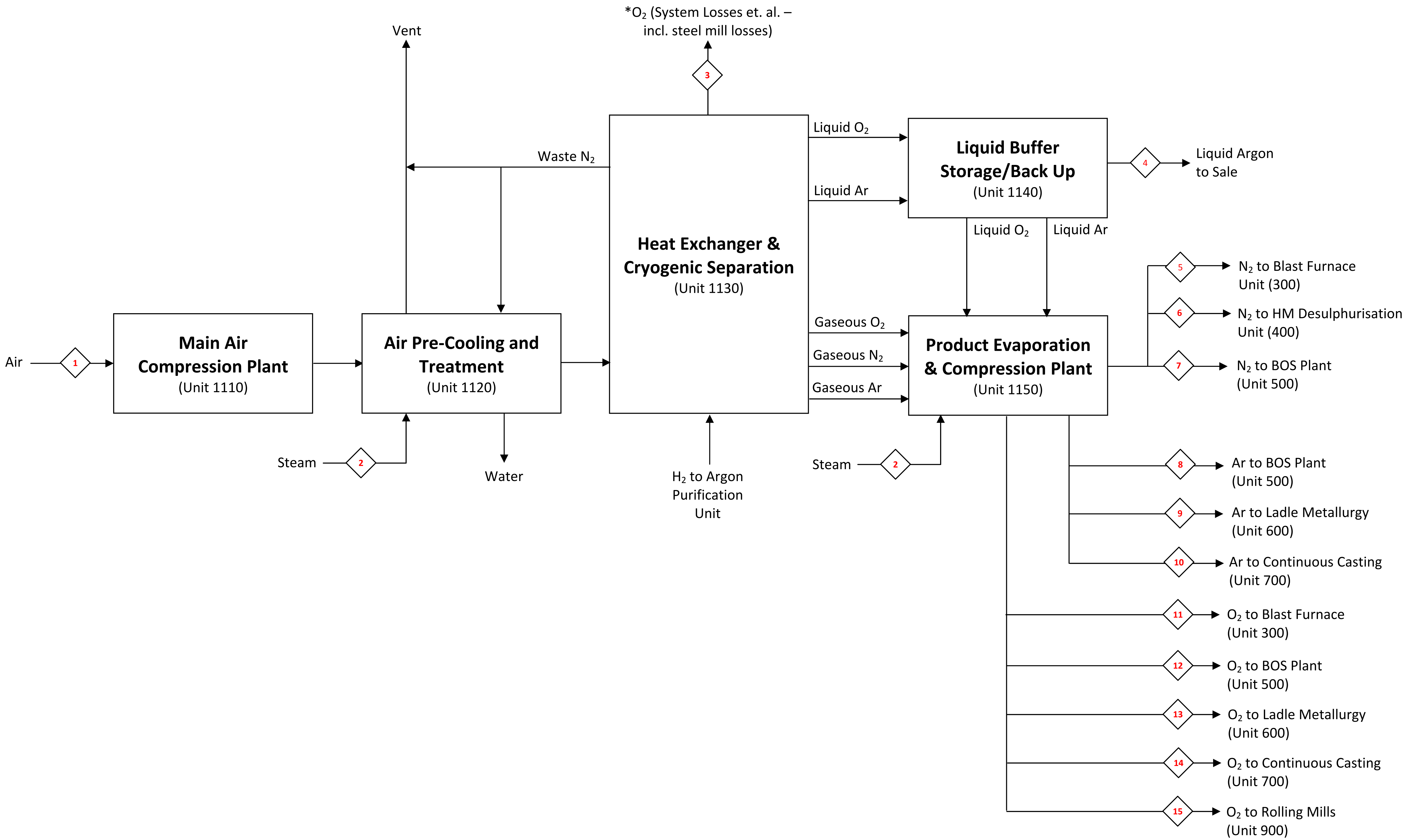

Figure D-10: PFD of the air separation unit (Unit 1100)

Table D-20: Mass Balance (Unit 1100: Air Separation Unit)

		1	2	3	4	5a	5b	6	7
Stream		**Air**	**Steam**	**O2 (Lost or Flared)**	**Ar to Sale**	**N2 to BF (RM Feeder)**	**N2 to BF (PCI Coal Feeder)**	**N2 to HM Desulph.**	**N2 to BOF**
Total Mass Flow (wet)	**t/y**	**3,142,730**	**29,139**	**63,042**	**26,865**	**9,923**	**14,884**	**715**	**1,638**
Total Mass Flow (dry)	**t/y**	**3,120,932**	**29,139**	**63,042**	**26,865**	**9,923**	**14,884**	**715**	**1,638**
Specific Mass Flow (wet)	kg/Nm3 O2	6.471	0.060	0.130	0.055	0.020	0.031	0.001	0.003
Specific Mass Flow (dry)	kg/Nm3 O2	6.426	0.060	0.130	0.055	0.020	0.031	0.001	0.003
Pressure	Bara	1.03	9.01	1.03	1.01	7.01	25.01	25.01	25.01
Temperature	oC	12	175	60	-	60	60	60	60
Phase		gas	gas	gas	Liquid	gas	gas	gas	Gas
Specific Vol. Flow (wet)	Nm3/Nm3 O2	5.0298	-	0.0909	0.0310	0.0163	0.0245	0.0012	0.0027
Average MW		28.8	18.0	32.0	39.9	28.0	28.0	28.0	28.0
Gas Composition (wet basis)									
O2	%v.	20.71	-	99.90	0.01	0.02	0.02	0.02	0.02
N2	%v.	77.26	-	0.01	-	99.98	99.98	99.98	99.98
Ar	%v.	0.92	-	0.09	99.99	-	-	-	-
H2O	%v.	1.11	100.00	-	-	-	-	-	-

		8	9	10	11	12	13	14	15
Stream		**Ar to BOF**	**Ar to Ladle Metallurgy**	**Ar to Slab Casting**	**O2 to BF (Hot Stoves)**	**O2 to BOF**	**O2 to Ladle Metallurgy**	**O2 to Slab Casting**	**O2 to HRM**
Total Mass Flow (wet)	**t/y**	**3,348**	**2,232**	**774**	**271,454**	**318,495**	**13,030**	**12,409**	**15,031**
Total Mass Flow (dry)	**t/y**	**3,348**	**2,232**	**774**	**271,454**	**318,495**	**13,030**	**12,409**	**15,031**
Specific Mass Flow (wet)	kg/Nm3 O2	0.007	0.005	0.002	0.559	0.656	0.027	0.026	0.031
Specific Mass Flow (dry)	kg/Nm3 O2	0.007	0.005	0.002	0.559	0.656	0.027	0.026	0.031
Pressure	Bara	25.01	25.01	25.01	13.01	37.01	37.01	37.01	25.01
Temperature	oC	60	60	60	60	60	60	60	60
Phase		gas	gas	gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/Nm3 O2	0.0039	0.0026	0.0009	0.3914	0.4593	0.0188	0.0179	0.0217
Average MW		39.9	39.9	39.9	32.0	32.0	32.0	32.0	32.0
Gas Composition (wet basis)									
O2	%v.	0.01	0.01	0.01	99.90	99.90	99.90	99.90	99.90
N2	%v.	-	-	-	0.01	0.01	0.01	0.01	0.01
Ar	%v.	99.99	99.99	99.99	0.09	0.09	0.09	0.09	0.09
H2O	%v.	-	-	-	-	-	-	-	-

12. UNIT 1200: CAPTIVE POWER PLANT

12.1. Study Specification

The captive power plant of the REFERENCE Integrated Steel Mill is evaluated based on the performance of average power plant in Western Europe using steelworks off-gases as fuel – which is reported as having 32.1% efficiency.

The study assumed a balanced power plant (i.e. no export or import of electricity). The power plant is based on a gas fired subcritical boiler firing Blast Furnace Gas and Basic Oxygen Furnace Gas as the main fuel and Natural Gas as supplementary fuel.

The boiler has a working steam parameter of 120 Bara and $512^{o}C$ (with no steam reheat). Once through sea water cooling is assumed with condensing pressure of 0.03 Bara. Steam could also be readily extracted from the exit of the HP/IP turbine (prior to LP turbine) for steel mill use as back up.

A full description of the power plant is presented in the Synthesis Report (Supplementary Volume – Process Description). Table 21 summarises the specification of the captive power plant of the reference steel mill.

Table D-21: General Information – Study Specification (Unit 1200: Electricity Production)

Description	Summary - Relevant Specifications	
Captive Power Plant Specific Steel Mill Electricity Demand Nominal Output (NET) Load Factor Average Daily Output (NET) Net Efficiency	Sub-critical Gas Fired Boiler (120 Bar_a, $512^{o}C$) – no steam reheat 400.1 kWh/t HRC 215 MWe 85% 182.75 MWe 32.1%	
Fuel Input (wet)		
• BFG	2.318 Nm^3/kWh	927.37 Nm^3/t HRC (2.98 GJ/t HRC)
• BOFG	0.221 Nm^3/kWh	88.36 Nm^3/t HRC (0.66 GJ/t HRC)
• NG	0.052 Nm^3/kWh	20.88 Nm^3/t HRC (0.85 GJ/t HRC)

12.2. PFD and Mass Balance

Figure D-11 presents the process flow diagram of the captive power plant of the integrated steel mill (Reference Case). Table D-22 presents a summary of the mass balance for the captive power plant of the integrated steel mill – reference case.

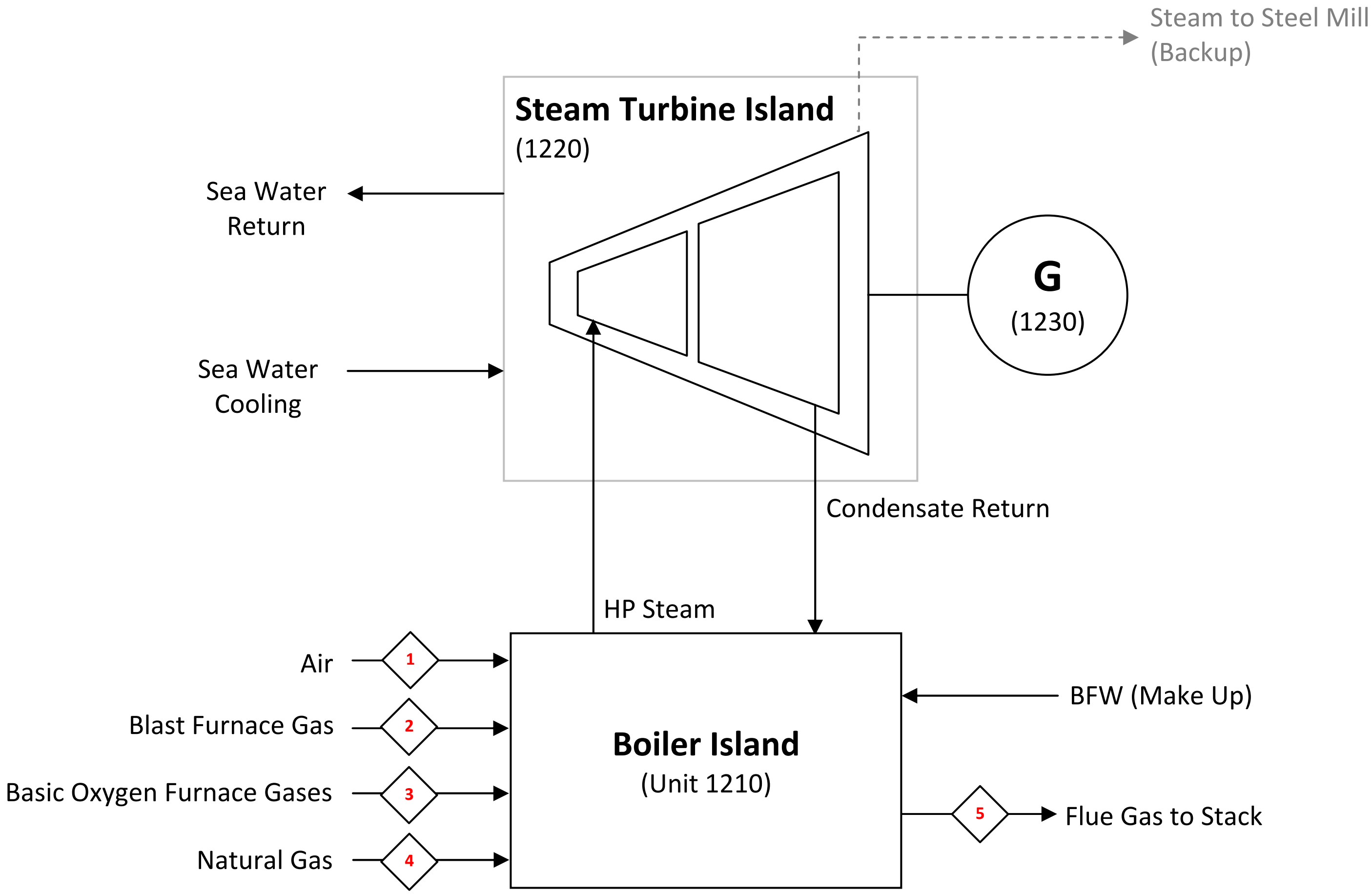

Figure D-11: PFD of the Captive Power Plant (Unit 1200)

Table D-22: Mass Balance (Unit 1200: Power Plant)

		1	2	3	4	5
Stream		**Combustion Air**	**BFG**	**BOFG**	**NG**	**Flue Gas**
Total Mass Flow (wet)	**t/y**	**5,130,503**	**5,012,747**	**448,186**	**72,410**	**10,663,327**
Total Mass Flow (dry)	**t/y**	**5,094,775**	**4,918,787**	**413,619**	**72,410**	**10,238,351**
Specific Mass Flow (wet)	kg/kWh	3.21	3.13	0.28	0.05	6.66
Specific Mass Flow (dry)	kg/kWh	3.18	3.07	0.26	0.05	6.40
Pressure	Bara	1.03	1.11	1.11	1.11	1.03
Temperature	oC	12	25	50	-	150
Phase		gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/kWh	2.5011	2.3178	0.2208	0.0522	4.7301
Average MW		28.7	30.3	28.4	19.4	31.6
Gas Composition (wet basis)						
CH4	%v.	-	-	-	83.90	-
C2H6	%v.	-	-	-	9.20	-
C3H8	%v.	-	-	-	3.30	-
C4H10	%v.	-	-	-	1.20	-
C5H12	%v.	-	-	-	0.20	-
H2	%v.	-	3.63	2.64	-	-
CO2	%v.	-	22.10	14.44	1.80	26.43
CO	%v.	-	22.34	56.92	-	-
O2	%v.	20.72	-	-	-	0.71
N2	%v.	78.17	48.77	13.83	0.40	65.88
H2O	%v.	1.11	3.15	12.16	-	6.98

13. REFERENCES

[1] Hooey, L., Boden, A., and Larsson, M. (2011). **"Assessing CO_2 Capture Application in Integrated Steel Plant – Reference Plant Design".** MEFOS Report – 560025.

[2] Carpenter, A. (2012). **"CO_2 Abatement in the Iron and Steel Industry".** Report No. CCC-193. IEA Clean Coal Centre, London, UK.

[3] Hooey, P.L., Boden, A., Wang, C., Grip, C.E. and Jansson, B. (2010). **"Design and Application of a Spreadsheet-based Model of the Blast Furnace Factory".** *ISIJ International*, Vol. 50., pp. 924–930.

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume I: Estimating the Cost of Steel Production from an Integrated Steel Mill (Reference Case)

Section E

Economic Evaluation of the "REFERENCE" Integrated Steel Mill (Base Case)

INDEX

1. INTRODUCTION

This section of the report describes the assessment of the CAPEX and OPEX of a "REFERENCE" Integrated Steel Mill without CO_2 capture. The cost model was developed by Tata Steel Consulting based on the information regarding material usage, specification and capacity of individual processes as described in Section D.

The breakdown of the breakeven price of the hot rolled coil has been presented and various sensitivities have also been evaluated.

2. FINANCIAL ASSUMPTIONS

2.1. Plant Location

The "REFERENCE" Integrated Steel Mill is located along the Coastal Region of Western Europe. The plant location has been described in Section B-3.

- Site should have no special civil works required to add onto the construction cost.
- The study assumed that the site is accessible to the Port of Rotterdam with no extra additional cost needed to deliver raw materials and goods from Rotterdam to the plant site.
- Adequate site and facility services should be accessible to the integrated steel mill to make it self sufficient.
- The breakeven price reported in this study should represent the gate price (i.e. excluding cost for delivery to customers)

2.2. Plant Life

The integrated steel mill is assumed to have an economic life of 25 years as the basis for appraisal.

2.3. Design and Construction Period

Plant design and construction will be completed within 60 months starting from issue of "Notice to Proceed" to the EPC contractor. Operations would start after three years of construction with the completion of one blast furnace and full production achieved at the end of second year of operation.

The curve of capital expenditure during construction is assumed to be:

Year	Capital Expenditure (% investment cost)
-3	10
-2	35
-1	30
1	20
2	5

2.4. Commissioning

The study assumed the start up of steel mill producing 50% of the plant capacity on year 1 and achieving the full capacity on year 4. The commissioning of the plant involves the following schedule of production for the period between 1st and 3rd year as shown below:

Year	Iron and Steel Production (% Capacity)	Power Plant (% Load Factor)
1	50%	42.5%
2	75%	63.8%
3	90%	76.5%
4 and onward	100%	85.0%

2.5. Decommissioning

Decommissioning and remediation of the land by the end of the steel mill's life is excluded in the cash flow analysis.

2.6. Capital Charges

- The discounted cash flow analysis is used to evaluate the breakeven price per tonne of hot rolled coil produced. A discount rate of 10% was assumed.
- All capital requirements will be available according to the schedule of capital expenditure as described in Section E2.3. The capital infusion could be assumed as cash available for the construction of the steel mill based on combined equity and debt. However, the level of debt is not considered or accounted for in this study. The Cost of Capital will also use the same discount rate of 10%, which represents the weighted average of capital charges (WACC).
- No interest during construction is applied but the timing of capital expenditure is taken into account in the discounted cash flow analysis (using end of the year as basis).

2.7. Recurring Capital Expenditure

The steel mill requires the refractory relining of the blast furnaces for every 10-15 years of continuous operation. The study assumed a relining to be done on the 15th year with steel production assumed to maintain at 100% full capacity during this period[1].

2.8. Working Capital

The storage time for materials and balance of trade were taken according to normal industry practice:

- Stocks - Raw Materials: 63 days
- Stocks - Slabs: 5 days
- HRC: 15 days
- Trade debtors: 15 days
- Trade creditors (excl. raw materials): 30 days

[1] Note: This is a simplifying assumption to reduce the complexity in the calculation of the breakeven price of the HRC

Working capital comprises the value of raw materials (coking coal, iron ores, fluxes, purchased scrap and ferroalloys), slabs and hot rolled coils stored in the stockyard and the balance of the trade between debtors and creditors.

The trade debtors only considered the sale value of the hot rolled coil, whilst the trade creditors only account for the value of goods used by the steel mill excluding the value of raw materials.

2.9. Currency

The cost evaluation was developed in US$ (2010). Where necessary, the conversion was based on the following exchange rates:

- € 1.00 = US$ 1.34
- £ 1.00 = US$ 1.55

2.10. Inflation

Inflation assumptions were not included. No allowance has been made for escalation of fuel, reductant, raw materials, labour and other cost relative to each other.

2.11. Depreciation

Although the study assumed that depreciation of the integrated steel mill is to follow a straight line at 4% rate, this is not included in the calculation of the breakeven price of the Hot Rolled Coil as calculation of HRC breakeven price is based on EBITDA cash flow analysis.

2.12. Estimate Accuracy

The estimate accuracy is within the range +/- 30%.

3. FINANCIAL COST MODEL

3.1. Cost Model Overview

The cost model developed by Tata Steel Consulting is shown schematically in Figure E-1 illustrating the evaluation methodology for the direct cost of the steel production.

This model is based on a cascading cost or transfer cost model for each plant /major process leading to the direct cost of producing the Hot Rolled Coil.

The model is robust, dynamic and flexible. It suits the evaluation of the cost of producing steel from an integrated steel mill that requires consideration of site specific assumptions, multi-processes interacting with each other, using several raw materials (externally and locally sourced) and producing several main products, intermediate products and by-products. This cost model is also flexible in the accounting and reporting of the cost of the direct CO_2 emissions from various processes within the defined boundary limit of the integrated steel mill.

The key features of the model are as follows:

- The only main product considered in the current version of the cost model used by this study is the hot rolled coil (HRC).

- For this study – the basic assumptions for the current cost model are:[2]

  (1.) Intermediate Products of a plant or process within the boundary limit become a "Local" raw material to other plants/processes. These are expressed as specific direct cost per tonne of intermediate product. The intermediate product(s) are sold to users at a price that matches the production cost - this represents the 'internal price".

  (2.) All the by-products produced by any plants / processes are sold at a fixed price set in the assumptions and revenues and are internally credited to the producer(s).

  (3.) By-products that go out of the boundary limit are sold at a fixed price over the economic life of the plant. The revenue of this by-product is credited to the plant / process that produced it.

  (4.) The "by-product" energy in the form of off-gases or steam that are produced from certain plant(s) or process(es) are sold to the users at a fixed price over the economic life and the internal revenue is credited to the producer(s) of the by-product energy.

  (5.) The direct costs of each plant / process are evaluated based on the consumption of the externally sourced or "imported" raw materials, "local" raw materials, fuel and

[2] Note:

- **<u>"Imported" or "External" Raw Material</u>** refers to the material input obtained from outside the boundary limit;

- **<u>"Local" Raw Material</u>** refers to as the intermediate product produced internally by another plant within the boundary limit and consumed by another plant/process also within the boundary limit.

energy (imported, local or both), consumables, direct labour cost, maintenance, and other OPEX and work's expenses specific to the plant. This does not include the capital cost component of the plant or process.

- The break even cost of producing the hot rolled coil was calculated using the discounted cash flow analysis over the economic life of the plant. This accounts for the total investment cost, which also includes the capital cost of each major process; the indirect cost of the whole integrated steel mill; and the direct cost specific to the operating cost of the hot rolling mills (plant that produces the HRC).

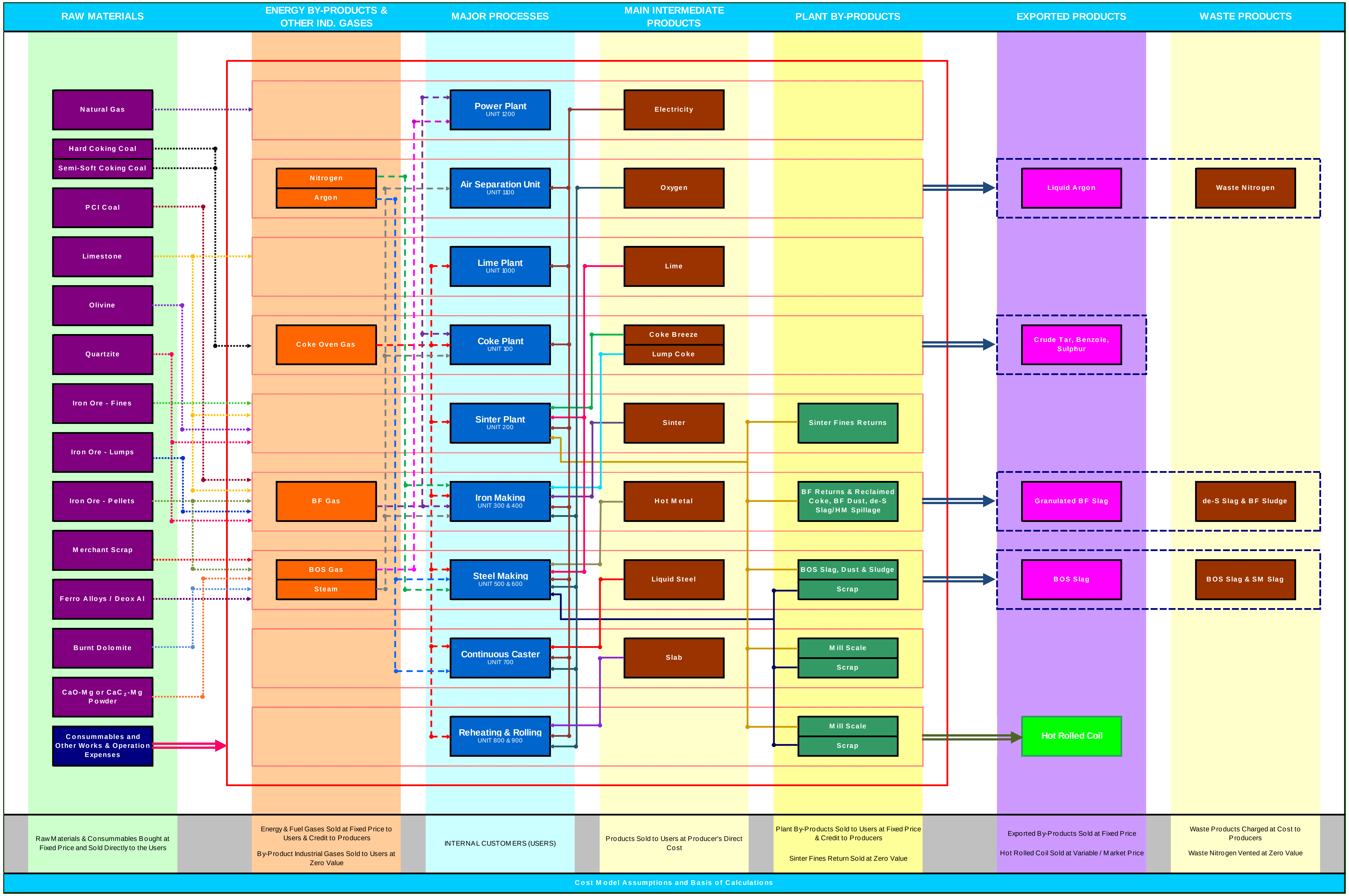

Figure E-1: Schematic representation of the cost model showing the evaluation of the direct cost of the integrated steel mill.

3.2. Database and Input Data

3.2.1. Price Database

The study has made extensive use of various databases from relevant publications and actual steel mill operational data (including information from Tata Steel Consulting Internal Database) to establish the key price inputs of the raw materials, consumables, disposal cost, and by-products – adjusted to reflect long term European price trends.

3.2.2. Summary - Key Price Inputs

Table E-1 presents the key price inputs for the raw materials, consumables, disposal costs, and by-products used in the cost evaluation of the operating expense of the REFERENCE Integrated Steel Mill without CO_2 Capture (Base Case).

3.2.3. Summary – Annual Operating Data

Tables E-2 & E-3 summarises the list of raw materials, consumables and other items accounted for in the calculation of the annual operating expense for each plant or process.

The operating data used in the evaluation of the annual operating expenses of the REFERENCE Integrated Steel Mill is based on the mass balance of each plant/process as presented and described in Section D. The mass flow is expressed as per tonne of product of the process and/or as mass flow per tonne of hot rolled coil. Figures E-2 to E-4 summarised these mass and energy balance calculations.

Table E-1: Summary of Key Price Inputs of Raw Materials, Consumables, Disposal and By-Products REFERENCE Integrated Steel Mill without CO_2 Capture (Base Case)

	Unit	Unit Price
Iron Ore		
Fines (fob Brazil) – dry	dmtu[3]of Fe	**$0.97**
Fines (fob Sweden) – dry	dmtu of Fe	**$1.06**
Fines (fob Australia) – dry	dmtu of Fe	**$0.95**
Pellets (fob Brazil) – dry	dmtu of Fe	**$1.44**
Lump (fob Australia) – dry	dmtu of Fe	**$1.23**
Energy		
Natural Gas (delivered)	GJ	**$9.77**
Coal		
Hard Coking Coal (fob Australia)	Tonne	**$148.00**
Semi-Soft Coking Coal (fob Australia)	Tonne	**$107.00**
PCI Coal (fob Australia)	Tonne	**$109.48**
Scrap		
Scrap – Rotterdam (Mixed)	Tonne	**$228.00**
Freight & Handling		
Voyage Rate - Iron Ore (Brazil - Netherlands)	Tonne	**$10.00**
Voyage Rate - Iron Ore (Scandinavia - Netherlands)	Tonne	**$5.00**
Voyage Rate - Iron Ore (Australia - Netherlands)	Tonne	**$22.00**
Voyage Rate - Coal (Australia - Netherlands)	Tonne	**$21.00**
Handling Charges - Iron Ore	Tonne	**$6.00**
Handling Charges - Coal	Tonne	**$6.00**
Fluxes and Ferro Alloys		
Limestone	Tonne	**$23.25**
Quartzite	Tonne	**$18.00**
Olivine	Tonne	**$17.00**
Burnt Dolomite (Dolomet)	Tonne	**$92.00**
Powder Calcium Carbide (CaC2)	Tonne	**$800.50**
FeMnC	Tonne	**$1,403.17**
FeSi75	Tonne	**$1,650.29**
Deox Al	Tonne	**$2,208.58**
By Products		
Crude Tar	Tonne	**$176.00**
Benzole/BTX	Tonne	**$466.17**
Sulphur	Tonne	**$85.00**
Slag (Blast Furnace)	Tonne	**$16.00**
Slag (BOS Furnace)	Tonne	**$2.00**
Argon (Sale)	Nm^3	**$0.93**
Other Consumables, Utilities and Disposal		
Water	m^3	**$0.11**
Refractories (Iron Making Production) – excl. Blast Furnace	Tonne	**$820.00**
Refractories (Steelmaking Production)	Tonne	**$847.00**
Refractories (Continuous Caster)	Tonne	**$630.00**
Electrodes (Secondary Steelmaking)	Tonne	**$4,057.00**
Casting Powder	Kg	**$0.67**
Work Rolls - HRM	per Tonne HRC	**$2.25**
Banding	per Tonne HRC	**$0.09**
Slag Processing	Tonne	**$5.89**
Slag Tip / Quench & Dig	Tonne	**$1.55**
BOS Slag Land Fill Tax	Tonne	**$3.87**
SM (Ladle) Slag Land Fill Tax	Tonne	**$86.79**
BF Sludge Disposal Charge	Tonne	**$20.00**
Site Haulage	Tonne	**$0.31**

[3] dmtu = Dry metric tonne unit . Cost for 1% Fe contained in 1 tonne of ore on dry basis

Table E-2: List of Externally Sourced Raw Materials and Consumables Accounted for in Each Plant or Process

Materials	Material Consumers (Users)								
	Coke Production	**Sinter Production**	**Iron Making Production**	**Steelmaking Plant**	**Continuous Casting**	**Reheating and HRM**	**Lime Plant**	**Oxygen Plant**	**Power Plants**
Unit No.	100	200	300 & 400	500 & 600	700	800 & 900	1000	1100	1200
Energy & Reductant									
Hard Coking Coal	X								
Soft Coking Coal	X								
PCI Coal			X						
Natural Gas									X
Raw Materials (Metal Inputs)									
Iron Ore Fines (Brazil)		X							
Iron Ore Fines (Australia)		X							
Iron Ore Fines (Sweden)		X							
Iron Ore Lumps (Australia)			X						
Iron Ore Pellets (Brazil)			X	X					
Purchased Scrap				X					
FeMnC				X					
FeSi75				X					
DeOx Aluminium				X					
Raw Materials (Fluxes)									
Limestone		X	X				X		
Quartzite		X	X						
Olivine		X							
Burnt Dolomite				X					
CaC2 Powder					X				
Consumables									
Raw Water	X	X	X	X	X	X			X
Electrodes				X					
Casting Powder					X				
Banding						X			
Refractory			X	X	X				
Work Rolls						X			
Others									
Works' Expense	X	X	X	X	X	X	X		
Misc. OPEX (incl. Environmental)	X	X	X	X	X	X			
Disposal									
Slag/Sludge Disposal	X		X	X					

Table E-3: List of Locally Produced Raw Materials and Recycled By-Products Accounted for in Each Plant or Process

Materials	Material Consumers (Users)								
	Coke Production	Sinter Production	Iron Making Production	Steelmaking Plant	Continuous Casting	Reheating and HRM	Lime Plant	Oxygen Plant	Power Plants
Unit No.	100	200	300 & 400	500 & 600	700	800 & 900	1000	1100	1200
Energy & Reductant									
Lump Coke			X						
Coke Breeze		X							
Reclaimed Coke		X							
Coke Oven Gas	X	X	X	X	X	X	X		
Blast Furnace Gas	X		X						X
Basic Oxygen Furnace Gas									X
Electricity	X	X	X	X	X	X	X	X	
Steam	X		X					X	
Raw Materials (Metal Inputs)									
Sinter			X						
Hot Metal				X					
Liquid Steel					X				
Slab						X			
Scrap (Internally Generated)				X					
BF Undersize (excl. reclaimed coke)		X							
Mill Scales		X							
Raw Materials (Fluxes)									
Lime		X		X					
Slag (de-S & BOS)		X							
Raw Materials (Utilities and Others)									
Compressed Air			X			X			
Oxygen			X	X	X	X			
Argon				X	X				
Nitrogen			X	X					
BF/BOS Dust & Sludge		X							

Production: 4,000,000 tonnes HRC/y
(YEAR 06)

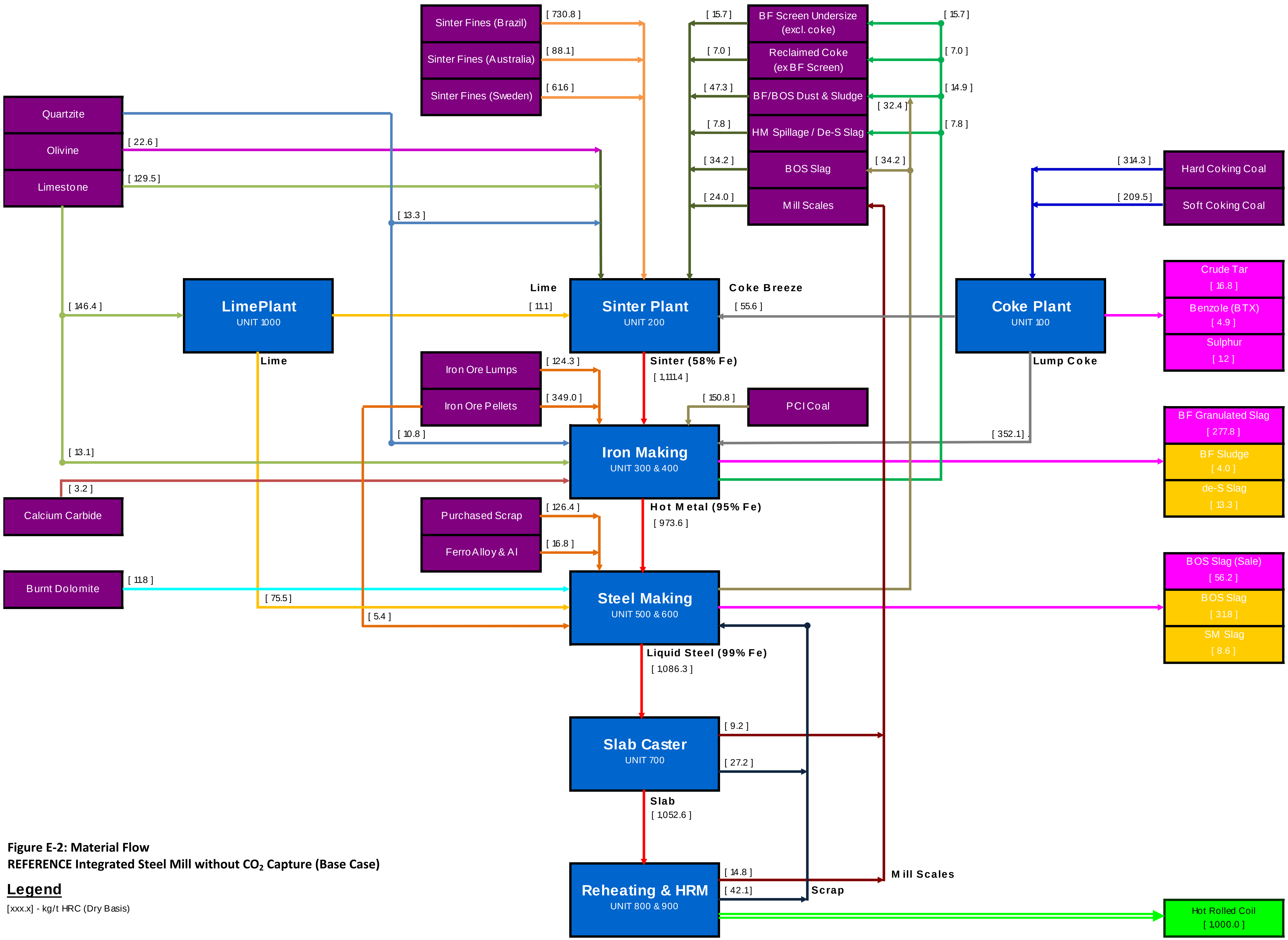

Figure E-2: Material Flow
REFERENCE Integrated Steel Mill without CO_2 Capture (Base Case)

Legend

[xxx.x] - kg/t HRC (Dry Basis)

Production: 4,000,000 tonnes HRC/y
(YEAR 06)

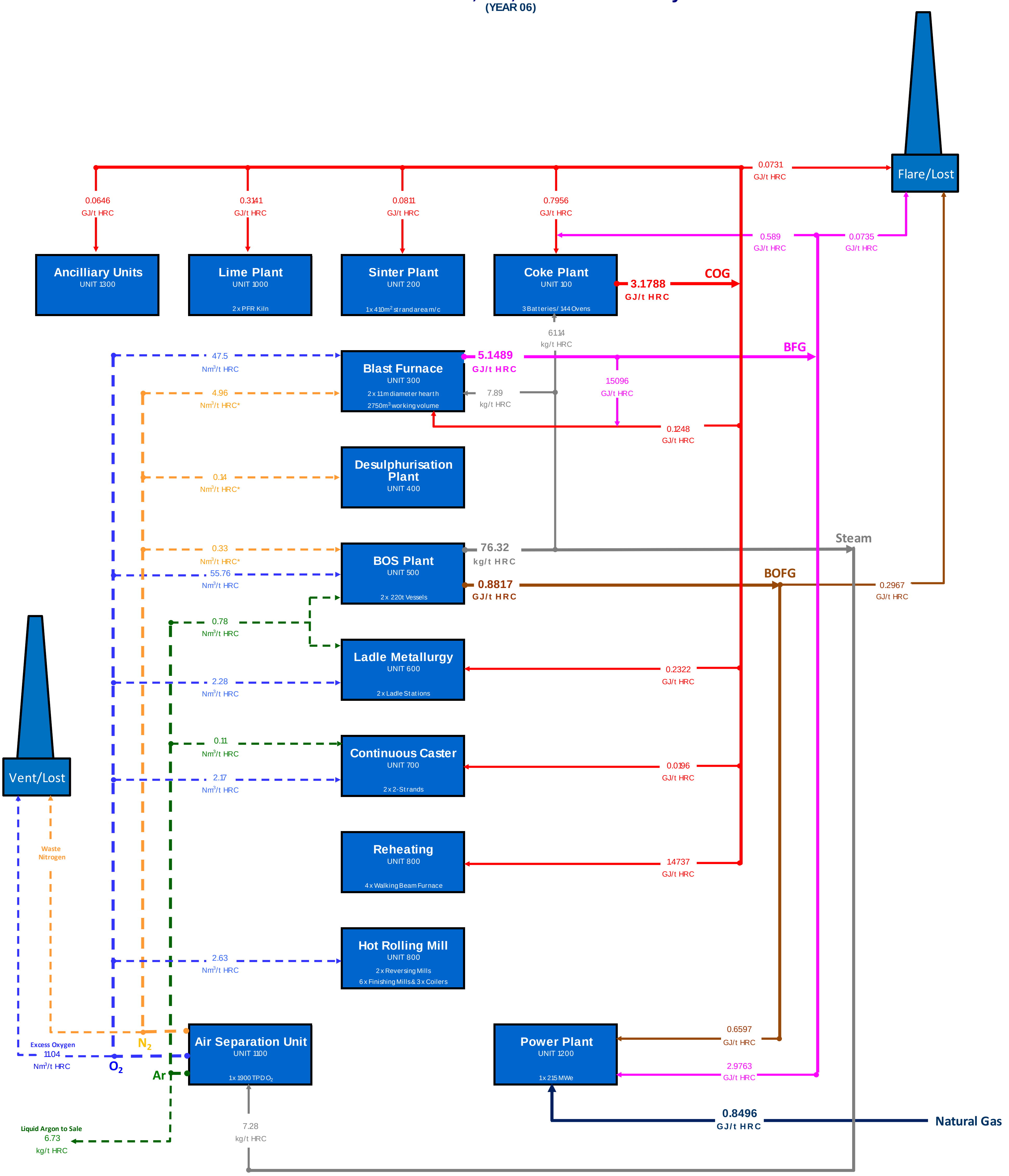

Figure E-3: Gas Flow – REFERENCE Integrated Steel Mill without CO_2 Capture (Base Case)
(Note: All numbers quoted in this flow diagram are on dry basis)

Production: 4,000,000 tonnes HRC/y

(YEAR 06)

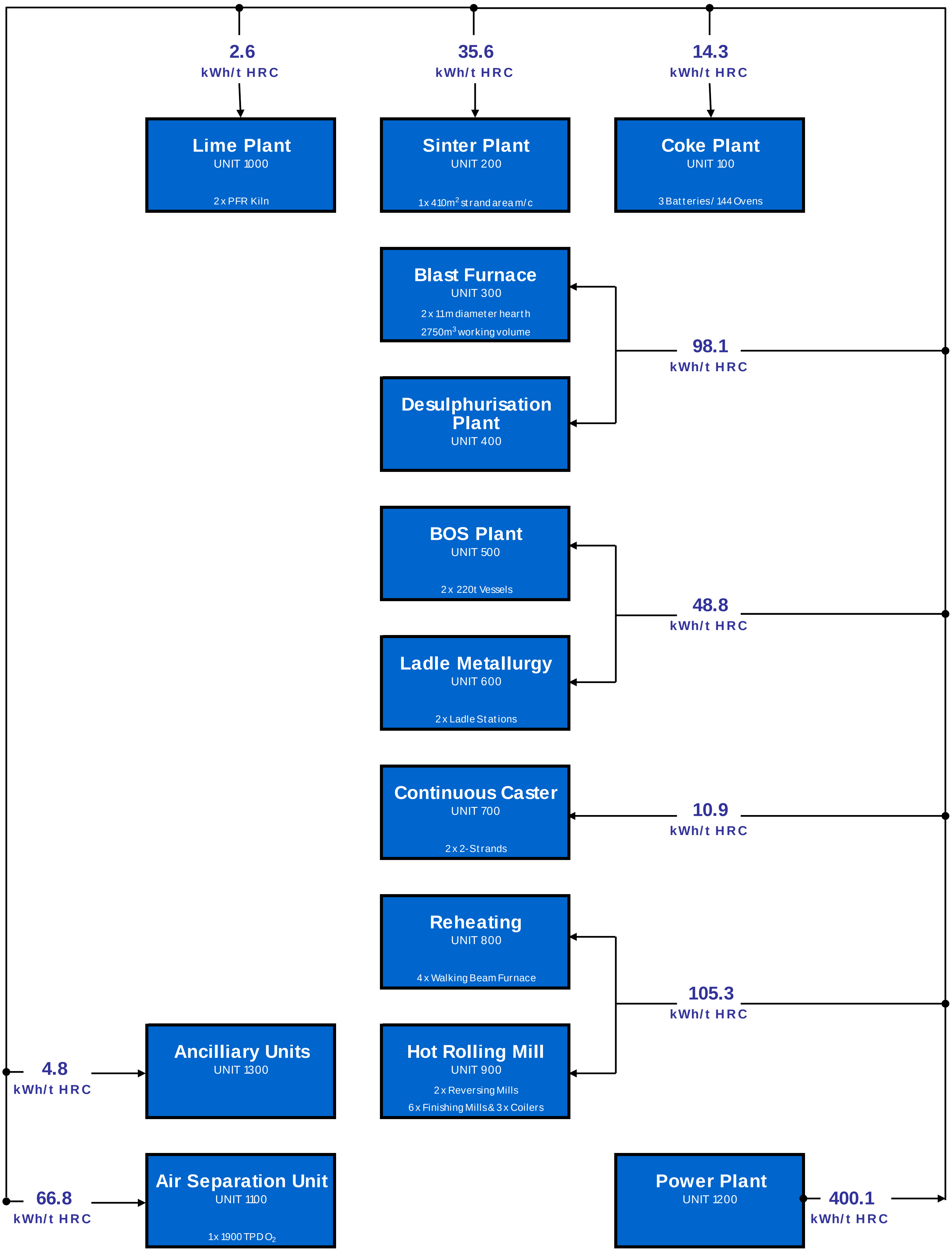

Figure E-4: Electricity Consumption – REFERENCE Integrated Steel Mill without CO_2 Capture (Base Case)

4. INVESTMENT COST

The basis of estimating the total investment cost accounts for the following:

- Total installed cost for plant and equipment
- Site Development and Construction
- Recurring Capital Expenditure
- Contingency

4.1. Plant and Equipment – Major Processes

The total installed cost for major plant and equipment was estimated at US$ 2.772 Billion.

The capital cost of the major plant and equipment considered in the "REFERENCE" Integrated Steel Mill are estimated based on the process specification as described in Section D.

The cost estimates are subdivided according to the following Units or Block of Units:

- UNIT 100: Coke Production
- UNIT 200: Sinter Production
- UNIT 300 & 400: Blast Furnace, Hot Stoves and HM Desulphurisation
- UNIT 500 & 600: Steelmaking, Ladle Metallurgy
- UNIT 700: Continuous Caster
- UNIT 800 & 900: Reheating Furnace and Hot Rolling Mills
- UNIT 1000: Lime Production
- UNIT 1100: Oxygen Production (Air Separation Unit)
- UNIT 1200: Power Plant

The total installed cost for each plant or process accounts for (but is not limited to):

- Direct material – including plant, equipment and bulk materials
- Plant Construction
  - Installation cost includes the mechanical erection, piping installation, etc...;
  - instrumentation, process control automation and electrical installation;
  - civil works, and where necessary other site preparation.
- EPC Services – including contractor's home office and construction supervision.
- Other Costs - including temporary buildings, training and plant start up (excl. spare parts and first fill).

The equipment cost was estimated from quoted prices from equipment suppliers and database of Tata Steel Consulting adjusted to 2010 prices. All capital cost estimates should be within ±30% accuracy.

Table E-4 summarizes the investment breakdown and the total figures for each major Unit or Block of Units considered within the boundary limit of the "REFERENCE" Integrated Steel Mill without CO_2 Capture.

A list of major plant components accounting for the majority of the total equipment cost reported for each Unit or Block of Units is enumerated for illustration purposes only. A detailed list of the plant and equipment is not provided as this is not part of the scope of this study.

Table E-4: Capital Cost Allocation of the Major Processes
"REFERENCE" Integrated Steel Mill without CO_2 Capture

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)
100	**Coke Production** • Coking coal blending yard & handling (incl. rail cars, etc…) • Coke Oven Batteries (3x @48 ovens each) o Underfiring Heating, Combustion Air Blowers, FD & ID Fans o Combustion Air & BF Gas Pre-heater o Flue Gas Cleaning o Coke Ovens o Coke Pushing and Discharging Facility o Coke Quenching Car o Coke Quenching Towers, Water Pumps o Coke Screening • Coke By-Product Plant o Gas Collecting Main, NH_3 Water Wash & Tar Separation o Primary Gas Cooler o Tar Electrostatic Precipitator o Tar Decanting and Recovery Plant o Naphthalene Stripper Unit o NH_3 and H_2S Stripper Unit o Combined NH_3 Cracker and Claus Plant o BTX Stripper o BTX Distillation Plant o Gas Exhauster o Gas Switch Over Station o Gas holder o Flaring System o Biological Waste Water Treatment Facility	**1.7 million tpy**	**400**

Table E-4 (cont'd): Capital Cost Allocation of the Major Processes
"REFERENCE" Integrated Steel Mill without CO_2 Capture

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)
200	**Sinter Production** • Raw materials handling o Grinding Mill – Coke & Reclaimed Coke o Raw Material Bins for Iron Ore Fines & Revert Materials o Silo for Lime, Sinter Fines Return, Coke Breeze o Mixing Drums o Process Water Pumps • Sinter Strand – Travelling Grate (1x @ 410 m^2 working area) o Feed Hopper o Ignition Furnace o Sinter Strand - Travelling grate o Combustion Air Blowers, FD & ID Fans • Flue Gas Cleaning (Sinter Strand) – ESP and Fabric Filter • Sinter Crusher, Cooler and Screening o Sinter Crusher o Hot Screening o Rotary Cooler and ID Fans o Cold Screening • Gas Cleaning (Sinter Cooler) – ESP	**4.5 million tpy**	**220**

Table E-4 (cont'd): Capital Cost Allocation of the Major Processes
"REFERENCE" Integrated Steel Mill without CO_2 Capture

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)

300	**Blast Furnace / Hot Stoves (Iron Making)**
	• Raw material handling – conveyor & feed hoppers within the BF
	• Blast Furnace (2x BF @ 11m diameter/2750 m^3 working volume)
	    o Bell Less Top Feeding System
	    o PCI Coal Injection Facility (including PCI Coal Drying Unit)
	    o Cast House and Dedusting Facility (Fabric Filter)
	    o Hot Metal Tap
	    o Slag Tap and Runner
	• BF Slag - Wet Granulation Plant
	    o Settling Tank and Pumps
	    o Cooling Tower
	    o Air Compressors
	    o Slag Pit / Stockyard
	• Cowper Stoves (3x stoves staggered operation per BF)
	    o Recuperator
	    o Combustion Air Blowers, FD and ID Fans
	• Main Air Compressor (2x) – Blast Air
	• BF Gas Processing
	    o Primary Gas Cleaning (Cyclone)
	    o Secondary Gas Cleaning (Wet Scrubber)
	    o Dust and Sludge Handling
	    o Gas Switch Over Station
	    o Gas holder
	    o Flaring System
		3.9 million tpy	**622**
			(estimate incl. Unit 400)

400	**Hot Metal Desulphurization Plant**
	• Hot Metal Desulphurization Station (2x)
	    o Reagent Silo (CaC2 Power)
	    o Reagent Injection Lance
	    o Slag and Metal Spill Processing (Slag pot & skimmer)
	    o Gas Cleaning (Fabric Filter)
			See Unit 300

Table E-4 (cont'd): Capital Cost Allocation of the Major Processes "REFERENCE" Integrated Steel Mill without CO_2 Capture

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)
500	**Basic Oxygen Steelmaking Plant** • Scrap Handling & Scrap Transfer Cars • Basic Oxygen Steelmaking Furnace (2x 220 tonnes) o BOF Converter Vessel o Hot Metal Charging Facility o Oxygen Top Blowing System (Lance Injection) o Inert Gas Bottom Stirring System o Slag Removal and Handling Facility • BOF Gas Recovery Unit (2x – suppressed combustion type) o BOF Gas Recovery Hood o Waste Heat Boiler, BFW/Condensate Pumps • BOF Gas Cleaning o Dedusting (Wet Scrubbing) o ID Fans o Gas Switch Over Station o Gas holder o Flaring System o Dust and Sludge Handling	**4.4 million tpy**	**459** (estimate incl. Unit 600)
600	**Ladle Metallurgy (Secondary Steel Refining)** • Ladle Refining Furnace Station (2x) o Ladle Refining Furnace and Roof o Ladle Cars o Ferro Alloy and Aluminium Handling and Charging o Material Handling and Charging (Fluxes, Scrap) o Ladle Metallurgy Furnace Voltage Transformers o Electrode Gantries (Arc Heating) o Inert Gas Stirring & Oxidation Shielding System o Slag Removal and Handling Facility • Water Cooled Hood and Off Gas Cleaning (Fabric Filter)		**See Unit 500**

Table E-4 (cont'd): Capital Cost Allocation of the Major Processes
"REFERENCE" Integrated Steel Mill without CO_2 Capture

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)
700	**Continuous Slab Caster** • Twin Strand Continuous Caster (2x) o Ladle Turret o Tundish o Mould o Strand Guide Systems o Slab Cutting and Roller Tables o Water Pumps • De-scaling System • Slab Yard	4.3 million tpy	195
800 / 900	**Reheating Furnace & Hot Rolling Mills** • Walking Beam Furnace (4x – 2 per HRMs) o Slab Handling o Combustion Air Blowers, FD and ID Fans o Flue Gas Cleaning o Cooling Water Pumps o Recuperators • Hot Rolling Mills (2x) o Reversing Mills (2x) o Finishing Mills (6x) o Coilers(3x) • De-scaling System	4.0 million tpy	450

Table E-4 (cont'd): Capital Cost Allocation of the Major Processes
"REFERENCE" Integrated Steel Mill without CO_2 Capture

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)
1000	**Lime Production** • Limestone Silo / Crusher • PFR Kiln (2x 600 tpd) o Weight Hopper o Combustion Air Blowers, Cooling Fans and ID Fans o Fuel & Cooling Air Lances • Flue Gas Cleaning – Fabric Filter • Screen	**0.4 million tpy**	**16**
1100	**Air Separation Unit** • Main Air Compressor • Air Pre-Treatment Plant • Cold Box (Heat Exchangers and Cryogenic Separation) • Liquid Product Storage • Re-gasification and Product Compression Plant	**1900 tpd O_2**	**130**
1200	**Power Plant** • Boiler Island and Flue Gas Cleaning o Combustion Air Blowers, FD and ID Fans o Boiler Feed Water and Condensate Pumps o Flue Gas Cleaning – SCR • Steam Turbine Island o Steam Turbines and Condenser o Cooling Water Pumps (seawater once through cooling) • Generator Set	**215 MWe**	**280**

4.2. Plant and Equipment – Raw Materials Handling and Spare Parts

The total investment cost for raw material handling used in handling of iron ore and other raw materials was estimated at US$ 128 Million.

Major raw materials handling equipment that specifically supports the operation of the blast furnace but also serves the whole steel mill includes the following:

- Ore unloaders (3x @1500 tph each)
- Stacker and Reclaimers (3x)
- Misc. material handling, screens, crushers, etc…
- Conveyors

The total investment cost for primary spare parts, tools, refractories for various furnaces, first fill and consumables used during the commissioning and plant start up was estimated at US$ 116 Million.

4.3. Plant and Equipment – Auxiliary, Utilities and BOP

The total investment cost for the auxiliary plant and equipment was estimated at US$ 350 Million.

The auxiliary plant and equipment accounts for all utilities and balance of plant which include the following:

- Site Water Treatment Plant (used for cooling water system, demin-water plant, etc…)
- Site Waste Water Treatment Plant (excl. Coke Plant)
- Substation and HV Distribution Network
- Fire Fighting Systems
- Other Process Control Integration and Site Automation
- Computer Site Networks
- Workshop Equipment
- Laboratory Equipment
- Heavy Duty Cranes
- Light Cranes
- Torpedo Ladles (10x)
- Trains (3x)
- Vehicles & Cars

4.4. Site Development, Construction and Project Engineering

The overall project engineering and management, site construction, civil works and plant commissioning of the REFERENCE Steel Mill were estimated at a total cost of US$562 Million.

This cost breakdown for construction and commissioning includes the following:

• Pre-operating Expenses	US$	21 Million
• Land Preparation, Site Development & Waste Disposal		144 Million
• Project Engineering		201 Million
• Buildings and Site Infrastructure		196 Million

The pre-operating expenses include the feasibility and pre-engineering study, legal and planning activities, permitting, environmental impact assessment study, etc…

Land preparation, site development and waste disposal includes (but is not limited to) ground preparation for foundation work, survey, civil works related to site preparation and and construction related waste disposal.

Project engineering accounts for the process and engineering design, patent and licensing fees, plant commissioning, consultant's fee, etc...

The buildings and infrastructure accounts for the following development within the site:

- Support Building
- Auxiliary Buildings (10x at $200m^2$ each)
- Workshops buildings
- Service Building
- Amenity Building
- Miscellaneous Site Offices
- Control Rooms – In plant and equipment
- Laboratory
- Sub Station
- Ware House
- Car Workshop
- Medical Centre
- Fire Station
- Main Entrance & Security
- Boundary Fence
- Road Network
- Rail Network
- Parking Areas
- Green Area @ 2% of Land
- Gas Station
- Water Storage
- Weigh Bridge
- Lighting (30m high lighting towers)
- Street Lightings
- Stocking Areas / Site Preparation (incl. installation of concrete slab/leachate drainage)

4.5. Recurring Capital Expenditure

The relining of the refractory and the replacement of cooling stave is the only recurring capital expenditure accounted for in this study. It was estimated at US$232 Million and disbursement will be made on every 15th year of the operation.

The study assumed that relining of the blast furnace should not affect the overall steel production capacity. This assumption is made for simplification purposes only. In reality, it should be expected that there will be some loss of hot metal production. Nonetheless, measures would be taken to reduce the impact of the production loss due to shutting down of the blast furnaces for relining.

4.6. Contingency

Contingency is a provisional sum to take into account of any possibility of cost overruns which is meant to cover any estimating errors or omissions.

The contingency has been estimated at US$ 196 Million (which is approximately 5% of the total installed cost – excluding recurring CAPEX). This has been determined on the basis of the estimate quality and methodology adopted to develop the estimates.

4.7. Summary of Results

4.7.1. Total Investment Cost

Table E-5 presents the summary of the total investment cost for the "REFERENCE" Integrated Steel Mill without CO_2 Capture.

4.7.2. Capital Expenditure and Scrap Value

Capital Investment

The schedule for the infusion of the capital investment was described in Section E2.3.

Year	Capital Expenditure (% investment cost)	Capital Expenditure (US$ Million)
-3	10	604
-2	35	1,413
-1	30	1,160
1	20	764
2	5	184

Working Capital

The basis of calculation for the working capital is described in Section E2.7. The infusion of the required working/revolving capital to the operation of the steel mill was also assumed to follow the schedule of the ramping up of the operation during the first four years.

Year	Working Capital Investment Schedule (US$ Million)	Working Capital (US$ Million)
1	174	174
2	90	264
3	54	318
4	36	354
5 and onward	0	354

Scrap Value of the Steel Mill

Based on a straight-line depreciation at 4%, the end of life value of the "REFERENCE" Integrated Steel Mill at 26^{th} year was estimated at US$ 137 Million. This is not included in the cash flow analysis as it was assumed that this will be used to cover partly of the decommissioning of the steel mill.

The terminal value of the steel mill (net asset of the plant at 26^{th} year) including the return of the working capital was estimated at US$ 494 Million. It should be noted that only the return of the working capital at the end of economic life will be included in the cash flow analysis (as the scrap value was assumed to be used to partly to cover the decommissioning of the plant).

Table E-5: Summary of Results - Total Investment Cost
REFERENCE Integrated Steel Mill without CO_2 Capture (Base Case)

Unit No.	Plant Section	Cost Breakdown	CAPEX (US$ Million)
Plant and Equipment – Major Processes			**2,772**
100	Coke Production	400	
200	Sinter Production	220	
300 & 400	Blast Furnace and Hot Metal Desulphurisation	622	
500 & 600	Basic Oxygen Steelmaking and Ladle Metallurgy	459	
700	Continuous Slab Caster	195	
800 & 900	Reheating Furnace & Hot Rolling Mills	450	
1000	Lime Production	16	
1100	Air Separation Unit	130	
1200	Power Plant	280	
Plant and Equipment – Raw Material Handling and Spare Parts			**244**
	Raw Material Handling	128	
	Spare Parts and First Fill	116	
Plant and Equipment – Auxiliary, Utilities and BOP			**350**
Site Development, Construction and Project Engineering			**562**
	Pre-operating Expenses	21	
	Land Preparation, Site Development & Waste Disposal	144	
	Buildings and Site Infrastructure	196	
	Project Engineering	201	
		Total Installed Cost (US$ Million)	**3,928**
Contingency (5% of Total Installed Cost)			**196**
		Total Investment Cost – excl. Recurring CAPEX (US$ Million)	**4,124**
		Specific Investment Cost (US$/t HRC)	**1,031**
Recurring Capital Expenditure (every 15th year)			**232**

5. ANNUAL OPERATING AND MAINTENANCE COST

The basis of calculation of the annual operating and maintenance cost accounts for the following:

- Fixed Cost
  - Maintenance Cost
  - Direct Labour Cost
  - Indirect Labour, Management and Overhead Cost
- Variable Cost
  - Energy and Reductants
  - Raw Materials
  - Fluxes
  - Consumables
  - Utilities
- Other Cost
  - Miscellaneous Works Expenses
  - Other Operational Expense (Environmental Clean Up, etc...)
  - On-Site Haulage Fee
  - Slag Processing Fee
  - Disposal and Landfill Cost

5.1. Fixed Cost

5.1.1. Maintenance

The annual maintenance cost of the REFERENCE Integrated Steel Mill was estimated at around US$142.00 Million per year. Table E-6 summarised the breakdown of this cost.

Table E-6: Annual Maintenance Cost of the REFERENCE Integrated Steel Mill

Unit No.	Plant / Process	CAPEX (US$ Million)	Maintenance (% CAPEX)	Maintenance Cost (US$ Million/y)
100	Coke Production	400.0	5.0%	20.000
200	Sinter Production	220.0	5.0%	11.000
300 & 400	Blast Furnace and Hot Metal Desulphurisation	622.0	4.0%	24.880
500 & 600	Basic Oxygen Steelmaking and Ladle Metallurgy	459.0	5.0%	22.950
700	Continuous Slab Caster	195.5	8.0%	15.636
800 & 900	Reheating Furnace & Hot Rolling Mills	450.0	8.0%	36.000
1000	Lime Production	16.0	8.0%	1.280
1100	Air Separation Unit	130.0	2.5%	3.250
1200	Power Plant	280.0	2.5%	7.000
	Total	**US$ 2,772M**	**5.12%**	**US$ 141.996 M/y**

This cost was estimated using a fixed percentage of the installed cost of each process. The maintenance cost (as % of CAPEX) was determined by Tata Steel Consulting using their internal database.

It should be noted that some items, which could be generally classified as maintenance cost, were excluded. This includes the refractory re-lining of the blast furnaces that would require major capital expenditure on a regular time interval. This has been considered as recurring capital expenditure. Also not included are items that would require frequent replacement and these are categorised as consumables in this study. These comprise the refractories used in iron making production, steelmaking and continuous casters and works rolls for hot rolling mills.

A precise evaluation of maintenance cost would require a detailed listing of equipment, where maintenance cost is correlated with statistical maintenance data provided by the equipment suppliers. This type of cost evaluation is considered premature at this level of study.

The annual maintenance cost typically consists of fixed and variable cost components. This normally includes the maintenance materials and labour. The variable components – especially the maintenance materials – are generally estimated based on number of cumulative operating hours attained by the equipment. However, for simplification, this study assumed that the variable elements of the maintenance cost is part of the fixed costs on the basis that plants and equipment operate at their design capacity and service factor.

5.1.2. Direct Labour

The annual direct labour cost of the REFERENCE Integrated Steel Mill when operating at full capacity was estimated at US$ 204.58 Million per year.

Table E-7 presents the number of personnel who are directly engaged in the operation of the steel mill. The direct labour cost was estimated by assuming that each personnel has an average salary of US$ 94,000 per year (incl. social benefits).

5.1.3. Indirect Labour, Corporate and Management Overheads

The annual fixed indirect labour cost was estimated at US$ 76.14 Million per year. This represents about 37.2% of the direct labour cost.

Indirect Labour consists of all personnel who are involved in other company related services but not directly engaged with the operation of the steel mill. This component of the cost varies between every organisation. Nonetheless, it could be assumed that indirect labour will be made up of the following personnel related to:

- Management
- Administration
- Commercial and marketing services
- Personnel and HR services
- Clerical staff
- Technical, R&D and engineering services
- Rail operators and support staff

Table E-8 presents the breakdown of the number of personnel under this classification and the breakdown of the cost. The indirect labour cost was also estimated by assuming that each personnel has an average salary of US$ 94,000 per year (incl. social benefits).

Table E-7: Annual Direct Labour Cost of the REFERENCE Integrated Steel Mill

Unit No.	Business Unit	Operating Period					Total Personnel at Full Capacity	Personnel Cost (US$ Million/y)
		1	2	3	4	5 … 25		
100	**Coke Production**							
	Operators	104	156	187	208	208	208	
	Support Staff	32	32	32	32	32	32	
	Sub-Total	**136**	**188**	**219**	**240**	**240**	**240**	**22.560**
200	**Sinter Production**							
	Operators	118	176	212	235	235	235	
	Support Staff	35	35	35	35	35	35	
	Sub-Total	**153**	**211**	**247**	**270**	**270**	**270**	**25.380**
300 & 400	**Iron Making**							
	Operators	139	208	249	277	277	277	
	Support Staff	44	44	44	44	44	44	
	Sub-Total	**183**	**252**	**293**	**321**	**321**	**321**	**30.174**
500 & 600	**Steelmaking**							
	Operators	176	263	316	351	351	351	
	Support Staff	45	45	45	45	45	45	
	Sub-Total	**221**	**308**	**361**	**396**	**396**	**396**	**37.224**
700	**Continuous Casting**							
	Operators	151	226.5	271.8	302	302	302	
	Support Staff	58	58	58	58	58	58	
	Sub-Total	**209**	**285**	**330**	**360**	**360**	**360**	**33.840**
800 & 900	**Reheating & HRM**							
	Operators	209	313	376	417	417	417	
	Support Staff	63	63	63	63	63	63	
	Sub-Total	**272**	**376**	**439**	**480**	**480**	**480**	**45.157**
1000	**Lime Production**							
	Operators	15	23	27	30	30	30	
	Support Staff	4	4	4	4	4	4	
	Sub-Total	**19**	**27**	**31**	**34**	**34**	**34**	**3.196**
1100	**Oxygen Production**							
	Operators	15	23	27	30	30	30	
	Support Staff	5	5	5	5	5	5	
	Sub-Total	**20**	**28**	**32**	**35**	**35**	**35**	**3.290**
1200	**Power Plant**							
	Operators	36	36	36	36	36	36	
	Support Staff	4	4	4	4	4	4	
	Sub-Total	**40**	**40**	**40**	**40**	**40**	**40**	**3.760**
Total								
	Operators	961	1424	1701	1886	1886	1,886	
	Support Staff	290	290	290	290	290	290	
	Plant Total	**1251**	**1714**	**1991**	**2176**	**2176**	**2176**	**US$ 204.581 M/y**

Table E-8: Indirect Labour Cost of the REFERENCE Integrated Steel Mill

Unit No.	Business Unit	Operating Period					Total Personnel at Full Capacity	Personnel Cost (US$ Million/y)
		1	2	3	4	5 … 25		
	Central Engineering							
	Operators Support Staff	145 20	218 20	261 20	290 20	290 20	290 20	
	Sub-Total	**165**	**238**	**281**	**310**	**310**	**310**	**29.140**
	Corporate Functions							
	Management & Admin Staff	500	500	500	500	500	500	
	Sub-Total	**500**	**500**	**500**	**500**	**500**	**500**	**47.000**
Total								
	Operators Support Staff	145 520	218 520	261 520	290 520	290 520	290 520	
	Plant Total	**810**	**810**	**810**	**810**	**810**	**810**	**US$ 76.140 M/y**

5.2. Energy and Reductant (Externally Sourced)

The iron and steel production uses energy and reductants that are externally (imported) sourced and internally (local) produced. Tables E-2 and E-3 summarizes the list of energy and reductants used by the steel mill. This section presents a summary of the annual cost of the externally sourced energy and reductants. The specifications of the externally sourced energy and reductants are briefly described in Section C.

Externally sourced energy and reductants include:

- Coking Coal (Hard and Soft)
- PCI Coal
- Natural Gas

5.2.1. Coking Coal and PCI Coal

The annual cost of coking and PCI coal consumed by the steel mill, when operating at full capacity, was estimated at US$ 450.74 Million per year. The breakdown of this cost is presented in Table E-9.

Table E-9: Annual Cost and Consumption of Coking and PCI Coal

		Hard Coking Coal	Soft Coking Coal	PCI Coal
Moisture Content	%wt.	8.0	8.0	8.0
Coal Price (dry basis)	$/tonne	148.00	107.00	109.48
Voyage Rate (to Rotterdam)	$/tonne	21.00	21.00	21.00
Handling Charge	S/tonne	6.00	6.00	6.00
Total Price	**$/tonne**	**190.22**	**145.65**	**148.35**
ANNUAL CONSUMPTION			**Year 4 to 25**	
100: Coke Production	Tonnes/y	1,257,292	838,194	
300: Blast Furnace	Tonnes/y			603,251
Total Consumption	**Tonnes/y**	**1,257,292**	**838,194**	**603,251**
Annual Cost (US$ Million/y)		**239.159**	**122.085**	**89.491**

The price (per tonne) of coal was calculated based on coal price (on dry basis), voyage rate and handling charge as illustrated in Table E-9. The price and voyage rate are obtained using long term trend prices reported from various databases.

5.2.2. Natural Gas

The annual cost of natural gas consumed by the steel mill, when operating at full capacity, was estimated at US$ 33.203 Million per year. The cost was calculated based on natural gas price of US$9.77 per GJ. Annual consumption of natural gas was reported as 2.9268 PJ per year and this is solely used by the captive power plant (UNIT 1200).

It is important to note that not included in the accounting of this cost is the consumption of natural gas by the steel mill when this is used as backup fuel to other off-gases – as this consumption was not determined in the study.

5.3. Raw Materials (Externally Sourced)

The iron and steel production uses raw materials that are externally (imported) sourced and internally (local) produced. Tables E-2 and E-3 summarizes the list of raw materials used by the steel mill. This section presents a summary of the annual cost of the externally sourced raw materials. The specifications of these raw materials are briefly described in Section C.

Externally sourced raw materials include:

- Iron Ores (Fines, Lumps and Pellets)
- Purchased Scrap Metal
- Ferroalloys
- Fluxes (Limestone, Quartzite, Olivine, Calcium Carbide Powder)

5.3.1. Iron Ores (Fines, Lumps and Pellets)

The annual cost for iron ore consumed by the steel mill, when operating at full capacity, was estimated at US$ 492.05 Million per year. The breakdown of this cost is summarised in Table E-10.

Table E-10: Annual Cost and Consumption of Iron Ore

		Sinter Fines			Lumps	Pellets
		Brazil	Australia	Sweden	Australia	Brazil
Iron Content	%Fe	66.20	57.95	69.77	61.00	65.50
Iron Ore Price (dmtu of Fe)	$/dmtu	$0.970	$0.945	$1.060	$1.225	$1.440
Iron Ore Price[4]	$/tonne	64.21	54.76	73.96	74.73	94.32
Voyage Rate (to Rotterdam)	$/tonne	10.00	22.00	5.00	22.00	10.00
Handling Charge	S/tonne	6.00	6.00	6.00	6.00	6.00
Total Price (Iron Ore)	**$/tonne**	**80.21**	**82.81**	**84.96**	**102.73**	**110.32**
ANNUAL CONSUMPTION		Year 4 to 25				
200: Sinter Production	Tonnes/y	2,923,276	352,202	246,541		
300: Blast Furnace	Tonnes/y				497,139	1,396,178
600: Ladle Metallurgy	Tonnes/y					21,544
Total Consumption (Iron Ore)	**Tonnes/y**	2,923,276	352,202	246,541	497,139	1,417,721
Annual Cost (US$ Million/y)		**234.488**	**29.149**	**20.945**	**51.069**	**156.403**

The cost per tonnes of iron ore is calculated using the price of the ore (in dmtu – using %Fe content), delivery cost and handling charge. This is illustrated in Table E-10. The prices of iron ore and voyage rate were determined using the long term trend price reported from various databases.

5.3.2. Purchased Scrap and Ferroalloys

The annual cost for purchased scrap and ferroalloys used by the steel mill, when operating at full capacity, was estimated at US$ 218.23 Million per year. The breakdown of this cost is presented in

[4] Iron Ore price is calculated as (%Fe) x (Price of Ore in dmtu)

Table E-11. The price for the scrap and ferroalloys are quoted from the long term trend prices reported in various databases.

Table E-11: Annual Cost and Consumption of Purchased Scrap and Ferroalloys

		Purchased Scrap	FeMnC	FeSi75	DeOx Aluminum
Price	**$/tonne**	**228.00**	**1,403.17**	**1,650.29**	**2,208.58**
ANNUAL CONSUMPTION			**Year 4 to 25**		
500: BOF Steelmaking	Tonne/y	505,492			
600: Ladle Metallurgy	Tonne/y		47,798	13,036	6,518
Total Consumption	**Tonne/y**	**505,492**	**47,798**	**13,036**	**6,518**
Annual Cost (US$ Million/y)		**115.252**	**67.068**	**21.513**	**14.395**

5.3.3. Fluxes

The annual cost for fluxes used by the steel mill, when operating at full capacity, was estimated at US$ 44.65 Million per year. The breakdown of this cost is presented in Table E-12. The prices of these fluxes are quoted from Tata Steel Consulting internal database.

Table E-12: Annual Cost and Consumption of Fluxes

		Limestone	Quartzite	Olivine	CaC2 Powder	Burnt Dolomite
Price	**$/tonne**	**23.25**	**18.00**	**17.00**	**800.00**	**92.00**
ANNUAL CONSUMPTION						
200: Sinter Production	Tonne/y	517,872	53,347	90,349		
300: Blast Furnace	Tonne/y	52,497	43,129			
400: HM Desulphurisation	Tonne/y				12,710	
500: BOF Steelmaking	Tonne/y					47,164
1000: Lime Production	Tonne/y	585,449				
Total Consumption	**Tonne/y**	**1,155,819**	**96,475**	**90,349**	**12,710**	**47,164**
Annual Cost (US$ Million/y)		**26.871**	**1.737**	**1.536**	**10.168**	**4.339**

5.4. Consumables and Other Utilities

This section summarizes the annual consumption and cost of various consumables and raw water used by the steel mill when operating at full capacity.

Consumables included in the accounting of annual operating expense are:

- Refractories (iron making, steelmaking, casting)
- Electrodes (ladle metallurgy)
- Casting Powder (continuous casters)
- Works Back Up Rolls (hot rolling mills)
- Banding (hot rolling mills)
- Chemicals and Consumables (Power Plant)
- Raw Water

5.4.1. Refractories (Iron Making, Steelmaking, Casting)

The annual spend on refractories by the steel mill, when operating at full capacity, was estimated at US$ 22.60 Million per year. The breakdown of this cost is presented in Table E-13.

Table E-13: Annual Consumption of Refractory

		Iron Making	Steelmaking	Casting
Unit No.		300/400	500/600	700
Price	**$/tonne**	**820.00**	**847.00**	**630.00**
ANNUAL CONSUMPTION			**Year 4 to 25**	
Refractories	Tonne/y	5,062	15,208	8,842
Annual Cost (US$ Million/y)		**4.151**	**12.881**	**5.571**

5.4.2. Electrodes (UNIT 600 – Ladle Metallurgy)

The annual spend on electrodes consumed by the steel mill (UNIT 600: Ladle Metallurgy), when operating at full capacity, was estimated at US$ 5.29 Million per year. The cost was calculated based on electrode price of US$ 4,057 per tonne. Annual consumption of electrode by the ladle metallurgy station was estimated at about 1,304 tonnes per year.

5.4.3. Casting Powder (UNIT 700 – Continuous Casting)

The annual spend on casting powder consumed by the steel mill (UNIT 700: Slab Casting), when operating at full capacity, was estimated at US$ 2.26 Million per year. The cost was calculated based on casting powder price of US$ 0.670 per tonne. Annual consumption of casting powder by the continuous casters was estimated at about 3,368 tonnes per year.

5.4.4. Works Backup Rolls and Banding (UNIT 900 – Hot Rolling Mills)

The annual spend on backup rolls and banding used by the steel mill (UNIT 900: Hot Rolling Mills), when operating at full capacity, was estimated at US$ 9.00 Million and US$ 0.36 Million per year respectively.

The cost of backup rolls was calculated based on a unit price of US$ 2.25 per tonne HRC. Annual replacement of works rolls by the Hot Rolling Mills was assumed at 1 unit per tonnes HRC (4 million units per year).

Banding is part of the packaging of HRC prior to delivery. The cost of banding was estimated based on a unit price of US$ 0.09 per tonne HRC. Annual banding required was assumed at 1 unit per tonnes HRC (4 million units per year).

5.4.5. Chemical and Consumables (UNIT 1200 – Power Plant)

Chemicals and consumables used by the captive power plant include all reagents consumed by the water treatment facility, waste water treatment plant, and others dedicated to the power plant. This item also includes the utilities used by the power plant – such as water, plant air, etc...

The annual spend on chemicals and consumable by the captive power plant was estimated at US$7.88 Million per year. This was estimated based on a rate of US$ 0.004924 per kWh.

5.4.6. Other Utilities

<u>Water Consumption</u>

The annual spend on raw water consumption by the steel mill, when operating at full capacity, was reported at US$ 2.39 Million per year. This was estimated based on a fixed price of US$ 0.1135 per m^3 water. The breakdown of this cost is summarized in Table E-14.

Table E-14: Annual Cost and Consumption of Other Utilities (Raw Water)

Price		Raw Water	
		$/m^3	0.1135
100	Coke Production	m^3/y	2,931,317
200	Sinter Production	m^3/y	1,324,616
300 &400	Iron Making	m^3/y	3,483,639
500 & 600	Steelmaking	m^3/y	1,673,679
700	Continuous Casting	m^3/y	3,655,576
800 & 900	Reheating & Rolling	m^3/y	8,000,000
Total		**m^3/y**	**21,068,407**
Annual Cost (US$ Million/y)		**2.392**	

5.5. Miscellaneous Cost

When operating at full capacity, the annual spend for miscellaneous OPEX cost was estimated at US$62.25 Million per year. The breakdown of this cost for each plant and process is summarised in Table E-15. These costs were recommended by Tata Steel Consulting based on their internal database.

Miscellaneous expense primarily consists of various services required by the plant to support production operations. This includes services related to – logistics, engineering, analysis, infrastructure, HR, information, etc... The environmental clean-up related expense includes chemicals / reagents used in all water and waste treatment plant, cleaning, etc...

Table E-15: Miscellaneous Cost

		Misc. Works Expense	Misc. OPEX (incl. Environmental Cleanup)
Annual Cost		Year 4 to 25	
100:Coke Production	US$ Million/y	9.801	3.703
200: Sinter Production	US$ Million/y	3.206	1.603
300 & 400: Iron making	US$ Million/y	10.403	1.300
500 & 600: Steel making	US$ Million/y	10.738	2.844
700: Continuous Casting	US$ Million/y	5.905	0.956
800 & 900: Reheating and HRM	US$ Million/y	7.747	1.443
1000: Lime Production	US$ Million/y	2.598	-
Annual Cost (US$ Million/y)		**50.398**	**11.849**

5.6. Other O&M Cost

5.6.1. Slag Processing Fee

The annual slag processing fee of the steel mill, when operating at full capacity, was estimated at US$ 3.58 Million per year.

This consists of the cost of processing the de-S, BOS (LD Slag) and SM (Ladle) Slag. The cost was estimated based on a unit price of US$ 5.89 per tonne of slag processed. The breakdown of the cost is presented below.

Table E-16: Annual Slag Processing Cost

		HM Spillage & De-S Slag	BOS Slag	SM Slag
UNIT No.		**400**	**500**	**600**
Annual Tonnage		**Year 4 to 25**		
Slag Processing Fee	$/tonne	5.89		
Total Tonnage	Tonnes/y	84,235	488,920	34,412
Total Processing Cost (US$ Million/y)		**0.496**	**2.880**	**0.203**

5.6.2. On-Site Haulage Fee

The on-site haulage cost primarily consists of the delivery of recycled materials to the Sinter Production (UNIT 200) and Steelmaking Plant (UNIT 500). The haulage fee for any materials delivered to the Sinter Plant is charged to the producers of the materials, while the fee for the delivery of the internal scrap is charged to the Steelmaking Plant. The annual haulage cost was estimated at US$ 0.27 Million per year. The breakdown of this cost is presented in Table E-17.

Table E-17: Annual On-Site Haulage Cost

Materials	From	To	Annual Tonnage (Tonnes/y)	Site Haulage Cost US$ ('000) per y	Cost Debit to Unit No.
BF Undersize Screens (excl. coke)	Blast Furnace	Sinter Plant	62,630	19.414	300/400
Reclaimed Coke	Blast Furnace	Sinter Plant	28,165	8.730	300/400
BF Dust	Blast Furnace	Sinter Plant	59,531	18.453	300/400
HM Spillage & de-Slag	HM Desulphurization	Sinter Plant	31,167	9.661	300/400
BOS Dust & Sludge	BOS Furnace	Sinter Plant	129,700	40.204	500/600
BOS Slag (LD Slag)	BOS Furnace	Sinter Plant	136,893	42.434	500/600
Mill Scales	Continuous Casting	Sinter Plant	36,772	11.399	700
Mill Scales	Reheating & HRM	Sinter Plant	59,387	18.409	800/900
Scrap (Internal)	Ladle Metallurgy	BOS Steelmaking	43,233	13.401	500/600
Scrap (Internal)	Continuous Casting	BOS Steelmaking	108,631	33.673	700
Scrap (Internal)	Reheating & HRM	BOS Steelmaking	168,421	52.207	800/900
Total			543,294	US$ 267.984	

5.6.3. Disposal and Landfill Cost

The annual disposal cost of the steel mill, when operating at full capacity, was estimated at US$ 4.34 Million per year. The breakdown of this cost is presented in Table E-18. This cost was estimated based on unit cost for tipping fee, haulage fee and landfill tax.

Table E-18: Annual Disposal and Landfill Cost

		BF Sludge	HM Spillage & De-S Slag	BOS Slag	SM Slag
UNIT No.		**300**	**300**	**500**	**600**
Disposal / Tipping Fees					
Slag Quench, Dig & Tip	$/tonne	0.00	1.55	1.55	1.55
Landfill Tax	$/tonne	20.00	3.87	3.87	86.79
Total Disposal Fees	$/tonne	20.00	5.42	5.42	88.34
Total Tonnage	Tonnes/y	15,875	53,068	127,124	34,412
Total Disposal Cost (US$ Million/y)		**0.318**	**0.288**	**0.690**	**3.040**

5.7. SUMMARY OF RESULTS

Table E-19 presents a summary of the annual O&M cost of the "REFERENCE" integrated steel mill without CO_2 capture (Base Case).

Table E-19: Summary of Results – Annual O&M Cost
REFERENCE Integrated Steel Mill without CO_2 Capture (Base Case)

Cost Item	Cost Breakdown (US$ Million/y)	Annual OPEX (US$ Million/y)
Fixed O&M Cost		**422.717**
Maintenance	141.996	
Direct Labour	204.581	
Indirect Labour	76.140	
Variable O&M Cost		**1288.650**
Fuel and Reductant	483.938	
Iron Ore (Fines, Lumps and Pellets)	492.054	
Purchased Scrap and Ferroalloys	218.228	
Fluxes	44.650	
Consumables & Other Utilities	49.781	
Miscellaneous OPEX Cost		**62.247**
Miscellaneous Works Expense	50.398	
Other OPEX (including environmental clean-up)	11.849	
Other O&M Cost		**8.181**
Slag Processing	3.578	
On-Site Haulage	0.268	
Disposal and Landfill	4.335	
	Annual O&M Cost (US$ Million/y)	**1,781.795**

6. ANNUAL REVENUES FROM SALE OF BY-PRODUCTS

This section summarises the annual revenue gained by the sale of by-products outside the battery limit of the REFERENCE Integrated Steel Mill (Base Case). In the cost model developed and presented by Tata Steel Consulting, it was assumed that:

- All by-products are sold at fixed price (as shown in Table E-1)
- All sale of these by-products are credited to the producer

The study assumed that only the following by-products were sold from the REFERENCE steel mill:

- Coke By-Products (Crude tar, Benzole, Sulphur)
- Granulated BF Slag
- BOS Slag
- Argon

The study did not include sale of other intermediate products of the steel mill or any sale of internally produced energy. It should be noted that steel mills usually sella significant variety of by-products, intermediate products or energy depending on their configuration or production capacity.

6.1. COKE BY-PRODUCTS

When operating at full capacity, the annual revenues earned by the steel mill from the sale of by-products of the coke production (UNIT 100) were US$ 21.42 Million per year. The breakdown of this cost is presented in Table E-20.

Table E-20: Summary of the Annual Sale of Coke By-Products

		Crude Tar	Benzole	Sulphur
Price	**$/tonne**	**176.00**	**466.17**	**85.00**
ANNUAL PRODUCTION			**Year 4 to 25**	
100: Coke Production	Tonne/y	67,080	19,729	4,937
Annual Sale (US$ Million/y)		**11.806**	**9.197**	**0.420**

6.2. SLAG

The annual revenues gained from the sale of the BF and BOS slag was reported as US$ 18.23 Million per year. The breakdown of this sale is presented in Table E-21.

Table E-21: Summary of the Annual Sale of Slag

		Granulated BF Slag (UNIT 300)	BOS Slag (UNIT 500)
Price	**$/tonne**	**16.00**	**2.00**
ANNUAL PRODUCTION		**Year 4 to 25**	
	Tonne/y	1,111,252	224,903
Annual Sale (US$ Million/y)		**17.780**	**0.450**

6.3. ARGON

The annual sale of Liquid Argon from the air separation unit (UNIT 1100) was reported to provide annual revenue of US$ 14.02 Million per year. This is based on an annual sale of about 15,073,913 Nm^3 of Argon at a fixed price of US$ 0.9299 per Nm^3.

6.4. SUMMARY OF RESULTS

Table E-22 presents a summary of the annual revenues from the sale of by-products of the "REFERENCE" integrated steel mill without CO_2 capture (Base Case).

Table E-22: Summary of Results – Annual Revenues from the Sale of By-Products REFERENCE Integrated Steel Mill without CO_2 Capture (Base Case)

Cost Items	Sale Breakdown (US$ Million/y)	Annual Sale (US$ Million/y)
Coke By Products		**21.423**
Crude Tar	11.806	
Benzole	9.197	
Sulphur	0.420	
Slag		**18.230**
Granulated BF Slag	17.780	
BOS Slag	0.450	
Argon		**14.018**
	Annual Sale (US$ Million/y)	**53.670**

7. VALUES OF INTERNALLY TRADED BY-PRODUCTS

By-Products that are internally traded include:

- Recycled Materials
  - BF undersize (ex-BF screens)
  - Reclaimed coke (ex-BF screens)
  - BF dust
  - Hot metal spillage & de-S slag
  - BOS dust & sludge (LD dust & sludge)
  - BOS slag (LD slag)
  - Mill scales
  - Scrap (internally generated)
- Off-gases
  - Coke oven gas (COG)
  - Blast furnace gas (BFG)
  - Basic oxygen furnace gas (BOFG)
- Steam
- Industrial gases (internally used)
  - Nitrogen
  - Argon

This section summarises the value of the internally traded by-products.

The value of all internally traded by-products was determined by assuming a fixed price for these materials and also to include the on-site haulage fee if required (as presented in Section E5.6.2). Table E-23 present a summary of the prices assigned to these materials.

Table E-23: Summary of Key Price Inputs of Internally Traded By-Products
REFERENCE Integrated Steel Mill without CO_2 Capture (Base Case)

	Unit	Unit Price
Energy		
Coke Oven Gas	GJ	**$9.77**
Blast Furnace Gas	GJ	**$9.77**
BOF Gas	GJ	**$9.77**
Steam	Tonne	**$10.90**
Scrap		
Scrap - Internal Arising (@ 85% of purchased scrap price)	Tonne	**$193.80**
Others		
Nitrogen (Internally Used)	Nm^3	**$0.00**
Argon (Internally Used)	Nm^3	**$0.00**
BF Undersize and Reclaimed Coke	Tonne	**$30.00**
BF/BOS Sludges & Dusts, HM Spillage, De-S Slag, etc.	Tonne	**$30.00**
Mill Scales	Tonne	**$20.00**
Slag Processing	Tonne	**$5.89**
Site Haulage	Tonne	**$0.31**

7.1. Recycled Materials

Table E-24 summarized the value of the internally traded goods when operating at full capacity. These values are balanced by taking into account the on-site haulage fee as described in Section E5.6.2.

Table E-24: Summary of the Value of the Internally Traded By-Products (For Year 4 to 25)

From	Tonnage (Tonne/y)	Credit (US$ Million/y)	To	Tonnage (Tonne/y)	Debit (US$ Million/y)
Undersize (ex-BF Screens)	US$ 30.00	per tonne			
300/400: Iron Making	62,630	1.879	200: Sinter Plant	62,630	1.879
- Site Haulage Fees		-0.019			
Total		**1.859**			**1.879**
Reclaimed Coke (ex-BF Screens)	US$ 30.00	per tonne			
300/400: Iron Making	28,165	0.845	200: Sinter Plant	28,165	0.845
- Site Haulage Fees		-0.009			
Total		**0.836**			**0.845**
BF Dust	US$ 30.00	per tonne			
300/400: Iron Making	59,531	1.786	200: Sinter Plant	59,531	1.786
- Site Haulage Fees		-0.018			
Total		**1.767**			**1.786**
HM Spillage & De-S Slag	US$ 30.00	per tonne			
300/400: Iron Making	31,167	0.935	200: Sinter Plant	31,167	0.935
- Site Haulage Fees		-0.010			
Total		**0.925**			**0.935**
BOS Dust & Sludge	US$ 30.00	per tonne			
500/600: Steelmaking	129,700	3.891	200: Sinter Plant	129,700	3.891
- Site Haulage Fees		-0.040			
Total		**3.851**			**3.891**
BOS Slag (LD Slag)	US$ 5.89	per tonne			
500/600: Steelmaking	136,893	4.107	200: Sinter Plant	136,893	4.107
- Site Haulage Fees		-0.042			
Total		**4.064**			**4.107**
Mill Scales	US$ 20.00	per tonne			
700: Continuous Casting	36,772	0.735	200: Sinter Plant	96,159	1.923
800/900: Reheating & Rolling	59,387	1.188			
- Site Haulage Fees		-0.030			
Total		**1.893**			**1.923**
Scrap (Internal Arising)	**US$ 193.00**	**per tonne**			
600: Ladle Metallurgy	43,233	8.379	500/600: Steelmaking	320,285	62.071
700: Continuous Casting	108,631	21.053			
800 & 900: Reheating & Rolling	168,421	32.640			
- Site Haulage Fees		-0.099			
Total		**61.972**			**62.071**
Total Credit (US$ Million/y)	**77.169**		**Total Debit (US$ Million/y)**	**77.437**	

7.2. Off-Gases

Table E-25 summarizes the value of the internally traded off-gases (fuel gases – COG, BFG & BOFG) when operating at full capacity.

Table E-25: Summary of Internally Traded Fuel (For Year 4 to 25)

From	Energy Export (GJ/y)	Credit (US$ Million/y)	To	Energy Import (GJ/y)	Debit (US$ Million/y)
Coke Oven Gas (COG)	**US$ 9.77**	**per GJ**			
100: Coke Production	9,240,413	90.279	200: Sinter Production	324,526	3.171
			300: Iron Making (Hot Stoves)	499,108	4.876
			1300: Iron Making (Ancillary Units)	258,427	2.525
			600: Ladle Metallurgy	928,613	9.073
			700: Continuous Casting	78,437	0.766
			800: Reheating Furnace	5,894,737	57.592
			1000: Lime Production	1,256,566	12.277
Total		**90.279**			**90.279**
Blast Furnace Gas (BFG)	**US$ 9.77**	**per GJ**			
100: Iron Making	14,263,072	139.350	100: Coke Production	2,357,936	23.037
			1200: Power Plant	11,905,137	116.313
Total		**139.350**			**139.350**
Basic Oxygen Furnace Gas (BOFG)	**US$ 9.77**	**per GJ**			
500: Steelmaking	2,638,853	25.782	1200: Power Plant	2,638,853	25.782
Total		**25.782**			**25.782**
Total (US$ Million/y)		**255.411**	**Total (US$ Million/y)**		**255.411**

***Ancillary unit including PCI Coal drying, torpedo car & ladle heating**

7.3. Steam

Table E-26 summarized the value of the internally traded steam (produced from the Steelmaking facility @ 9 bar abs. and 175°C) when operating at full capacity.

Table E-26: Summary of Internally Produced and Consumed Steam (For Year 4 to 25)

From	Tonnage (GJ/y)	Credit (US$ Million/y)	To	Tonnage (GJ/y)	Debit (US$ Million/y)
Steam (9 bar_a / 175°C)	US$ 3.93	per GJ			
500/600: Steelmaking	846,756	3.328	100: Coke Production	678,378	2.666
			300/400: Iron Making	87,556	0.344
			1200: Oxygen Plant	80,821	0.318
Total (US$ Million/y)		**3.328**	**Total (US$ Million/y)**		**3.328**

7.4. Industrial Gases (Internally Used)

Industrial gases such as argon and nitrogen are consumed internally by the steel mill. These gases are primarily used in the blast furnace, hot metal desulphurization, BOS furnace, ladle metallurgy and continuous casting. Consumption of these gases by the different processes is illustrated in Figure E-3. The value of the Nitrogen and Argon used internally are assumed to be zero ($0.00); as the value of these gases are accounted for or included in the cost of oxygen production.

8. VALUE OF INTERNALLY TRADED INTERMEDIATE PRODUCTS

Various processes as defined by the boundary limit of the reference integrated steel mill produce their own intermediate products that are used internally by other processes (also within the boundary of the integrated steel mill).

As illustrated in the cost model developed by Tata Consulting (See Figure E-1), the specific direct cost (i.e. cost per unit product) of producing these intermediate products becomes the price of the intermediate products debited to the users of the product. The cost of any intermediate products produced in excess (i.e. to adjust for system losses, buffer requirements, etc...) should be distributed to all users of the product weighted according to their levels of their utilisation.

Table E-27 summarises the main intermediate products ("internally produced raw materials") produced by the major processes incorporated with the boundary limits of the integrated steel mill.

Table E-27: Main Intermediate Products of the Steel Mill

Unit No.	Major Processes	Intermediate Product(s)
100	Coke Production	Coke & Coke Breeze
200	Sinter Production	Sinter
300 / 400 / 1300	Iron Making (incl. Hot Metal Desulphurization & Ancillary Units*)	Hot Metal
500 / 600	Steel Making (incl. Ladle Metallurgy)	Liquid Steel
700	Continuous Casting	Slab
1000	Lime Production	Lime
1100	Oxygen Production	Oxygen
1200	Power Plant	Electricity

***Ancillary unit including PCI coal drying, torpedo car & ladle heating**

This section summarises the components of the direct cost of producing these intermediate products. This section also summarises the balance of trades between the different unit processes.

8.1. UNIT 100: Coke Production

The cost accounting for the coke production (i.e. cost boundary) includes the operation of the 3 batteries of coke ovens (each having 48 ovens). Additionally, the cost estimates also incorporate the cost of operating the coking by-product plants (producing Coal Tar, Benzole and Sulphur), and waste water treatment plant.

At full capacity, the coke plant is producing 1,630,519 t/y of lump coke and coke breeze. The annual operating cost of the coke plant was estimated at US$ 338.79 Million per year. The lump coke is sold to the Iron Making Plant (UNIT 300/400); whilst the coke breeze is sold to Sinter Plant (UNIT 200). Both the coke and coke breeze are sold internally to the users at US$207.78 per tonne coke.

Table E-28 summarises the components of the annual operating cost of the coke production.

8.2. UNIT 200: Sinter Production

The cost accounting for the sinter production includes the operation of the raw materials and recycled materials handling facilities, a sinter strand (with 410m^2 working area), flue gas cleaning, sinter cooling, crushing and screening, and off-gas cleaning.

The annual production of the sinter is reported as 4,445,559 t/y at full capacity. The annual operating cost of the sinter plant was estimated at US$ 427.40 Million per year. The sinter produced by the plant is sold to the Iron Making Plant (UNIT 300) at US$ 96.14 per tonne sinter.

Table E-29 summarises the components of the annual operating cost of the sinter production.

8.3. UNIT 300/400: Iron Making (including Hot Metal Desulphurisation)

The cost accounting for the hot metal production comprises the operation of the 2 blast furnaces (each with hearth diameter of 11m and working volume of 2750m^3), hot stoves (3 stoves per BF), main air compressors (1 unit per BF), raw material handling (i.e. conveyors, bell less top feeding system, etc...), blast furnace gas cleaning, slag granulation plant, and 2 stations of hot metal desulphurisation units. Additionally, the cost of operating the Ancillary Unit - PCI coal drying, torpedo cars and ladles heating used in hot metal transport (ancillary) – were also included.

The annual operating cost of the hot metal production was calculated as US$ 1,007.28 Million per year. When operating at full capacity, the annual hot metal production was estimated at 3,894,263t/y. These were sold directly to the Steelmaking Plant (UNIT 500) at US$258.66 per tonne of hot metal.

Table E-30 summarises the components of the annual operating cost of the hot metal production when operating at full capacity.

8.4. UNIT 500/600: Steel Making (including Ladle Metallurgy)

The cost accounting for the liquid steel production consists of the operation of the 2 basic oxygen furnaces (each having 220 tonnes capacity operating at ~45-50 per cycle and availability of ~90%). The accounting of the cost also includes the operation of the BOFG gas recovery hoods, waste heat recovery boilers, BOFG wet gas cleaning equipment, slag processing facility, and 2 stations of ladle metallurgy.

The annual operating cost of the liquid steel production was calculated as US$ 1,418.16 Million per year. When operating at full capacity, the annual liquid steel production was estimated at 4,345,228 t/y. These were sold directly to the Steelmaking Plant (UNIT 500/600) at US$ 326.37 per tonne liquid steel.

Table E-31 summarises the components of the annual operating cost of the liquid steel production when operating at full capacity.

8.5. UNIT 700: Continuous Casting

The cost accounting for the slab production consists of the operation of the 2 lines of twin strand continuous slab casting (operating on an availability of > 90%).

The annual operating cost of the slab production was calculated as US$ 1,474.16 Million per year. When operating at full capacity, the annual liquid steel production was estimated at 4,210,526 t/y. This was sold directly to the Steelmaking Plant (UNIT 500/600) at US$ 350.11 per tonne slab.

Table E-32 summarises the components of the annual operating cost of slab production when operating at full capacity.

8.6. UNIT 1000: Lime Plant

The cost accounting for the lime production consists of the operation of the 2 trains of PFR kiln – each having a full production capacity of 600 tonnes per day.

The annual operating cost of the lime production was calculated as US$ 34.26 Million per year. The annual lime production was calculated at 346,412 t/y. This was sold directly to the Sinter Plant (UNIT 200) and Steelmaking Plant (UNIT 500/600) at US$ 98.91 per tonne lime.

Table E-33 summarised the components of the annual operating cost of lime production when operating at required capacity.

8.7. UNIT 1100: Air Separation Unit (Oxygen Plant)

The cost accounting for the oxygen production consists of the operation of a single train of ASU with a production capacity of 1900 tonnes oxygen per day.

The annual oxygen production was reported as 485,643,965 Nm^3/y. The annual operating cost of the air separation unit was calculated as US$ 26.31 Million per year.

The following industrial gases were delivered to the following facilities:

(Nm^3 @ 273K & 1 Bar)	Oxygen (Nm^3/y)	Nitrogen (Nm^3/y)	Argon (Nm^3/y)
Unit 300/400: Iron Making	190,092,062	20,415,709	-
Unit 500/600: Steelmaking	232,185,679	1,310,521	3,130,614
Unit 700: Continuous Casting	8,690,457	-	434,523
Unit 900: Hot Rolling Mill	10,526,316	-	-
Excess Production	44,149,451	-	-
Sale	-	-	15,073,913

The actual specific production cost for oxygen was calculated at $0.05417 per Nm^3. However, this was sold to the users at an adjusted price of $0.05958 per Nm^3 which accounts for the cost of excess production of oxygen to cover the demand buffer requirements and system losses.

Liquid Argon is sold externally at a price of \$0.9299 per Nm^3, whilst nitrogen and argon used internally by the integrated steel mill are sold at zero value (as the costs of nitrogen and argon for internal use were included in the cost of oxygen production).

Table E-34 summarises the components of the annual operating cost of oxygen production when operating at required capacity.

8.8. UNIT 1200: Power Plant

The cost accounting for the electricity production consists of the operation of a single power plant having a net output capacity of ~215 MWe and with a load factor of 85%.

The annual electricity production was reported as 1,600,463 MWh/y. The annual operating cost of the power plant was calculated as US\$ 193.98 Million per year.

The table below summarises the annual electricity consumption of the different processes:

Consumers	Unit No.		Annual Electricity Consumption
Coke Plant	100	MWh/y	57,068
Sinter Plant	200	MWh/y	142,258
Iron Making	300/400	MWh/y	392,206
Steelmaking	500/600	MWh/y	195,097
Continuous Casting	700	MWh/y	43,452
Reheating and Rolling	800/900	MWh/y	421,053
Lime Plant	1000	MWh/y	10,392
Air Separation Unit	1100	MWh/y	267,104
Ancillary Units	1300	MWh/y	19,272
Others (incl. off-site & system losses)	-	MWh/y	52,560

The actual specific production cost for electricity was calculated at \$0.1212 per kWh. However, this was sold to the users at an adjusted price of \$0.1253 per kWh which accounts for the cost of electricity used by other off-site facilities and system losses.

The cost of electricity used by the ancillary unit was charged to the iron making (UNIT 300/400) since this mostly covers the electricity used by the air compressors of the slag granulation plant and fans and blowers of the PCI coal drying facility.

Table E-35 summarises the components of the annual operating cost of electricity production when operating at required capacity.

Table E-28: Total Annual Operating Cost of the Coke Production (For Year 4 – 25)

Product ID	Coke & Coke Breeze	
Annual Production (Year 4 - 25)	1,630,519 t/y	407.63 kg/t HRC

Description	Annual Consumption		Annual Cost (US $)		Cost Reference
Raw Materials & Energy (Externally Sourced)					
Hard Coking Coal	1,257,292	t/y	$239.159	Million/y	Table E-9
Soft Coking Coal	838,194	t/y	$122.085	Million/y	Table E-9
Raw Materials & Energy (Internally Sourced)					
Coke Oven Gas (Export)	9,240,413	GJ/y	($90.279)	Million/y	Table E-35
Blast Furnace Gas	2,357,936	GJ/y	$23.037	Million/y	Table E-25
Electricity	57,068,151	kWh/y	$7.150	Million/y	Table E-25
Steam	244,578	t/y	$2.666	Million/y	Table E-26
Consumables & Other Utilities					
Raw Water	2,931,317	m^3/y	$0.333	Million/y	Table E-14
By-Product Sales					
Coal Tar	67,080	t/y	($11.806)	Million/y	Table E-20
Benzole (BTX)	19,729	t/y	($9.197)	Million/y	Table E-20
Sulphur	4,937	t/y	($0.420)	Million/y	Table E-20
Production Fixed Cost and Misc. Expense					
Direct Labour	240	Operation Staff	$22.560	Million/y	Table E-7
Annual Maintenance Expense	5.0%	CAPEX	$20.000	Million/y	Table E-6
Misc. Works Expense			$9.801	Million/y	Table E-15
Misc. OPEX (incl. environmental cleanup)			$3.703	Million/y	Table E-15

Total Annual Operating Cost (Direct Cost of Coke Production)	US$ 338.791 Million/y

Specific Cost (Internal Price of Coke)	$ 207.78 per tonne coke	$ 84.70 per tonne HRC

Table E-29: Total Annual Operating Cost of the Sinter Production (For Year 4 – 25)

Product ID	Sinter	
Annual Production (Year 4 - 25)	4,445,559 t/y	1,111.39 kg/t HRC

Description	Annual Consumption		Annual Cost (US $)		Cost Reference
Raw Materials & Energy (Externally Sourced)					
Iron Ore Fines (Brazil)	2,923,276	t/y	$234.488	Million/y	Table E-10
Iron Ore Fines (Australia)	352,202	t/y	$29.149	Million/y	Table E-10
Iron Ore Fines (Sweden)	246,541	t/y	$20.945	Million/y	Table E-10
Limestone	517,872	t/y	$12.040	Million/y	Table E-12
Quartzite	53,347	t/y	$0.960	Million/y	Table E-12
Olivine	90,349	t/y	$1.536	Million/y	Table E-12
Raw Materials & Energy (Internally Sourced)					
Lime	44,456	t/y	$4.397	Million/y	Table E-33
BF Undersize (excl. Reclaimed Coke)	62,630	t/y	$1.879	Million/y	Table E-24
BF Dust	59,531	t/y	$1.786	Million/y	Table E-24
HM Spillage & de-S Slag	31,167	t/y	$0.935	Million/y	Table E-24
BOS Dust & Sludge	129,700	t/y	$3.891	Million/y	Table E-24
BOS Slag (LD Slag)	136,893	t/y	$4.107	Million/y	Table E-24
Mill Scales	96,159	t/y	$1.923	Million/y	Table E-24
Coke Breeze	222,278	t/y	$46.185	Million/y	Table E-28
Reclaimed Coke (ex BF Screens)	28,165	t/y	$0.845	Million/y	Table E-24
Coke Oven Gas	324,526	GJ/y	$3.171	Million/y	Table E-25
Electricity	142,257,877	kWh/y	$17.824	Million/y	Table E-35
Consumables & Other Utilities					
Raw Water	1,324,616	m^3/y	$0.150	Million/y	Table E-14
Production Fixed Cost & Misc. Expense					
Direct Labour	270	Operation Staff	$25.380	Million/y	Table E-7
Annual Maintenance Expense	5.0%	CAPEX	$11.000	Million/y	Table E-6
Misc. Works Expense			$3.206	Million/y	Table E-15
Misc. OPEX (incl. environmental cleanup)			$1.603	Million/y	Table E-15

Total Annual Operating Cost (Direct Cost of Sinter Production)	US$ 427.399 Million/y

Specific Cost (Internal Price of Sinter)	$ 96.14 per tonne sinter	$ 106.85 per tonne HRC

Table E-30: Total Annual Operating Cost of the Hot Metal Production (For Year 4 – 25)

Product ID	Hot Metal (Desulphurised)	
Annual Production (Year 4 - 25)	3,894,263 t/y	973.57 kg/t HRC

Description	Annual Consumption		Annual Cost (US $)		Cost Reference
Raw Materials & Energy (Externally Sourced)					
PCI Coal	603,251	t/y	$89.491	Million/y	Table E-9
Lump Ore (Australian)	497,139	t/y	$51.069	Million/y	Table E-10
Pellets (Brazil)	1,396,178	t/y	$154.026	Million/y	Table E-10
Limestone	52,497	t/y	$1.220	Million/y	Table E-12
Quartzite	43,129	t/y	$0.776	Million/y	Table E-12
CaC2 Powder (Desulphurisation)	12,710	t/y	$10.168	Million/y	Table E-12
Raw Materials & Energy (Internally Sourced)					
Sinter	4,445,559	t/y	$427.407	Million/y	Table E-29
Oxygen (Nm^3/y @ 273K and 1 Bar)	190,092,062	Nm^3/y	$11.326	Million/y	Table E-34
BF Undersize (excl. reclaimed coke)	62,630	t/y	($1.859)	Million/y	Table E-24
BF Dust (Recycled)	59,531	t/y	($1.767)	Million/y	Table E-24
HM Spillage & De-Slag (Recycled)	31,167	t/y	($0.925)	Million/y	Table E-24
Lump Coke	1,408,241	t/y	$292.606	Million/y	Table E-28
Reclaimed Coke (ex BF Screens)	28,165	t/y	($0.836)	Million/y	Table E-24
Coke Oven Gas (for Hot Stove)	499,108	GJ/y	$4.876	Million/y	Table E-25
Coke Oven Gas (for Ancillary Users)	258,427	GJ/y	$2.525	Million/y	Table E-25
Blast Furnace Gas (Export)	14,263,072	GJ/y	($139.350)	Million/y	Table E-25
Electricity (Iron Making incl. HM Desulph.)	392,205,884	kWh/y	$49.140	Million/y	Table E-35
Electricity (Ancillary Users)	19,272,000	kWh/y	$2.415	Million/y	Table E-35
Steam	31,567	t/y	$0.344	Million/y	Table E-26
Consumables & Other Utilities					
Refractories (excl. BF refractory)	5,063	t/y	$4.151	Million/y	Table E-13
Raw Water	3,483,639	m^3/y	$0.396	Million/y	Table E-14
Other Variable O&M Cost					
Slag Processing Fee (De-S Slag)	84,235	m^3/y	$0.496	Million/y	Table E-16
BF Sludge Disposal Fee	15,875	m^3/y	$0.318	Million/y	Table E-16
Slag Disposal Fee (De-S Slag)	53,068	t/y	$0.288	Million/y	Table E-16
By Product Sales					
Granulated BF Slag	1,111,252	t/y	($17.780)	Million/y	Table E-21
Production Fixed Cost & Misc. Expense					
Direct Labour	321	Operation Staff	$30.174	Million/y	Table E-7
Annual Maintenance Expense	4.0%	CAPEX	$24.880	Million/y	Table E-6
Misc. Works Expense			$10.403	Million/y	Table E-15
Misc. OPEX (incl. environmental cleanup)			$1.300	Million/y	Table E-15

Total Annual Operating Cost (Direct Cost of Hot Metal Production)	US$ 1,007.268 Million/y

Specific Cost (Internal Price of Hot Metal)	$ 258.66 per tonne Hot Metal	$ 251.82 per tonne HRC

Table E-31: Total Annual Operating Cost of the Liquid Steel Production (For Year 4 – 25)

Product ID	Liquid Steel	
Annual Production (Year 4 - 25)	4,345,228 t/y	1,086.31 kg/t HRC

Description	Annual Consumption		Annual Cost (US $)		Cost Reference
Raw Materials & Energy (Externally Sourced)					
Pellets	21,544	t/y	$2.377	Million/y	Table E-10
Purchased Scrap	505,492	t/y	$115.252	Million/y	Table E-11
FeMnC	47,798	t/y	$67.068	Million/y	Table E-11
FeSi-75	13,036	t/y	$21.513	Million/y	Table E-11
DeOx Aluminium	6,518	t/y	$14.395	Million/y	Table E-11
Burnt Dolomite	47,164	t/y	$4.339	Million/y	Table E-12
Raw Materials & Energy (Internally Sourced)					
Hot Metal	3,894,263	t/y	$1,007.268	Million/y	Table E-30
Lime	301,956	t/y	$29.866	Million/y	Table E-33
Oxygen (Nm^3/y @ 273K)	232,185,679	Nm^3/y	$13.834	Million/y	Table E-34
Scrap (Internal)	320,285	t/y	$53.706	Million/y	Table E-24
LD Slag to Sinter Plant	136,893	t/y	($4.064)	Million/y	Table E-24
LD Dust & Sludge	129,700	t/y	($3.851)	Million/y	Table E-24
Coke Oven Gas (Ladle Metallurgy)	928,613	GJ/y	$9.073	Million/y	Table E-25
Basic Oxygen Furnace Gas (Export)	2,638,853	GJ/y	($25.782)	Million/y	Table E-25
Electricity (incl. Ladle Metallurgy)	195,097,244	kWh/y	$24.444	Million/y	Table E-35
Steam	305,283	t/y	($3.328)	Million/y	Table E-26
Consumables & Other Utilities					
Refractories (BOS furnace, Ladle vessels)	15,208	t/y	$12.881	Million/y	Table E-13
Electrodes	1,304	t/y	$5.289	Million/y	Section 5.4.2
Raw Water	1,673,679	m^3/y	$0.190	Million/y	Table E-14
Other Variable O&M Cost					
Slag Processing Fee (LD Slag)	488,920	t/y	$2.880	Million/y	Table E-16
Slag Processing Fee (Ladle Slag)	34,412	t/y	$0.203	Million/y	Table E-16
Disposal Fee (LD Slag)	127,124	t/y	$0.690	Million/y	Table E-18
Disposal Fee (Ladle Slag)	34,412	t/y	$3.040	Million/y	Table E-18
Consumables & Other Utilities					
LD Slag	224,903	t/y	($0.450)	Million/y	Table E-21
Production Fixed Cost & Misc. Expense					
Direct Labour	396	Operation Staff	$37.224	Million/y	Table E-7
Annual Maintenance Expense	5.0%	CAPEX	$22.950	Million/y	Table E-6
Misc. Works Expense			$10.738	Million/y	Table E-15
Misc. OPEX (incl. environmental cleanup)			$2.844	Million/y	Table E-15

Total Annual Operating Cost (Direct Cost of Liquid Steel Production)	US$ 1,424.589 Million/y

Specific Cost (Internal Price of Liquid Steel)	$ 327.85 per tonne Liquid Steel	$ 356.15 per tonne HRC

Table E-32: Total Annual Operating Cost of the Slab Production (For Year 4 – 25)

Product ID	Slab					
Annual Production (Year 4 - 25)	4,210,526 t/y			1,052.63 kg/t HRC		
Description	**Annual Consumption**		**Annual Cost (US $)**		**Cost Reference**	
Raw Materials & Energy (Internally Sourced)						
Liquid Steel	4,345,228	t/y	$1,424.589	Million/y	Table E-31	
Oxygen (Nm^3/y @ 273K and 1 Bar)	8,690,457	Nm^3/y	$0.518	Million/y	Table E-34	
Scrap (to BOS furnace)	108,631	t/y	($21.019)	Million/y	Table E-24	
Scale (to Sinter)	36,772	t/y	($0.724)	Million/y	Table E-24	
Coke Oven Gas	78,437	GJ/y	$0.766	Million/y	Table E-25	
Electricity	43,452,284	kWh/y	$5.444	Million/y	Table E-35	
Consumables & Other Utilities						
Refractories (Casters)	8,842	t/y	$5.571	Million/y	Table E-13	
Casting Powder	3,368,421	t/y	$2.257	Million/y	Section 5.4.3	
Raw Water	3,655,576	m^3/y	$0.415	Million/y	Table E-14	
Production Fixed Cost & Misc. Expense						
Direct Labour	360	Operation Staff	$33.840	Million/y	Table E-7	
Annual Maintenance Expense	8.0%	CAPEX	$15.636	Million/y	Table E-6	
Misc. Works Expense			$5.905	Million/y	Table E-15	
Misc. OPEX (incl. environmental cleanup)			$0.956	Million/y	Table E-15	
Total Annual Operating Cost (Direct Cost of Slab Production)			**US$ 1,474.154 Million/y**			
Specific Cost (Internal Price of Slab)	**$ 350.11 per tonne Slab**			**$ 368.54 per tonne HRC**		

Table E-33: Total Annual Operating Cost of the Lime Production (For Year 4 – 25)

Product ID	Lime				
Annual Production (Year 4 - 25)	346,412 t/y			86.60 kg/t HRC	
Description	**Annual Consumption**		**Annual Cost (US $)**		**Cost Reference**
Raw Materials & Energy (Internally Sourced)					
Limestone	585,449	t/y	$13.611	Million/y	Table E-12
Raw Materials & Energy (Internally Sourced)					
Coke Oven Gas (Lime Kiln)	1,256,566	GJ/y	$12.277	Million/y	Table E-25
Electricity	10,392,357	kWh/y	$1.302	Million/y	Table E-35
Production Fixed Cost & Misc. Expense					
Direct Labour	34	Operation Staff	$3.196	Million/y	Table E-7
Annual Maintenance Expense	8.0%	CAPEX	$1.280	Million/y	Table E-6
Misc. Works Expense			$2.598	Million/y	Table E-15
Total Annual Operating Cost (Direct Cost of Lime Production)			**US$ 34.263 Million/y**		
Specific Cost (Internal Price of Lime)	**$ 98.91 per tonne Lime**			**$ 8.57 per tonne HRC**	

Table E-34: Total Annual Operating Cost of the Oxygen Production (For Year 4 – 25)

Product ID	Oxygen				
Annual Production (Year 4 - 25)	485,643,965 Nm3/y		121.41 Nm3/t HRC		
Description	**Annual Consumption**		**Annual Cost (US $)**		**Cost Reference**
Raw Materials & Energy (Internally Sourced)					
Electricity	267,104,181	kWh/y	$33.466	Million/y	Table E-35
Steam	29,139	GJ/y	$0.318	Million/y	Table E-25
By-Product Sales					
Argon (Nm^3/y @ 273K)*	15,073,913	Nm^3/y	($14.018)	Million/y	Table E-22
Production Fixed Cost & Misc. Expense					
Direct Labour	35	Operation Staff	$3.290	Million/y	Table E-7
Annual Maintenance Expense	2.5%	CAPEX	$3.250	Million/y	Table E-6
Total Operating Cost (Direct Cost of Oxygen Production)			**US$ 26.306 Million/y**		
Specific Cost of Oxygen)	**$ 0.05417 per Nm3 Oxygen**		**$ 6.58 per tonne HRC**		
Adjusted Internal Price of Oxygen**	**$ 0.05958 per Nm3 Oxygen**		-		

*** Sold as Liquid Argon (>99.9% purity)**
**** Adjustment to price is to account for the buffer requirements and system losses**

Table E-35: Total Annual Operating Cost of the Electricity Production (For Year 4 – 25)

Product ID	Electricity				
Annual Production (Year 4 - 25)	1,600,463 MWh/y		400.12 MWh/t HRC		
Description	**Annual Consumption**		**Annual Cost (US $)**		**Cost Reference**
Raw Materials & Energy (Internally Sourced)					
Natural Gas	3,398,486	GJ/y	$33.203	Million/y	Section 5.2.2
Raw Materials & Energy (Internally Sourced)					
Blast Furnace Gas	11,905,137	GJ/y	$116.313	Million/y	Table E-25
Basic Oxygen Furnace Gas	2,638,853	GJ/y	$25.782	Million/y	Table E-25
Consumables and Other Utilities					
Chemicals and Consumables	4.924	$/MWh	$7.880	Million/y	Section 5.4.5
Production Fixed Cost & Misc. Expense					
Direct Labour	40	Operation Staff	$3.760	Million/y	Table E-7
Annual Maintenance Expense	2.5%	CAPEX	$7.000	Million/y	Table E-6
Total Annual Operating Cost (Direct Cost of Electricity Production)			**US$ 193.938 Million/y**		
Specific Cost (Internal Price of Electricity)	**$ 0.1212 per kWh Electricity**		**$ 48.48 per tonne HRC**		
Adjusted Internal Price of Electricity	**$ 0.1253 per kWh Electricity**		-		

*** Adjustment to price is to account for the electricity used by the off-sites and system losses**

8.9. Summary of Results

Table E-36 presents the summary of the annual production cost of the different producers of the intermediate products and their creditors (customers of the intermediate products).

Table E-36: Annual Operating Cost of Each Processes and the Transfer Value to their Users

From / Intermediate Products	Trade Volume	Production Cost (US$ Million/y)	Delivered To (Customers)	Trade Volume	Trade Value (US$ Million/y)
100: Coke Production	**$ 207.78 per tonne coke**				
Lump Coke (t/y) – to Iron Making	1,408,241	292.606	300/400: Iron Making	1,408,241	292.606
Coke Breeze (t/y) – to Sinter Plant	222,278	46.185	200: Sinter Plant	222,278	46.185
Total		**$338.791**			**$338.791**
200: Sinter Production	**$ 96.14 per tonne Sinter**				
Sinter (t/y)	4,445,559	427.399	300/400: Iron Making	4,445,559	427.399
Total		**$427.399**			**$427.399**
300/400: Iron Making	**$ 258.66 per tonne Hot Metal**				
Hot Metal (t/y)	3,894,263	1007.268	500/600: Steelmaking	3,894,263	1007.268
Total		**$1,007.268**			**$1,007.268**
500/600: Steelmaking	**$ 327.85 per tonne Liquid Steel**				
Liquid Steel (t/y)	4,345,228	1424.589	700: Continuous Casting	4,345,228	1424.589
Total		**$1,424.597**			**$1,424.589**
700: Continuous Casting	**$ 350.11 per tonne Slab**				
Slab (t/y)	4,210,526	1,474.154	800/900: Reheating and Rolling	4,210,526	1474.154
Total		**$1,474.154**			**$1,474.154**
1000: Lime Production	**$ 98.91 per tonne Lime**				
Lime (t/y)	346,412	34.263	200: Sinter Plant	44,456	4.397
			500/600: Steelmaking	301,956	29.866
Total		**$34.263**			**$34.263**
1100: Air Separation Unit	**$ 0.0596 per Nm3 Oxygen**				
Oxygen (Nm^3/y @ 273K)	441,494,513	26.306	300/400: Iron Making	190,092,062	11.326
	44,149,451	-	500/600: Steelmaking	232,185,679	13.834
			700: Continuous Casting	8,690,457	0.518
			800/900: Reheating and Rolling	10,526,316	0.627
Total		**$26.306**			**$26.306**
1200: Power Plant	**$ 125.3 per MWh Electricity**				
Electricity (MWh/y)	1,547,903	193.938	100: Coke Production	57,068	7.150
	52,560	-	200: Sinter Plant	142,258	17.824
			300/400: Iron Making	392,206	49.140
			500/600: Steelmaking	195,097	24.444
			700: Continuous Casting	43,452	5.444
			800/900: Reheating and Rolling	421,053	52.754
			1000: Lime Production	10,392	1.302
			1100: Air Separation Unit	267,104	33.466
			1300: Ancillary (Unit: 300/400)	19,272	2.415
Total		**$193.938**			**$193.938**

9. ANNUAL OPERATING COST OF HOT ROLLED COIL PRODUCTION

The annual operating cost of producing 4 million tonnes of hot rolled coil was estimated at $1,651.99 million per year. This includes the operation cost of the 4x reheating furnaces (walking beam type with recuperators), 2 lines of hot rolling mills (consisting of 2x reversing mills, 6x finishing mills and 3x coilers).

Table E-37 summarises the components of the annual operating cost of hot rolled coil production when operating at required capacity**.**

Table E-37: Total Annual Operating Cost of the Hot Rolled Coil Production (For Year 4 – 25)

Product ID	Hot Rolled Coil				
Annual Production (Year 4 - 25)	4,000,000 t/y		1,000.00 kg/t HRC		
Description	**Annual Consumption**		**Annual Cost (US $)**		**Cost Reference**
Raw Materials & Energy (Internally Sourced)					
Slab	4,210,526	t/y	$1,474.154	Million/y	Table E-32
Oxygen (Nm^3/y @ 273K and 1 Bar)	10,526,316	Nm^3/y	$0.627	Million/y	Table E-34
Scrap (to Steelmaking)	168,421	t/y	($32.588)	Million/y	Table E-24
Mill Scales (to Sinter)	59,387	t/y	($1.169)	Million/y	Table E-24
Coke Oven Gas (Reheating Furnace)	5,894,737	GJ/y	$57.592	Million/y	Table E-25
Electricity (Reheating & Rolling Mills)	421,052,632	kWh/y	$52.754	Million/y	Table E-35
Consumables & Other Utilities					
Works and Back Up Rolls	1	Unit	$9.000	Million/y	Table E-13
Banding	1	Unit	$0.360	Million/y	Section 5.4.3
Raw Water	8,000,000	m^3/y	$0.908	Million/y	Table E-14
Production Fixed Cost & Misc. Expense					
Direct Labour	480	personnel	$45.157	Million/y	Table E-7
Annual Maintenance Expense	8.0%	CAPEX	$36.000	Million/y	Table E-6
Misc. Works Expense			$7.747	Million/y	Table E-15
Other OPEX (incl. environmental cleanup)			$1.443	Million/y	Table E-15
Total Annual Operating Cost (Direct Cost of Hot Rolled Coil Production)			US$ 1,651.985 Million/y		
Specific Cost (Internal Price of Hot Rolled Coil)	**$ 413.00 per tonne Hot Rolled Coil**		-		

10. ANNUAL OPERATING COST OF THE REFERENCE INTEGRATED STEEL MILL WITHOUT CO_2 CAPTURE

The overall annual operating cost of the "REFERENCE" integrated steel mill without CO_2 capture could be calculated by two methods.

- The first method is based on the difference between the overall annual O&M cost (as presented in Table E-19), and the revenues obtained from the sale of by-products (as presented in Table E-22).
- The second method is based on the sum of the annual production cost of the hot rolled coil (which represents the direct cost of the hot rolled coil production as presented in Table E-37), and the indirect cost of the steel mill (which mainly consists of the indirect labour cost as presented in Table E-8).

Table E-38 summarises the results of the calculation of the annual operating cost of the "REFERENCE" Integrated Steel Mill using the two different accounting methods for the assumed economic life of the steel mill (i.e. 25 years of operation).

Table E-38: Annual Operating Cost of the "Reference" Integrated Steel Mill without CO_2 Capture

Annual Operating Cost	Operating Period					Cost Reference (Year 4-25)
	1	2	3	4	5 … 25	
Annual HRC Production (t/y)	**2,000,000**	**3,000,000**	**3,600,000**	**4,000,000**	**4,000,000**	
Accounting Method 01						
Annual O&M Cost	1001.66	1391.73	1625.77	1781.80	1781.80	Table E-19
Revenues (By-Product Sales)	(26.84)	(40.25)	(48.30)	(53.67)	(53.67)	Table E-22
Total (US$ Million/y)	**974.83**	**1351.48**	**1577.47**	**1728.13**	**1728.13**	
Accounting Method 02						
Direct Cost of HRC Production	912.32	1282.15	1504.06	1651.99	1651.99	Table E-37
Indirect Cost of Steel Mill	62.51	69.33	73.41	76.14	76.14	Table E-8
Total (US$ Million/y)	**974.83**	**1351.48**	**1577.47**	**1728.13**	**1728.13**	

It could be noted that the annual operating cost of the steel mill for Year 1 to 3 is not proportional to the operating cost of the steel mill when operating at full capacity of 4 million tonnes per year. This is primarily due to the assumed fixed cost components – mainly the maintenance cost and admin staff; and higher specific cost of electricity ($/kWh) during commissioning phase of the steel mill.

10.1. Cost Base of the Major Plants and Processes (Distribution of Annual O&M Cost and Sale Revenues of By-Products)

Based on Accounting Method 01 (Table E-38), Figure E-5 illustrates the breakdown of the annual O&M cost and by-products sales revenues of the different major plants and processes (excluding internal cost of raw materials).

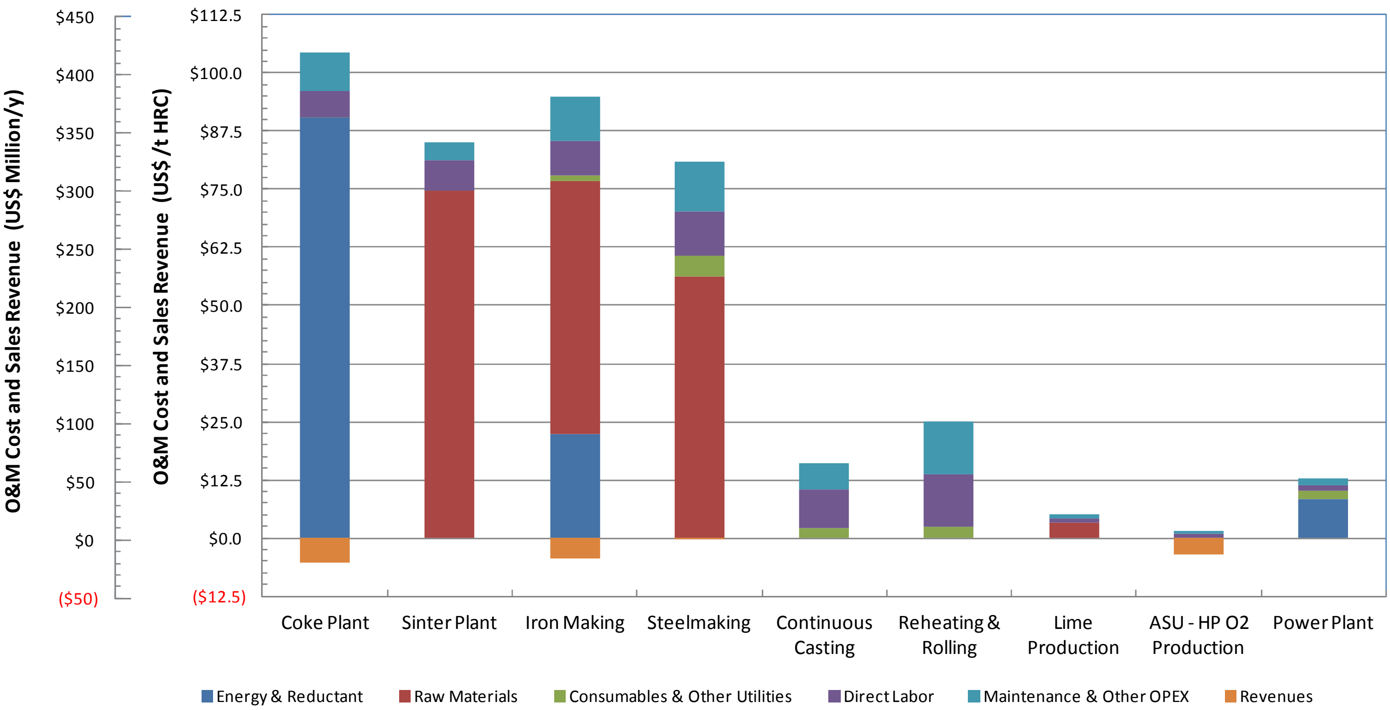

Figure E-5: Cost Base of the Major Processes of the "REFERENCE" Steel Mill (excl. Indirect Labour Cost)

It should be noted that the cost presented in the figure does not include the indirect labour cost of the "REFERENCE" steel mill. This figure should also demonstrate the cost base of each plants and processes by presenting the cost of externally sourced raw materials, energy and reductants, consumables and other utilities used by each business units (major plants and processes).

The following could be referred to with regard to the calculation of the cost distribution as presented in Figure E-5:

- Energy and Reductants
    - Coking and PCI coal (Table E-9)
    - Natural Gas (Section E-5.2.2)
- Raw Materials
    - Iron Ore (Table E-10)
    - Purchased Scrap and Ferroalloys (Table E-11)
    - Fluxes (Table E-12)
- Consumables and Other Utilities (Section E-5.4)
- Direct Labour (Table E-7)
- Maintenance and Other OPEX
    - Annual Maintenance Cost (Table E-6)
    - Miscellaneous Cost (Section E-5.5)
    - Other O&M Cost (Section E-5.6)
- Revenues – Sale of By Products (Section E-6)

11. BREAK EVEN PRICE

The breakeven price of the hot rolled coil - ex-works (or levelised cost of HRC production) is calculated based on the discounted cash flow presented in Annex 1.

The breakeven price of the hot rolled coil produced from the "REFERENCE" Integrated Steel Mill without CO_2 capture producing 4 million tonnes per year was estimated at US$ 575.23 per tonne HRC. The breakdown of this price is presented in Figure E-6.

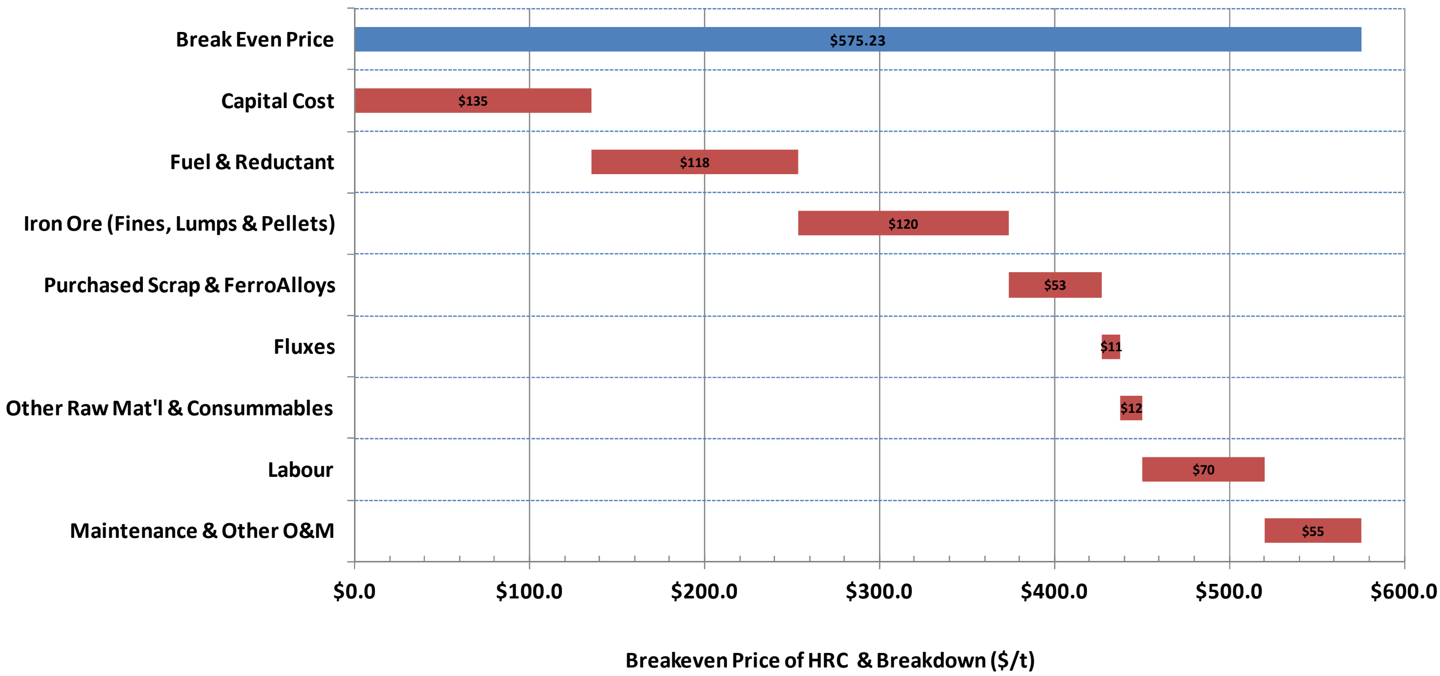

Figure E-6: Breakeven Price and Price Breakdown of Hot Rolled Coil (Ex-Works)

11.1. Simplified Profit and Loss Account

The simplified profit and loss account of the "REFERENCE" Integrated Steel Mill at breakeven price of the hot rolled coil (ex-works) is presented in Table E-39. This is to indicate the minimum annual profit (EBITDA) required to achieve break even of the operation of "REFERENCE" steel mill without CO_2 capture (i.e annual profit or loss needed to achieved NPV = 0 before any consideration of payment to interest, tax, depreciation and amortization).

11.2. Sensitivity Analysis

The sensitivity analysis to the breakeven price of the hot rolled coil was made by adjusting the key variables by +/-20% of the reported cost or price used by the base case. The results of the sensitivity analysis are presented in Table E-40.

Table E-39: Simplified Profit and Loss Account of the "REFERENCE" Integrated Steel Mill

	UNIT #	Amount ($'000)	Cost Reference
Sales Revenues			
Hot Rolled Coil (@ US$ 575.23 per tonne)	800/900	$ 2,300,934.15	Section E-11
Coke By-Products	100	21,422.91	Table E-22
Granulated Slag	300/400	17,780.03	Table E-22
LD Slag	500/600	449.81	Table E-22
Argon	1100	14,017.68	Table E-22
		$ 2,354,604.57	
Fixed Production Cost			
Annual Maintenance Cost		$ (141,996.10)	Table E-6
Direct Labour		(204,580.78)	Table E-7
Indirect Labour		(76,140.00)	Table E-8
		$ (422,716.88)	
Variable Production Cost			
Energy and Reductant		$ (483,937.74)	Table E-19
Iron Ore Products		(492,061.58)	Table E-19
Purchased Scrap & Ferroalloys		(218,228.11)	Table E-19
Fluxes		(44,649.89)	Table E-19
Consumable & Other Utilities		(49,780.77)	Table E-19
Miscellaneous Cost		(62,246.77)	Table E-19
Other OPEX		(8,181.34)	Table E-19
		$ (1,359,086.20)	
ANNUAL PROFIT/(LOSS) - EBITDA		$ 572,801.50	

Table E-40: Sensitivity Analysis – Breakeven Price of Hot Rolled Coil

Variable	Main Case				
	-20%	-10%	0%	+10%	+20%
Capital Expenditure	$549.08	$562.16	$575.23	$588.31	$601.39
Coking Coal	$559.88	$567.56	$575.23	$582.91	$590.59
PCI Coal	$571.56	$573.39	$575.23	$577.07	$578.91
Natural Gas	$573.58	$574.41	$575.23	$576.06	$576.89
Iron Ore Products	$554.94	$565.09	$575.23	$585.38	$595.52
Purchased Scrap	$569.42	$572.33	$575.23	$578.14	$581.05

12. IMPACT OF CO_2 EMISSIONS TRADING SCHEME

To illustrate the impact of the price of CO_2 Emissions Trading Scheme, nominal prices of $20, $40 and $60 per tonnes of CO_2 were incorporated in the discounted cash flow and the breakeven prices of the HRC, including the cost of CO_2 emissions, were calculated.

Table E-41 summarises the results of calculations of breakeven price including Direct CO_2 Emissions Cost. Table E-42 presents the annual direct CO_2 emissions from the different plants and processes. Table E-43 summarises the composition of the flue gases from the different major CO_2 emitters within the steel mill. Figure E-7 illustrates how the CO_2 emissions cost could impact the cost base of the different plants and processes within the integrated steel mill.

Table E-41: Sensitivity Analysis – Breakeven Price of Hot Rolled Coil

Variable	Main Case	CO_2 ETS Price ($/tonne CO_2)		
	$ 0.00	$20.00	$40.00	$60.00
Breakeven Price of HRC	$575.23	$617.08	$658.93	$700.77

Table E-42: Breakdown of the CO_2 Emissions Sources

UNIT	Source of CO_2 Emissions	Emissions (kg/t HRC)	Annual Emission (tonnes CO_2/y)	No. of Emission Points (i.e. Stacks)
100	Flue Gas – Coke Oven	**191.37**	**765,495**	**3**
100	Flare – Coke Oven	**3.30**	**13,196**	**1**
200	Flue Gas – Sinter Plant (incl. CO emissions as CO2)	**289.46**	**1,157,825**	**1**
300	Flue Gas – Hot Stoves	**415.19**	**1,660,769**	**2**
400/1300	HM Desulphurisation & Ancillaries (PCI Drying et. al.)	**7.76**	**31,042**	**5**
300	Flare – Blast Furnace	**19.73**	**78,931**	**2**
500/600	Flare (incl. losses) - BOF, Diffuse Emissions from SM	**51.02**	**204,089**	**2**
700	Diffuse Emissions – Continuous Casting	**0.80**	**3,188**	**1**
800	Flue Gas – Reheating Furnaces	**57.71**	**230,833**	**2**
900	Diffuse Emissions – Hot Rolling Mills	**0.04**	**179**	**2**
1000	Flue Gas – Lime Plant	**71.62**	**286,493**	**1**
1200	Flue Gas – Power Plant	**982.13**	**3,928,513**	**1**
1300	Ancillaries transport fuel emissions (trucks and rails)	**4.00**	**16,000**	**-**
	Total Emissions	**2094.14**	**8,376,554**	**23**

Table E-43: Composition of the Flue Gases from the Major CO_2 Emission Sources

Unit No.		100	200	300	800	1000	1200
Plant Area		Coke Production	Sinter Production	Hot Metal Production	Slab Reheating	Lime Production	Electricity Production
Product		Ramp Coke	Sinter	Hot Metal	Hot Rolled Coil	Lime	Electricity (kWh)
Emission Point		Underfire Heating	Sinter Plant	Hot Stoves	Reheating Furnaces	Lime Kilns	Power Plant
Specific Vol. Flow (wet)	Nm3/t HRC	687.59	2654.45	898.63	640.23	187.90	1892.51
Specific Vol. Flow (wet)	Nm3/t Product	1619.34	2388.41	905.71	640.23	2169.76	4.73[3]
Specific CO_2 Emission	kg/t HRC	191.37	289.46[2]	415.19	57.71	71.62	982.13
Gas Composition (wet basis)							
CO2	%v.	14.77	4.81	27.30	4.59	19.41	26.43
CO	%v.	-	0.74	-	-	-	-
O2	%v.	5.00	14.90	0.80	7.20	7.77	0.71
N2	%v.	69.47	72.65	65.52	71.86	60.24	65.88
SOx[1]	mg/Nm3	10	300	10	10	10	10
NOx[1]	mg/Nm3	280	200	60	500	30	60
Dust[1]	mg/Nm3	< 5	< 5	< 5	< 5	< 5	< 5
H2O	%v.	10.76	6.90	6.38	16.34	12.58	6.98

[1] Indicative value only – not calculated in the model.
[2] Excluding CO, the specific CO2 emission of the sinter plant is ~252 kg/t HRC
[3] Nm3/kWh

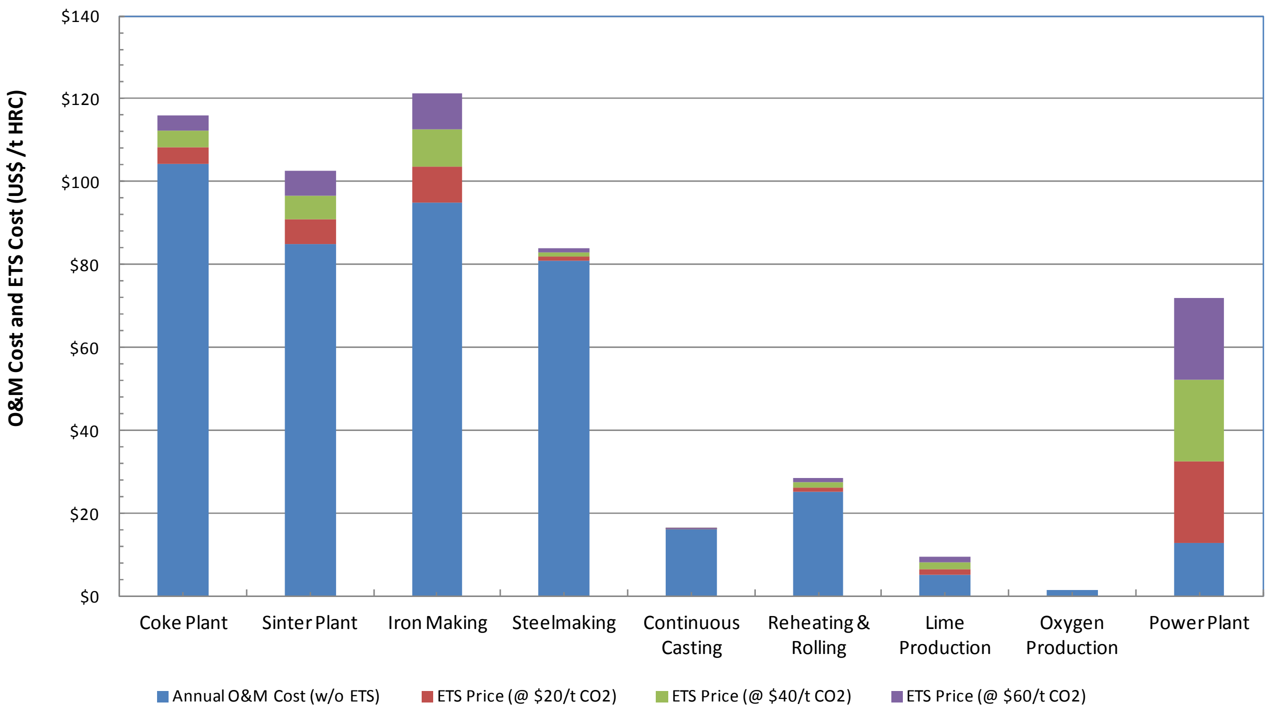

Figure E-7: Impact of the CO_2 ETS Price to the Cost Base of the Different Plants and Processes within the "REFERENCE" Integrated Steel Mill

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume I: Estimating the Cost of Steel Production from an Integrated Steel Mill (Reference Case)

<u>Section F</u>

Cost and Performance Considerations of the "REFERENCE" Steel Mill with Different Captive Power Plant Options

I N D E X

1. INTRODUCTION

This section of the report aims to demonstrate the impact to the cost and its specific CO_2 emissions of the HRC produced from the "REFERENCE" integrated steel mill with respect to the CHOICE of the Captive Power Plant selected for this study. This should form the basis for the evaluation of the CO_2 avoidance cost and looking at its sensitivity for steel mill without and with CO_2 capture. Four different cases based on the original "REFERENCE" Steel Mill using slightly different captive power plant options were evaluated to assess the effect on performance and economics. These scenarios include:

- *Base Case:*
  Nominal 215MWe power plant firing BFG, BOFG and NG with steam parameters of 120 bar_a, 512^oC. Net efficiency estimated at 32.1% LHV basis.

- *Case 1A:*
  Nominal 215MWe power plant firing BFG, BOFG and NG with steam parameters of 169 bar_a, 565^oC with single reheat at 565^oC. Net efficiency estimated at 37.0% LHV basis.

- *Case 1B:*
  Nominal 215MWe power plant integrated with the steel mill, firing BFG and BOFG with steam parameters of 169 bar_a, 565^oC with single reheat at 565^oC. Net efficiency estimated at 39.9% LHV basis.

- *Case 1C:*
  Nominal 200MWe combine cycle power plant firing BFG and BOFG. This is based on an E-class gas turbine firing low CV fuel, heat recovery steam generation (HRSG) with supplementary duct firing, and a triple pressure with reheat steam turbine. Net efficiency estimated at 42.2% LHV basis.

- *Case 1D:*
  Nominal 200MWe combine cycle power plant firing BFG and BOFG. This is based on an E-class gas turbine firing low CV fuel, heat recovery steam generation (HRSG), and a dual pressure with no reheat steam turbine. This configuration also includes an auxiliary boiler firing BOFG to provide extra steam to meet the electricity generation requirements. Net efficiency estimated at 41.9% LHV basis.

Previous sections of this report presented the performance and cost of the "REFERENCE" steel mill (i.e. **Base Case**) based on the utilisation of the steel mill's by-product gases (BFG & BOFG) and natural gas to produce steam in a boiler to drive a steam turbine to generate electricity. The net efficiency of the captive power plant of the original "REFERENCE" steel mill was estimated at 32.1%. The cost of steel produced was estimated at US$ 575.23 per tonne of Hot Rolled Coil. Using the results of the **Base Case** as reference point, a sensitivity analysis was undertaken to evaluate the cost and CO_2 emissions of the steel production with different captive power plant options.

It should be re-emphasised that a constraint of this study is that there will be no export or import of energy from the defined boundary of the "REFERENCE" steel mill. This is one of the extra-ordinary assumptions used in this study not representative of actual operating steel mills. However, this assumption simplifies the accounting allowing demonstration to the relationship between cost of steel produced and CO_2 emissions of the steel mill. It avoids the added complexity of accounting for the indirect CO_2 emissions due to energy export or import which occurs in reality.

2. CAPTIVE POWER PLANT OPTIONS

The process flow diagrams of the base case and the three different step-off cases are presented in Figures F-1 to F-3 and Figure F-6. This section of the report summarises the performance of the different captive power plant options evaluated.

2.1. Base Case: Power Plant with 32% Net Efficiency

Also described in Section D, the power plant utilises the BFG, BOFG and NG as fuel. There is no integration between the power plant and the steel mill. The power plant is equipped with a sub-critical boiler generating steam to drive the HP and LP steam turbines. The power plant condenser is based on a once through sea water cooling system. Table F-1 below summarises the performance of the power plant.

Table F-1: Performance of the Captive Power Plant (Base Case)

CAPTIVE POWER PLANT - BASE CASE		
Nominal Electricity Output (NET)	215	MWe
Load Factor	85	%
Fuel Input		
Blast Furnace Gas	377.5	MWth
Basic Oxygen Furnace Gas	83.7	MWth
Natural Gas	107.8	MWth
Total Thermal Input – (A)	**569.0**	**MWth**
Gross Electricity Output (Daily Average on Annual Basis) – (B)	**203.6**	**MWe**
Auxiliary Power	**10.8**	**MWe**
Fuel Delivery Auxiliary		
Boiler Auxiliary (Blowers, ID and FD Fans, et. al.)		
Cooling Water Pumps		
Boiler Feed Water Pumps and Dearators		
Net Power Output (Daily Average on Annual Basis) – (C)	**182.7**	**MWe**
Gross Electrical Efficiency (B/A *100%)	**35.8**	**%**
Net Electrical Efficiency (C/A *100%)	**32.1**	**%**

The performance of the power plant is evaluated based on the following parameters:

- Off-Gas (BFG & BOFG) feeding into the boiler at 461 MJ/s.
- Natural Gas feeding into the boiler at 108 MJ/s.
- HP steam turbine with steam parameter at 120 bar_a, 506^oC. (without steam reheat)
- LP steam turbine with steam parameter at 9 bar_a, 180^oC.
- Boiler feed water preheating at 120 bar_a, 10^oC and condensing pressure of 0.03 bar_a.
- Seawater is available at 12^oC. The temperature differential between in-coming and out-going seawater is assumed at 7^oC.

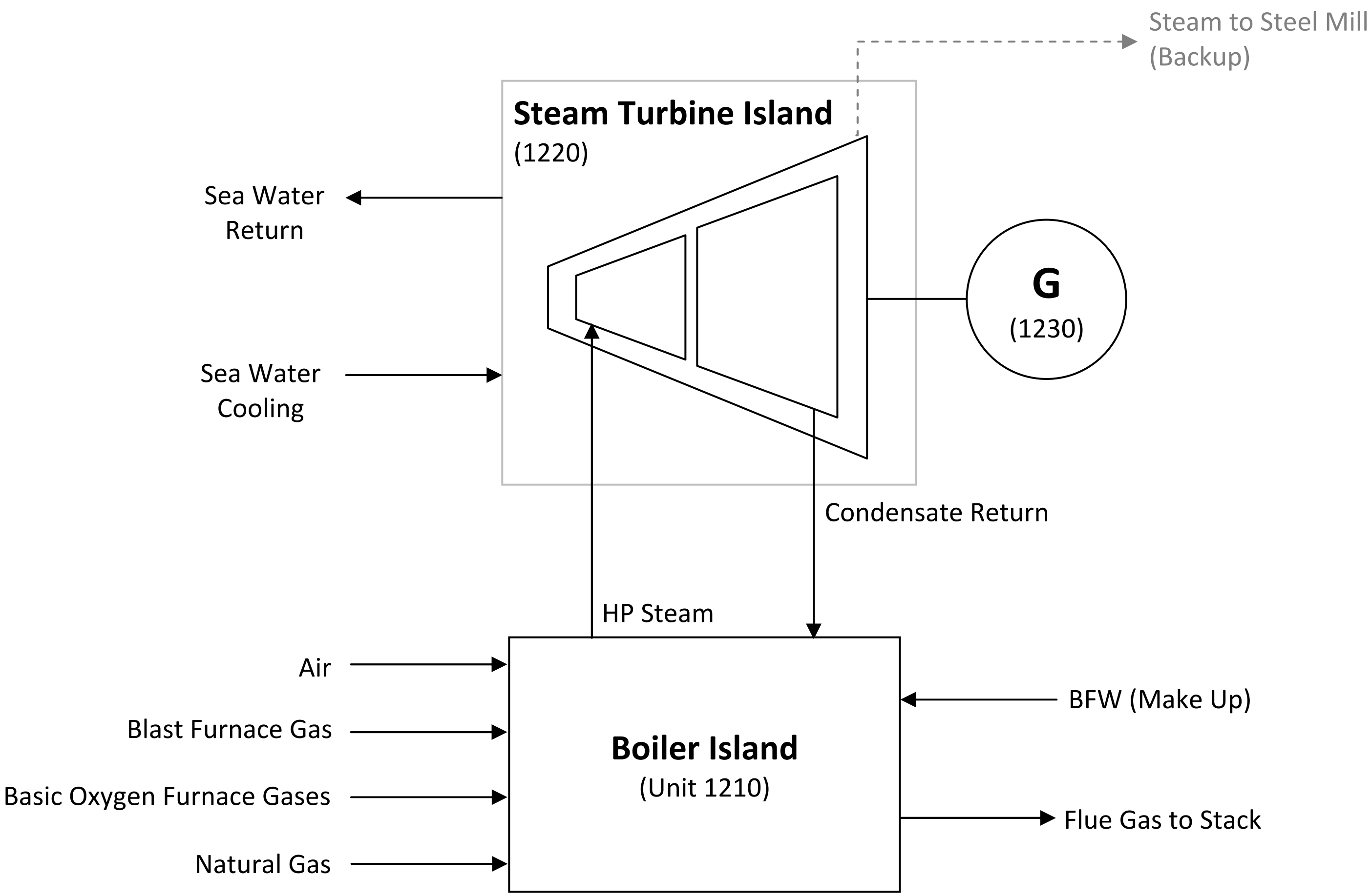

Figure F-1: Process Flow Diagram of the Power Plant (Base Case)
Net Electrical Efficiency of 32.1%

2.2. Case 1A: Power Plant with 37% Net Efficiency

The power plant utilises the BFG, BOFG and NG as fuel. There is no integration between power plant and the steel mill. The power plant is equipped with a sub-critical boiler generating steam and reheated steam to drive the HP, IP and LP steam turbines. The power plant condenser is based on a once through sea water cooling system. Table F-2 summarises the performance of the power plant.

Table F-2: Performance of the Captive Power Plant (Case 1A)

CAPTIVE POWER PLANT – CASE 1A		
Nominal Electricity Output (NET)	215	MWe
Load Factor	85	%
Fuel Input		
Blast Furnace Gas	377.5	MWth
Basic Oxygen Furnace Gas	83.7	MWth
Natural Gas	32.7	MWth
Total Thermal Input – (A)	**493.5**	**MWth**
Gross Electricity Output (Daily Average on Annual Basis) – (B)	**201.0**	**MWe**
Auxiliary Power	**8.2**	**MWe**
Fuel Delivery Auxiliary		
Boiler Auxiliary (Blowers, ID and FD Fans, et. al.)		
Cooling Water Pumps		
Boiler Feed Water Pumps and De-aerators		
Net Power Output (Daily Average on Annual Basis) – (C)	**182.7**	**MWe**
Gross Electrical Efficiency (B/A *100%)	**40.7**	**%**
Net Electrical Efficiency (C/A *100%)	**37.0**	**%**

The performance of the plant is evaluated based on the following parameters:

- Off-Gas (BFG & BOFG) feeding into the boiler at 461 MJ/s.
- Natural Gas feeding into the boiler at 33 MJ/s.
- HP steam turbine with steam parameter at 169 bar_a, 565^oC.
- IP steam turbine with steam parameter at 40 bar_a, 565^oC.
- LP steam turbine with steam parameter at 9 bar_a, 327^oC.
- Steam from HP turbine is returned to the boiler to be reheated from 354^oC to 565^oC.
- Boiler feed water preheating at 169 bar_a, 213^oC and condensing pressure of 0.03 bar_a.
- Seawater is available at 12^oC. The temperature difference between in-coming and out-going seawater is assumed to be 7^oC.

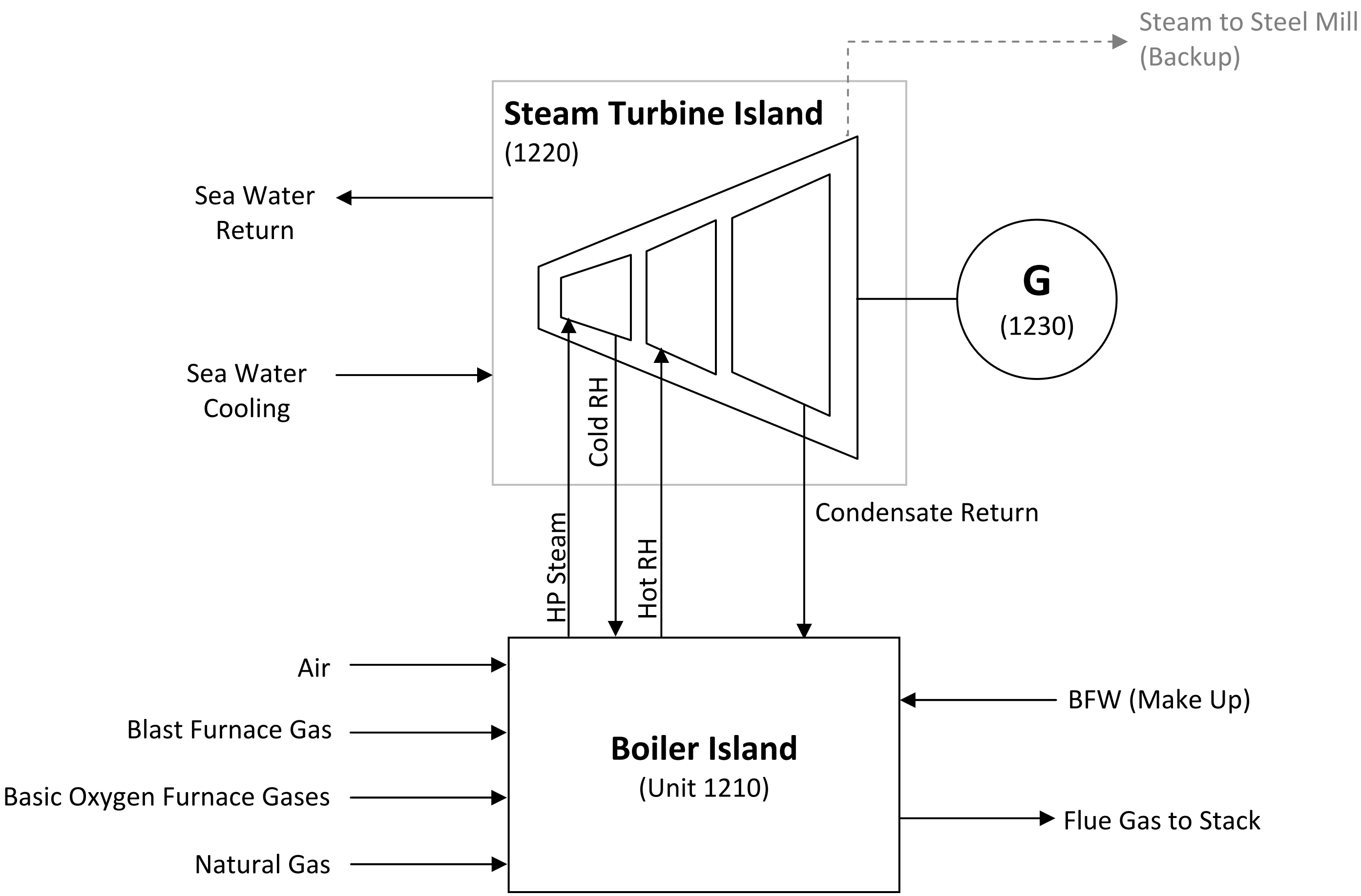

Figure F-2: Process Flow Diagram of the Power Plant (Case 1A)
Net Electrical Efficiency of 37.0%

2.3. Case 1B: Power Plant with 40% Net Efficiency & Integrated to Steel Mill

The power plant for this case has minimal heat integration with the steel mill that slightly reduces fuel consumption. Due to this energy saving measure, the power plant will only use BFG and BOFG as fuel. The power plant has the same configuration as the power plant for Case 1A except that it receives 33t/h (72 kg/t HRC) of superheated steam at 40 bar_a and 354^oC from the steel mill to be mixed with the IP steam coming from the HP steam turbine.

The steam is obtained from the waste heat boilers installed at the slab reheating facilities (UNIT 800), whilst a part of the condensates from the feed water pre-heater of the power plant are returned to the steel mill. Table F-3 presents the summary of the power plant performance. Figure F-4 illustrates the changes in the process flow diagram of the reheating furnace of the steel mill illustrating that steam production from the BOS plant could be maximised and used.

Table F-3: Performance of the Captive Power Plant (Case 1B)

CAPTIVE POWER PLANT – CASE 1B		
Nominal Electricity Output (NET)	215	MWe
Load Factor	86	%
Fuel Input		
Blast Furnace Gas	377.5	MWth
Basic Oxygen Furnace Gas	83.7	MWth
Total Thermal Input – (A)	**461.2**	**MWth**
Steam (@ 40 bar and 354^oC)	**28.4**	**MWth**
Gross Electricity Output (Daily Average on Annual Basis) – (B)	**201.5**	**MWe**
Auxiliary Power	**7.4**	**MWe**
Fuel Delivery and Boiler Auxiliaries (Blowers, ID & FD Fans, et. al.)		
Cooling Water Pumps		
Boiler Feed Water and Condensate Pumps, and De-aerators		
Net Power Output (Daily Average on Annual Basis) – (C)	**184.0**	**MWe**
Gross Electrical Efficiency (B/A *100%)	**43.7**	**%**
Net Electrical Efficiency (C/A *100%)	**39.9**	**%**

The performance of the plant is evaluated based on the following parameters:

- Off-Gas (BFG & BOFG) feeding into the boiler at 461 MJ/s.
- Steam at 40 bar_a & 354^oC received from the waste heat boilers of the reheating furnaces
- HP steam turbine with steam parameter at 169 $bar_{a,}$ 565^oC.
- IP steam turbine with steam parameter at 40 $bar_{a,}$ 565^oC.
- LP steam turbine with steam parameter at 9 $bar_{a,}$ 327^oC.
- Steam from HP turbine is returned to the boiler to be reheated from 354^oC to 565^oC.
- Boiler feed water preheating at 169 $bar_{a,}$ 154^oC and condensing pressure of 0.03 bar_a.
- Seawater is available at 12^oC. The temperature difference between in-coming and out-going seawater is assumed to be 7^oC.

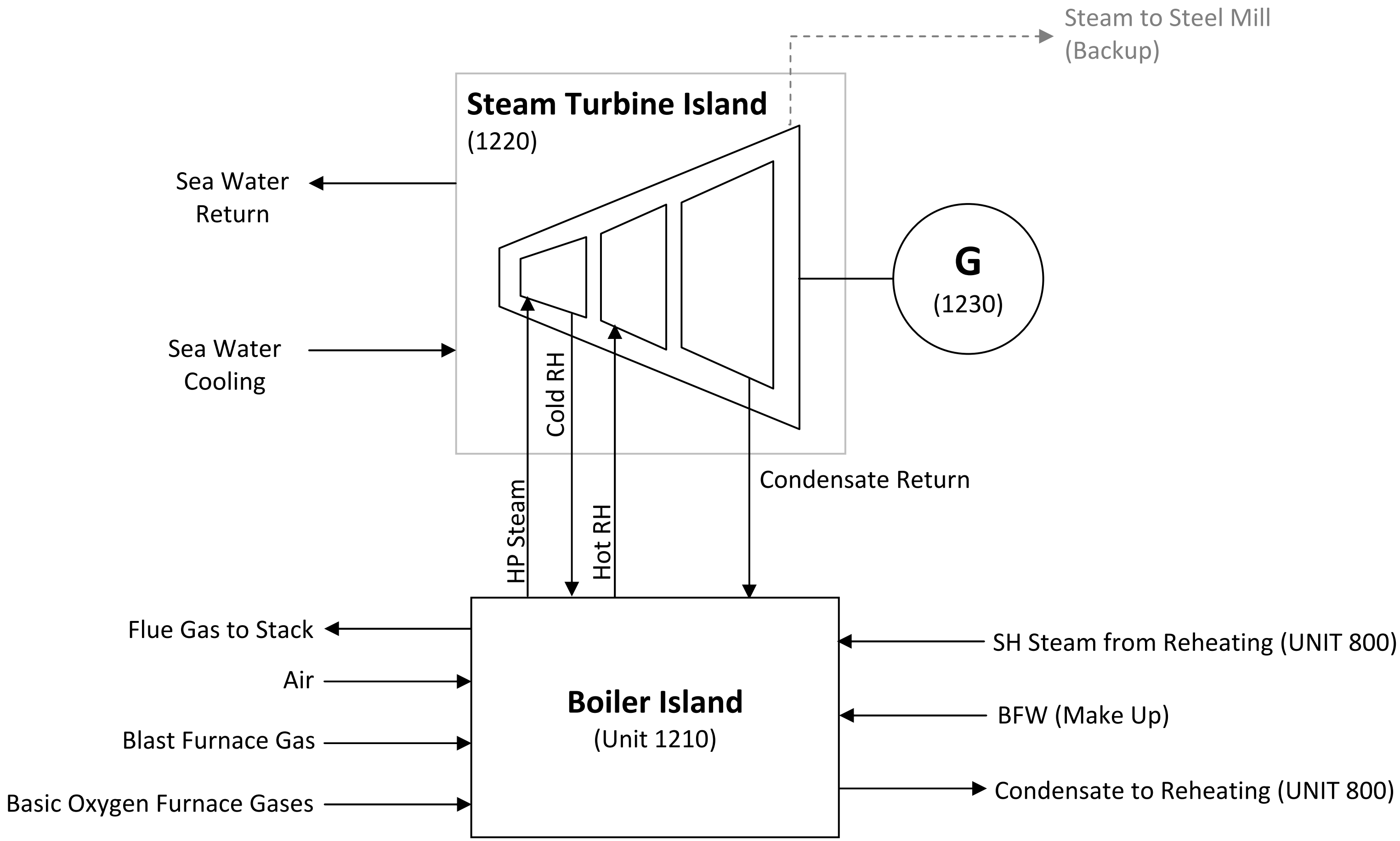

Figure F-3: Process Flow Diagram of the Power Plant Incorporating Heat Integration to the Steel Mill (Case 1B)
Net Electrical Efficiency of 39.9%

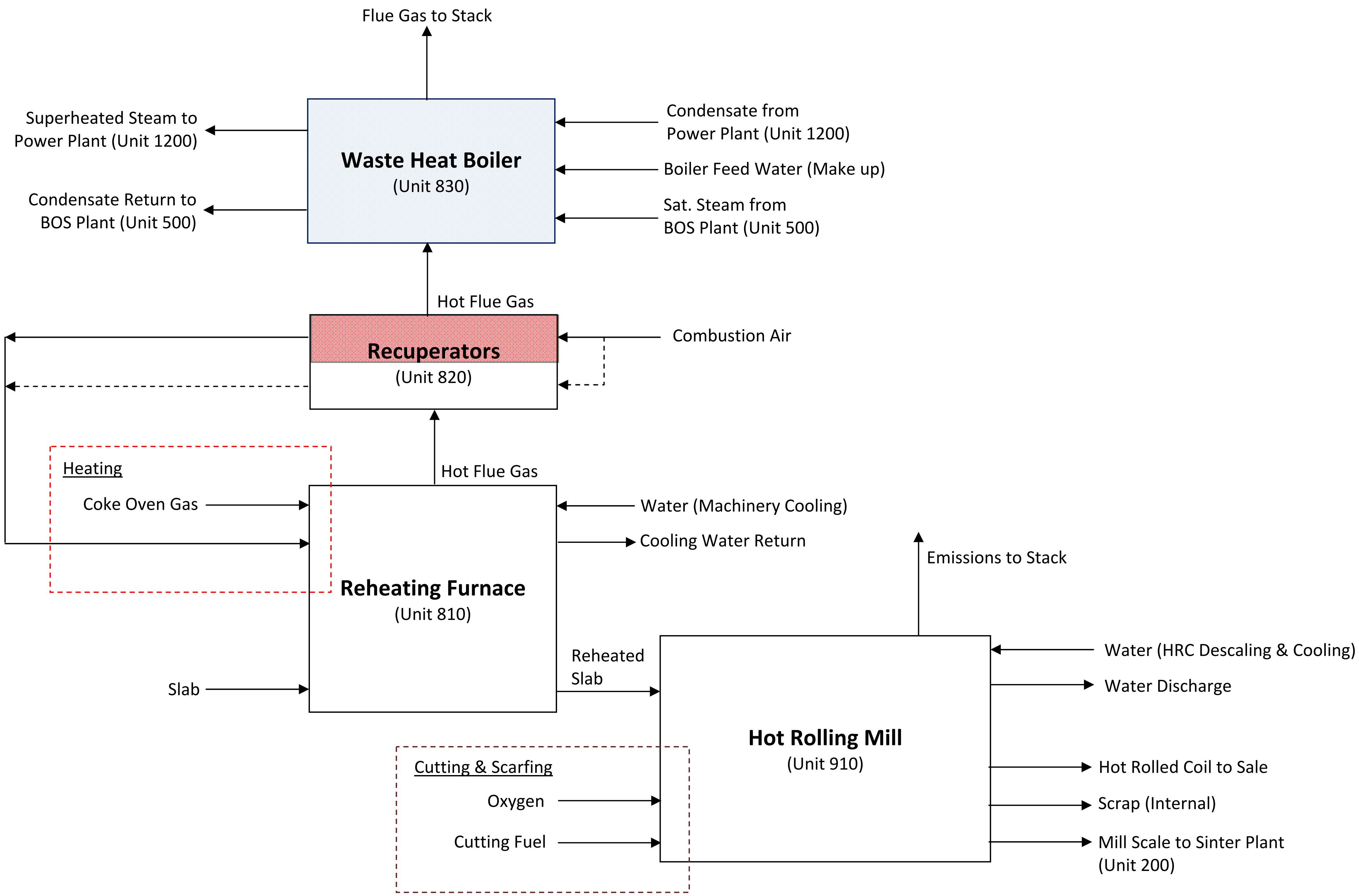

Figure F-4: Process Flow Diagram of the Reheating and Rolling Mill – including the Addition of the Waste Heat Recovery Boiler

Modification to the "REFERENCE" Steel Mill (Base Case)

During the evaluation of Case 1B (i.e. where power plant has been partly integrated with the steel mill by receiving steam for boiler feed water heating), considerations were made in defining what are the major changes to original "REFERENCE" Steel Mill (BASE CASE).

As consequence of delivering the superheated steam to the power plant from the steel mill, several modifications to the slab reheating plant of the original "REFERENCE" Steel Mill were made. The list below summarised the major modifications made.

Figure F-5 illustrates and highlights the changes in the steel mill's gas network.

<u>Modifications made to the original "REFERENCE" Steel Mill.</u>

- Two waste heat boilers were added to both lines of the Slab Reheating Facilities (UNIT 800) therefore recovering waste heat from the flue gases of the 4 reheating furnaces. This also includes the addition of ID fans to deliver the flue gas to the stack. Consequently, this increases the electricity consumption of the Reheating and Rolling Mills by ~2.8 kWh/t HRC.

- Maximised the utilisation of the steam output of the BOS plant (UNIT 500). Production of steam from the BOS plant has increased from 76.3 to 81.1 kg/t HRC (as compared to the Base Case). The excess steam that could be produced by the BOS plant is delivered to the waste heat boiler to pre-heat the condensate returning from the power plant from 19^{o}C to 62^{o}C.

- All piping and related auxiliaries necessary to deliver steam to the power plant and from the BOS plant.

- All piping and related auxiliaries necessary to deliver condensate from the power plant to the waste heat boilers installed at the slab reheating plant.

- Summary of the operating assumptions:

    - Flue gas of the reheating furnaces exiting from the waste heat boilers is about 220^{o}C. (Down from 500^{o}C just after the recuperator).

    - Superheated Steam produced by the waste heat boilers is delivered at 40 bar_a and 370^{o}C.

    - Superheated Steam received by the power plant to be mixed with the steam from the exhaust of the HP turbine is at 40 bar_a, 354^{o}C.

    - Condensate from the power plant is pumped at 9 bar_a and 19^{o}C delivered back to the slab reheating facilities. This is then pre-heated from 19^{o}C to 62^{o}C by the steam (@ 9 bar_a saturated) coming from the BOS plant in a condensate pre-heater and then pumped to 40 bar_a for used in the waste heat boilers.

    - A negligible increase of BFG flaring by 0.11 MJ/t HRC – due to reduction in BFG consumption by the power plant.

TATA STEEL

Flow Sheet (Steel Mill Gas Network)
Application of CO_2 Capture to an Integrated Steelworks
Reference Steel Mill (Base Case)

Production: 4,000,000 tonnes HRC/y
(YEAR 06)

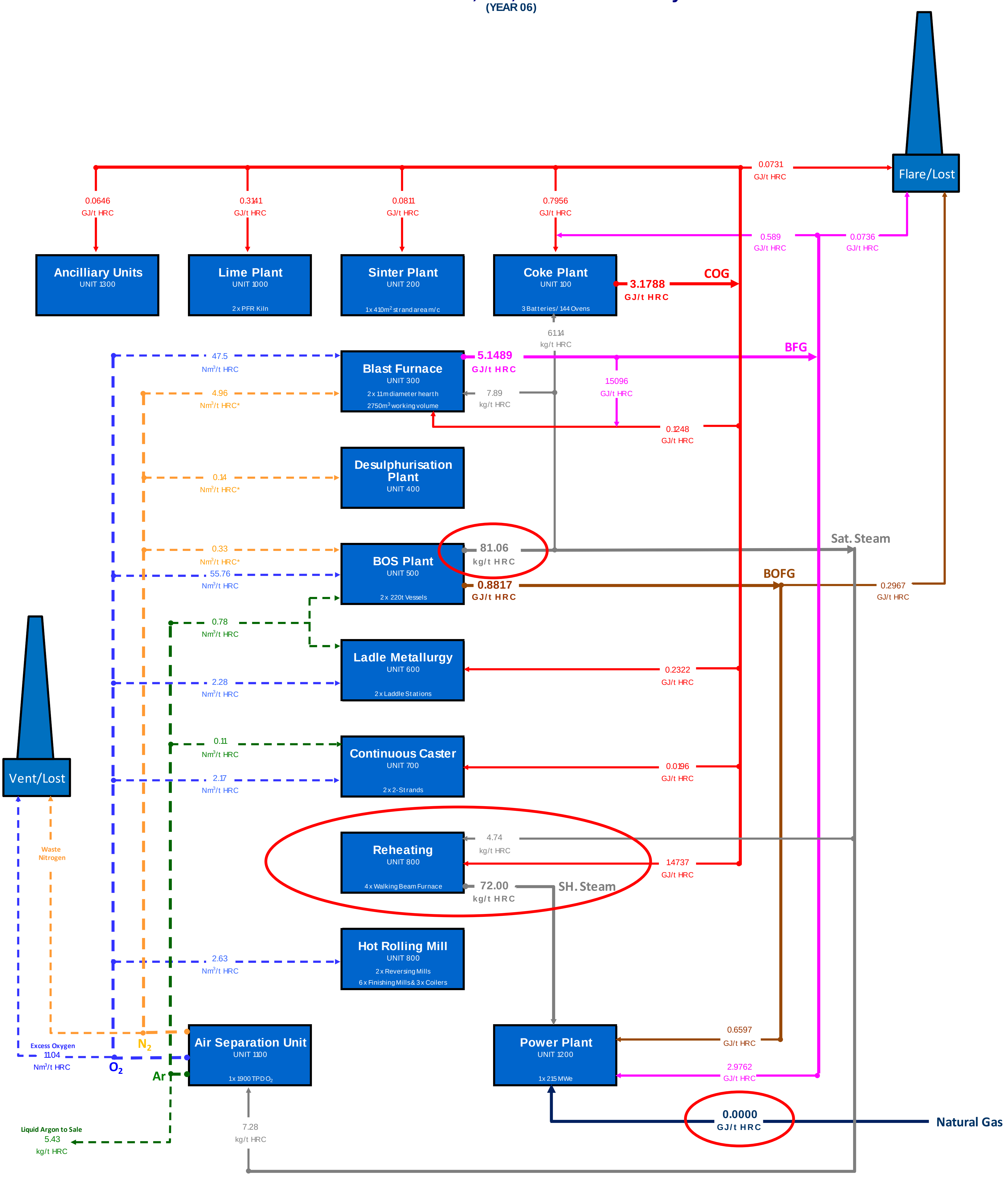

Figure F-5: Gas Network of the "REFERENCE" Steel Mill (CASE 1B)
(Modifications to the Gas Network has been encircled in Red)

2.4. Case 1C: Power Plant Based on GTCC with 42% Net Efficiency

This case is based on a combined cycle power plant using BFG and BOFG as fuel.

The purpose of this case is to demonstrate consumption of steel mill's by-product gases for power generation could be further reduced. Doing this will result in surplus BFG. However, due to energy import/export constraints of this study, the extra by-product gas saved in this case is assumed to be flared off. In reality, the excess off-gases saved by this measure could provide production of other forms of energy (i.e. district heating, electricity, or steam) that could be exported by the steel mill.

This power plant is equipped with a gas turbine capable of firing low CV off-gases to produce electricity, whilst heat is recovered from the GT exhaust gas through the Heat Recovery Steam Generation (HRSG) unit to produce steam that will drive the steam turbine. The HRSG is equipped with supplementary duct firing to increase steam production and increase the power generation from the steam turbine. Tables F-4 and F-5 summarise the performance and operating parameters of the combine cycle power plant. Figure F-6 presents the process flow diagram of the power plant based on GTCC.

Off-Gas Compressor and Gas Turbine Island

The technology class of the gas turbine chosen for this case is conservative and similar machines have been used in various steel mills and can be referenced worldwide. Performance of this power plant was evaluated using publicly published operation data.

The combine cycle power plant assumed for this case is a single gas turbine in a single shaft arrangement with the steam turbine, electricity generator and off-gas compressor.

The GT is fired with BFG and BOFG in a silo combustor. The air compressor is modified to suit burning of large volumes of off-gases. The GT is assumed to operate at between 230-240% excess air level. The dust in the BFG and BOFG are removed by the wet ESP. These off-gases are mixed and compressed in a gas compressor driven by the gas turbine on the same shaft as the electric generator and the steam turbine. Turbine exhaust gas temperature is expected to be around 550^{o}C. Nominal output of the gas turbine including the power consumed by the gas compressor is estimated at ~90MWe.

Heat Recovery Steam Generation (HRSG) and Steam Turbine Island

To achieve the nominal 200MWe net output desired for the study, the HRSG is equipped with duct burners firing BOFG as main fuel with NG as back up fuel. Turbine Exhaust Gas is used as comburent. Supplementary duct firing is necessary to achieve the heating of the Turbine Exhaust Gas from 550^{o}C to about 580/600^{o}C. The BOFG is also cleaned to ensure dust are removed and partly pre-heated. HRSG is equipped with SCR and catalytic converter to reduce NOx and CO emissions.

The HRSG is configured with triple pressure and steam reheat. The HP steam turbine operates at 100 $bar_{a,}$ 535^{o}C. Steam from the HP turbine is returned to the HRSG for reheating. This is mixed with the IP steam and returned to the steam turbine. The IP turbine operates at 25 $bar_{a,}$ 535^{o}C. Low pressure steam from the HRSG is then mixed with the steam from exhaust of the IP turbine at 9 $bar_{a,}$ 180^{o}C before re-entering the LP steam turbine. A small part of the LP steam is directed to the deaerator. Nominal output of the steam turbine is estimated at ~110 MWe.

Table F-4: Performance of the Captive Power Plant (Case 1C)

Operating Parameters of the Combine Cycle Power Plant		
GAS TURBINE	**Fuel**	BFG (349MJ/s) and BOFG (14MJ/s)
	Type	GT with silo combustor in single shaft arrangement
	Nominal Net Output	~90MWe (incl. the off-gas compressor consumption)
	GT Firing Temperature	~1200°C
	Turbine Exhaust Gas Temperature	~550°C
	Excess Air Level	~250%
HRSG	**Type**	Horizontal HRSG - Triple Pressure with Reheat
	Duct Firing	Yes
	Environmental Measures	SCR and Catalytic Converter
	Fuel	BOFG (70MJ/s)
	Comburrent	Turbine Exhaust Gas
	Flue Gas Temperature after Firing	~580°C
STEAM TURBINE	**Type**	Condensing Type
	Nominal Net Output	~110MWe
	Steam Import	None
	HP Steam	100 bar_a, 535°C
	IP Steam	25 bar_a, 535°C
	LP Steam	9 bar_a, 180°C

Table F-5: Performance of the Captive Power Plant (Case 1C)

CAPTIVE POWER PLANT – CASE 1C		
Nominal Electricity Output (NET)	200	MWe
Load Factor	92	%
Fuel Input		
Blast Furnace Gas (to Gas Turbine)	349.3	MWth
Basic Oxygen Furnace Gas (to Gas Turbine)	13.7	MWth
Basic Oxygen Furnace Gas (to HRSG Duct Firing)	70.0	MWth
Total Thermal Input – (A)	**432.9**	**MWth**
Net Power Output (Daily Average on Annual Basis) – (B)	**182.7**	**MWe**
Net Electrical Efficiency (B/A *100%)	**42.2**	**%**

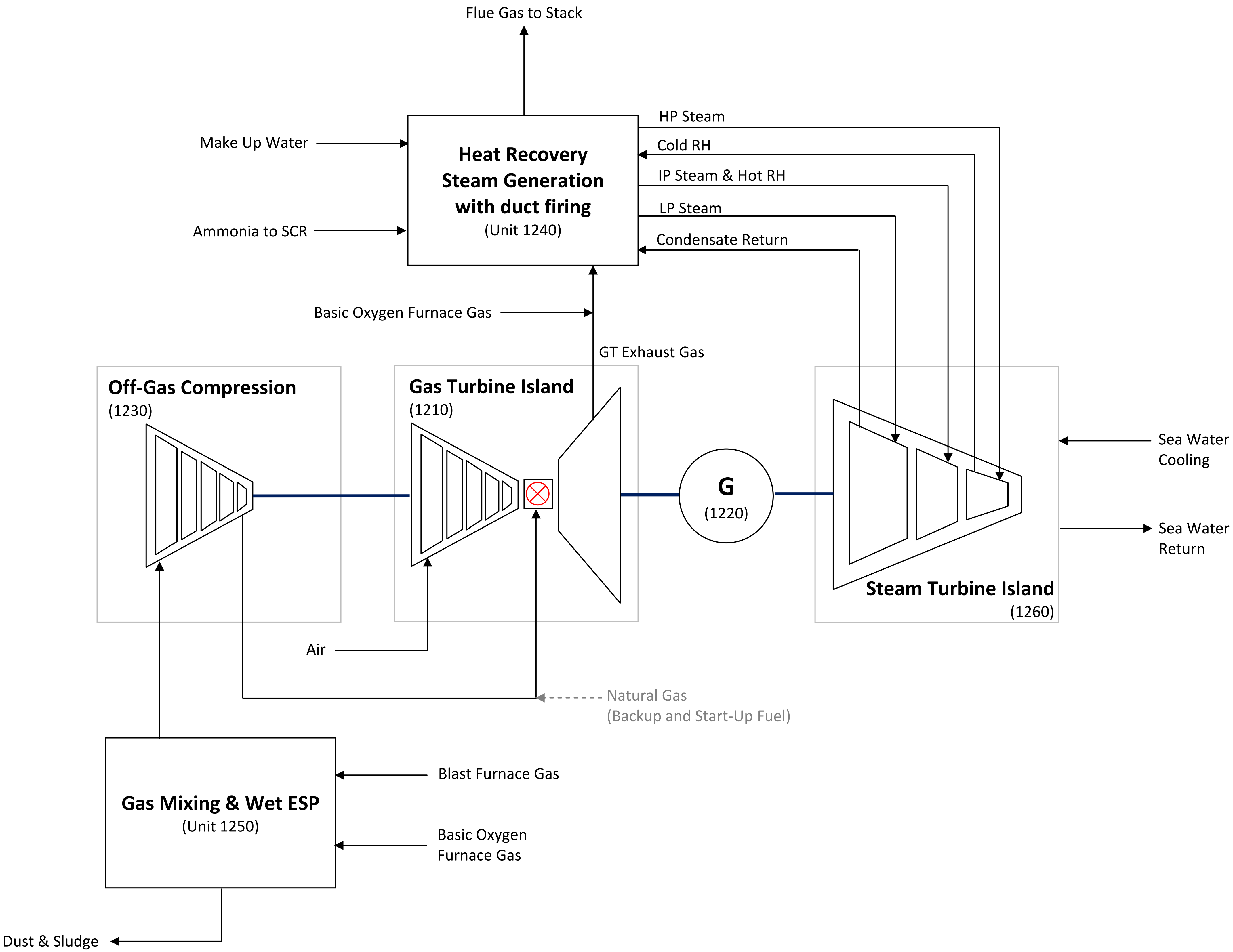

Figure F-6: Process Flow Diagram of the Power Plant Based on a GT Combined Cycle Firing Off-Gases (Case 1C)
Net Electrical Efficiency of 42.2%

2.5. Case 1D: Power Plant Based on GTCC & Auxiliary Boiler with 42% Net Efficiency

This case is based on a combined cycle power plant using BFG and BOFG as fuel with an auxiliary boiler providing the extra steam needed for the steam turbine. The boiler is fired by BOFG as the main fuel.

This case presents the alternative and cheaper version of Case 1C, illustrating the same principle wherein consumption of the steel mill's by-product gases for power generation could be further reduced but with less complexity to the GTCC power plant (i.e. without the supplementary duct firing and simple steam turbine based on dual pressure no reheat system).

This power plant is equipped with a gas turbine capable of firing low CV off-gases to produce electricity, whilst heat is recovered from the GT exhaust gas through the Heat Recovery Steam Generation (HRSG) unit to produce steam that will drive the steam turbine. The HRSG will be supplemented by an auxiliary boiler (instead of Duct Firing as compared to Case 1C) to increase the steam production to meeting electricity demand of the steel mill. Tables F-6 and F-7 summarised the performance and operating parameters of the combine cycle power plant. Figure F-7 presents the process flow diagram of the power plant based on GTCC.

Off-Gas Compressor and Gas Turbine Island

The technology class of the gas turbine chosen for this case is conservative and similar machines which have been used in various steel mills could be referenced worldwide. Performance of this power plant was evaluated using publicly published operation data.

The combine cycle power plant assumed for this case is a single gas turbine in a single shaft arrangement with the steam turbine, electricity generator and off-gas compressor.

The GT is fired with BFG and BOFG in a silo combustor. Air compressor is modified to suit burning of large volume of off-gases. The GT is assumed to operate at between 230-240% excess air level. The BFG and BOFG are cleaned and dust removed by the wet ESP, and then is compressed in a gas compressor driven by the gas turbine in the same shaft with the electric generator and the steam turbine. Turbine exhaust gas temperature is expected to be around 550^{o}C. Nominal output of the gas turbine including the power consumed by the gas compressor is estimated at ~90MWe.

Heat Recovery Steam Generation (HRSG) and Steam Turbine Island

To achieve the nominal 200MWe net output desired for the study, the HRSG's steam supply will be supplemented with an auxiliary boiler using BOFG as fuel.

The HRSG is configured with dual pressure and no steam reheat. Steam from the auxiliary boiler will be added to supplement the steam demand of the turbine. The ratio of the HP steam supplied by the HRSG to the HP steam supplied by the auxiliary boiler is around 2.362 (mass basis). The HP steam turbine operates at 88 bar_a, 520^{o}C.

Low pressure steam from the HRSG is then mixed with the steam from exhaust of the HP/IP turbine at 9 $bar_{a,}$ 180^{o}C before re-entering the LP steam turbine. A small part of the HP and the LP steam is directed to the deaerator and condensate preheating unit. Nominal output of the steam turbine is estimated at ~110 MWe.

Table F-6: Performance of the Captive Power Plant (Case 1D)

Operating Parameters of the Combine Cycle Power Plant		
GAS TURBINE	**Fuel**	BFG (352MJ/s) and BOFG (11MJ/s)
	Type	GT with silo combustor in single shaft arrangement
	Nominal Net Output	~90MWe (incl. the off-gas compressor consumption)
	GT Firing Temperature	~1200°C
	Turbine Exhaust Gas Temperature	~554°C
	Excess Air Level	~235%
HRSG	**Type**	Horizontal HRSG - Dual Pressure with No Reheat
	Duct Firing	None
	Environmental Measures	None
	Fuel	None
	Comburrent	None
	Flue Gas Temperature after Firing	N/A
STEAM TURBINE	**Type**	Condensing Type
	Nominal Net Output	~110MWe
	Steam Import	additional 84MW_t steam (88 Bar_a, 520°C) from Aux. Boiler
	HP Steam	88 Bar_a, 520°C
	IP Steam	N.R.
	LP Steam	9 bar_a, 180°C
AUXILIARY BOILER	**Type**	Water Tubed Boiler (Gas Fired)
	Nominal Net Output	~120 tph (HP steam generation at 88 Bar_a, 520°C)
	HP Steam	88 Bar_a, 520°C
	BFW De-aerator and Heaters	To include condensate preheating for HRSG

Table F-7: Performance of the Captive Power Plant (Case 1D)

CAPTIVE POWER PLANT – CASE 1D		
Nominal Electricity Output (NET)	200	MWe
Load Factor	92	%
Fuel Input		
Blast Furnace Gas (to Gas Turbine)	352.3	MWth
Basic Oxygen Furnace Gas (to Gas Turbine)	10.7	MWth
Basic Oxygen Furnace Gas (to Auxiliary Boiler)	73.0	MWth
Total Thermal Input – (A)	**435.9**	**MWth**
Net Power Output (Daily Average on Annual Basis) – (B)	**182.7**	**MWe**
Net Electrical Efficiency (B/A *100%)	**41.9**	**%**

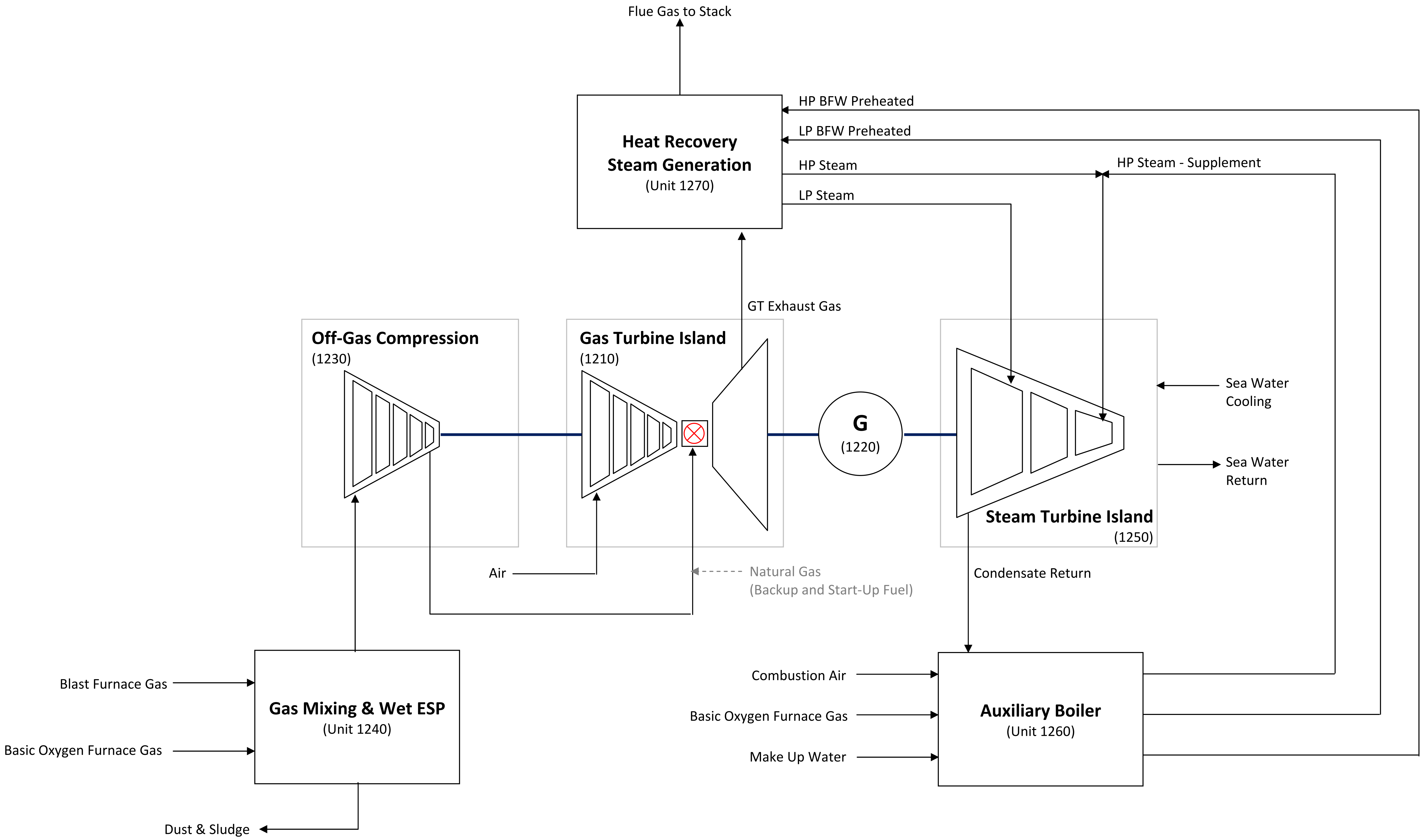

Figure F-7: Process Flow Diagram of the Power Plant Based on a GT Combined Cycle & Auxiliary Boiler Firing Off-Gases (Case 1D)
Net Electrical Efficiency of 41.9%

2.6. Summary of Results

Table F-8 summarises the key features and estimated performance of the captive power plants for the different "REFERENCE" Steel Mill Scenarios.

Table F-8: Key Features and Performance of the Captive Power Plant – Summary of Results

	Base Case	Case 1A	Case 1B	Case 1C	Case 1D
Type of Captive Power Plant	Subcritical Steam Boiler with HP/LP Steam Turbine	Subcritical Steam Boiler with HP/IP/LP Steam Turbine	Subcritical Boiler with Partial Heat Integration to the Steel Mill (UNIT 800 - Reheating)	Gas Turbine Combine Cycle Power Plant	Gas Turbine Combine Cycle Power Plant with Auxiliary Boiler
Nominal Output	215MWe	215MWe	215MWe	200MWe (GT – 90MWe & ST – 110MWe)	200MWe (GT – 90MWe & ST – 110MWe)
Annual Daily Average Output (Electricity Demand of Steel Mill)	183MWe (85% Load Factor)	183MWe (85% Load Factor)	184MWe (86% Load Factor)	183MWe (92% Load Factor)	183MWe (92% Load Factor)
Gross Electrical Efficiency (LHV)	35.8%	40.7%	43.7%	-	-
Net Electrical Efficiency (LHV)	32.1%	37.0%	39.9%	42.2%	41.9%
Fuel Input	BFG, BOFG and NG	BFG, BOFG and NG	BFG and BOFG	BFG and BOFG with part of BOFG as fuel of the Supplementary HRSG Firing	BFG & BOFG to Gas Turbine BOFG to Auxiliary Boiler
Remarks on Fuel Input	Base Case	Reduced NG consumption from 0.85 to 0.26 GJ/t HRC	Reduced NG consumption from 0.85 to 0 GJ/t HRC	Reduced BFG Consumption from 2.97 to 2.75 GJ/t HRC with NG as start-up fuel only	Reduced BFG Consumption from 2.97 to 2.78 GJ/t HRC with NG as start-up fuel only
Steam Import	none	None	Additional steam at 40 bar and 354°C from WHB of reheating furnace to be added to Cold RH	none	Additional steam at 88 bar and 520°C from aux. boiler of power plant to be added to HP inlet
Gas Turbine Parameters	NA	NA	NA	GT Firing Temperature ~1200°C Exhaust temperature of ~550°C (See Table F-4 for further details)	GT Firing Temperature ~1200°C Exhaust temperature of ~550°C (See Table F-6 for further details)
HP Turbine Steam Parameters	120 bar, 512°C without steam reheat	169 bar, 565°C with steam reheat	169 bar, 565°C with steam reheat	100 bar, 535°C with steam reheat	88 bar, 520°C without steam reheat
IP Turbine Steam Parameters	None	40 bar, 565°C	40 bar, 565°C	25 bar, 535°C	Not Reported
LP Turbine Steam Parameters	9 bar, 180°C	9 bar, 327°C	9 bar, 327°C	9 bar, 180°C	9 bar, 180°C
Condenser Pressure	0.03 bar	0.03 bar	0.03 bar	0.03 bar	0.03 bar
Modification to the Steel Mill	Base Case	None	Added Waste Heat Boilers to the Reheating Furnace (UNIT 800) & Maximised the production of steam from BOS plant (UNIT 500)	Additional Flaring of BFG from 0.073 to 0.296 GJ/t HRC	Additional Flaring of BFG from 0.073 to 0.273 GJ/t HRC
Other Remarks	-	-	Marginal decrease in BFG consumption leading to additional marginal increase of flaring at ~0.0004 GJ/t HRC	GT is based on E-Class technology capable of firing low calorific value gas with HRSG duct firing included to supplement steam demand	GT is based on E-Class technology capable of firing low calorific value gas with HRSG and steam supply supplemented by aux. boiler

3. CO_2 EMISSIONS

The CO_2 emissions of the different step-off cases evaluated are presented in Figure F-8 and breakdown of the CO_2 emissions among the different processes is summarised in Table F-9.

The reduction of CO_2 emissions for all cases is expected due to reduce natural gas consumption in the power plant. Further reduction as illustrated in Case 1C and Case 1D is not possible; as off-gases such as BFG and BOFG, once produced by the iron making and steelmaking processes should be used somewhere within the steel mill or be flared.

Only way to achieve further reduction in emissions or cost in these cases is to have options to export excess energy from the steel mill. This is constrained for the current study to simplify accounting of CO_2 emissions thus avoiding having to deal with the complexity of exporting or importing energy in or out of the defined boundary limit.

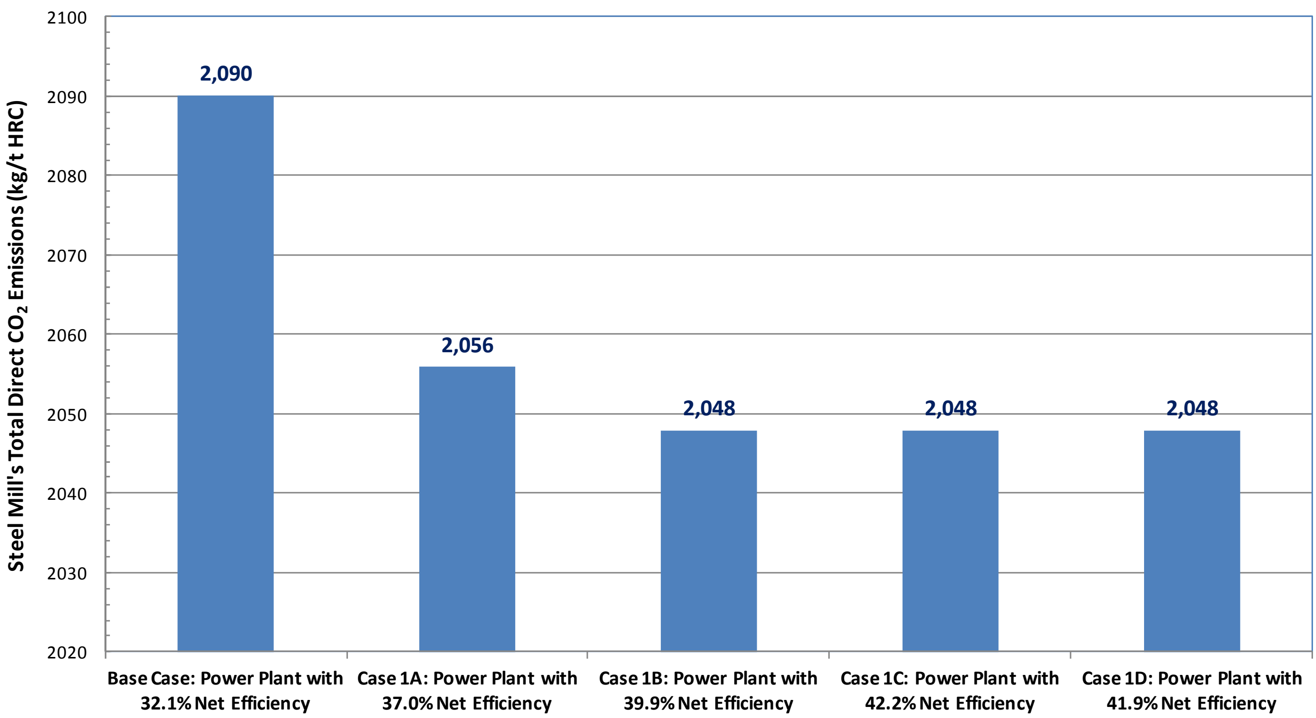

Figure F-8: Total Direct CO_2 Emissions from the Steel Mill without CO_2 Capture for different captive power plant options

Table F-9: Specific & Annual Emissions of the Steel Mill with Different Captive Power Plant Options

UNIT	Source of CO_2 Emissions	Base Case		Case 1A		Case 1B		Case 1C		Case 1D	
		Emissions (kg/t HRC)	Annual Emission (t/y)	Emissions (kg/t HRC)	Annual Emission (t/y)	Emissions (kg/t HRC)	Annual Emission (t/y)	Emissions (kg/t HRC)	Annual Emission (t/y)	Emissions (kg/t HRC)	Annual Emission (t/y)
100	Flue Gas – Coke Oven	191.37	765,495	191.37	765,495	191.37	765,495	191.37	765,495	191.37	765,495
100	Flare – Coke Oven	3.30	13,196	3.30	13,196	3.30	13,196	3.30	13,196	3.30	13,196
200	Flue Gas – Sinter Plant (incl. CO emissions as CO_2)	289.46	1,157,825	289.46	1,157,825	289.46	1,157,825	289.46	1,157,825	289.46	1,157,825
300	Flue Gas – Hot Stoves	415.19	1,660,769	415.19	1,660,769	415.19	1,660,769	415.19	1,660,769	415.19	1,660,769
400/1300	HM Desulphurisation & Ancillaries (PCI Drying et. al.)	7.76	31,042	7.76	31,042	7.76	31,042	7.76	31,042	7.76	31,042
300	Flare – Blast Furnace	19.73	78,931	19.73	78,931	19.84	79,359	87.23	348,923	80.79	323,170
500/600	Flare (incl. losses) - BOF, Diffuse Emissions from SM	51.02	204,089	51.02	204,089	51.02	204,089	51.02	204,089	51.02	204,089
700	Diffuse Emissions – Continuous Casting	0.80	3,188	0.80	3,188	0.80	3,188	0.80	3,188	0.80	3,188
800	Flue Gas – Reheating Furnaces	57.71	230,833	57.71	230,833	57.71	230,833	57.71	230,833	57.71	230,833
900	Diffuse Emissions – Hot Rolling Mills	0.04	179	0.04	179	0.04	179	0.04	179	0.04	179
1000	Flue Gas – Lime Plant	71.62	286,493	71.62	286,493	71.62	286,493	71.62	286,493	71.62	286,493
1200	Flue Gas – Power Plant	982.13	3,928,513	947.88	3,791,532	939.83	3,759,325	872.44	3,489,761	878.88	3,515,514
Total Direct Emissions from Steel Mill (without CO_2 Capture)		**2090.14**	**8,360,554**	**2055.89**	**8,223,573**	**2047.95**	**8,191,794**	**2047.95**	**8,191,794**	**2047.95**	**8,191,794**

4. COST ANALYSIS

The cost sensitivity of the Hot Rolled Coil produced by the "REFERENCE" Steel Mill to the choice of captive power plant has been evaluated.

This section of the report describes how the costs of HRC produced by the "REFERENCE" integrated steel mill with different types of captive power plant were estimated. Sensitivity to the ETS price of CO_2 was also assessed.

It should be re-emphasized that the cost analysis presented is limited by the constraints set for this study – the most important in which is that energy will not be imported or exported over the defined system boundary.

It should be noted that the cost dynamics of steel production would significantly change and the degree of complexity would increase if this constraint is removed .Evaluating these scenarios are not within the scope of this study.

4.1. Breakeven Price of HRC

The calculated breakeven price of the hot rolled coil produced by the "REFERENCE" Steel Mill (Base Case) as compared to the breakeven prices of the three other cases are presented in Figure F-9. This figure also illustrates which part of the CAPEX and the OPEX has changed for the different step-off cases as compared to the Base Case scenario.

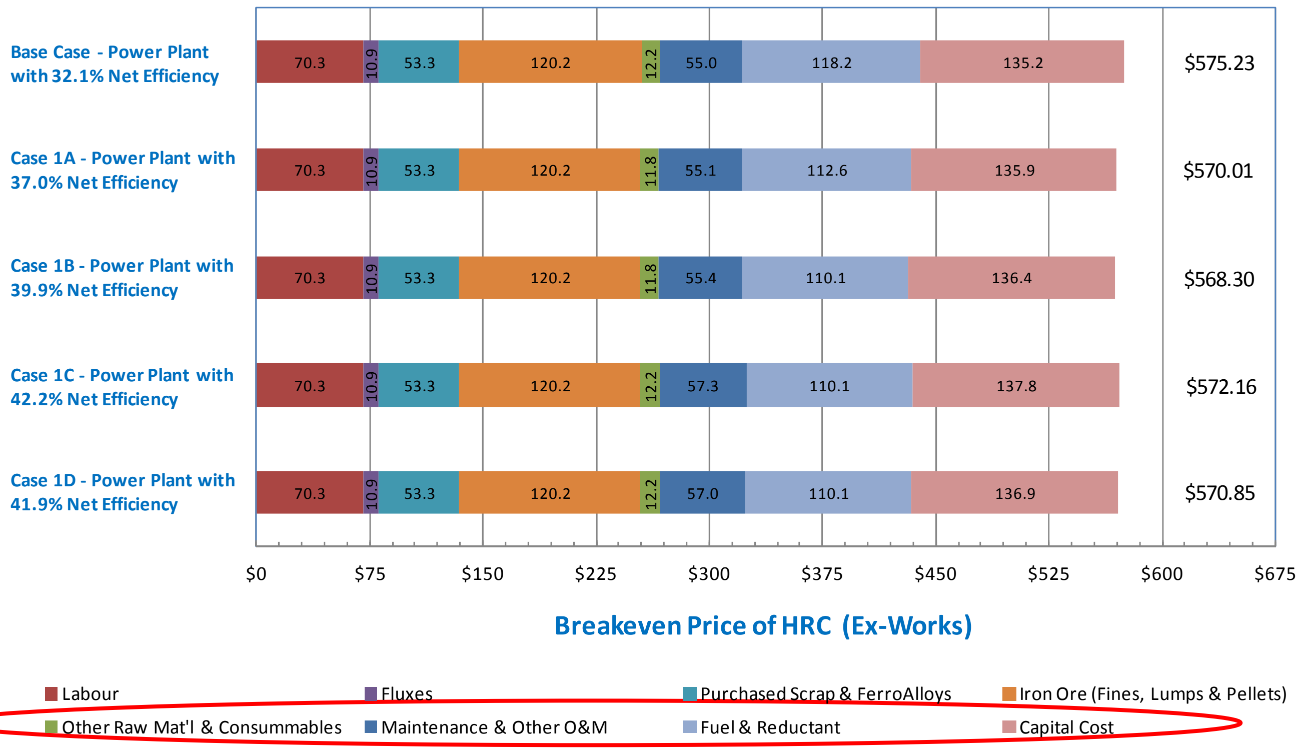

Figure F-9: Breakeven Price of HRC (Ex-Works)

4.2. Notes on CAPEX and OPEX

Total Investment Cost

Table F-10 and Figure F-10 present the breakdown of the investment cost of the “REFERENCE” steel mill with different captive power plant options. This also highlights the changes made to the total investment cost to each case evaluated (Table F-10), and the distribution of the investment cost between the steel mill and the captive power plant (Figure F-10).

Table F-10: Total Investment Cost of “REFERENCE” Steel Mill with Different Power Plant Options

Unit No.	Plant Section	Base Case	Case 1A	Case 1B	Case 1C	Case 1D
Plant and Equipment – Major Processes						
100	Coke Production	400	400	400	400	400
200	Sinter Production	220	220	220	220	220
300 & 400	Blast Furnace and Hot Metal Desulphurisation	622	622	622	622	622
500 & 600	Basic Oxygen Steelmaking and Ladle Metallurgy	459	459	459	459	459
700	Continuous Slab Caster	195	195	195	195	195
800 & 900	**Reheating Furnace & Hot Rolling Mills**	450	450	**462**	450	450
1000	Lime Production	16	16	16	16	16
1100	Air Separation Unit	130	130	130	130	130
1200	**Power Plant**	**280**	**302**	**304**	**355**	**324**
Plant and Equipment – Raw Material Handling and Spare Parts						
	Raw Material Handling	128	128	128	128	128
	Spare Parts and First Fill	**116**	**117**	**117**	**119**	**118**
Plant and Equipment – Others						
	Auxiliary, Utilities, and Balance of Plant	350	350	350	350	350
Site Development, Construction and Project Engineering						
	Pre-operating Expenses	21	21	21	21	21
	Land Preparation, Site Development & Waste Disposal	144	144	144	144	144
	Buildings and Site Infrastructure	196	196	196	196	196
	Project Engineering	201	201	201	201	201
Total Installed Cost (US$ Million)		**3928**	**3951**	**3965**	**4006**	**3974**
Contingency (5% of Total Installed Cost)		**196**	**198**	**198**	**200**	**199**
Total Investment Cost – excl. Recurring CAPEX (US$ Million)		**4124**	**4149**	**4164**	**4206**	**4172**

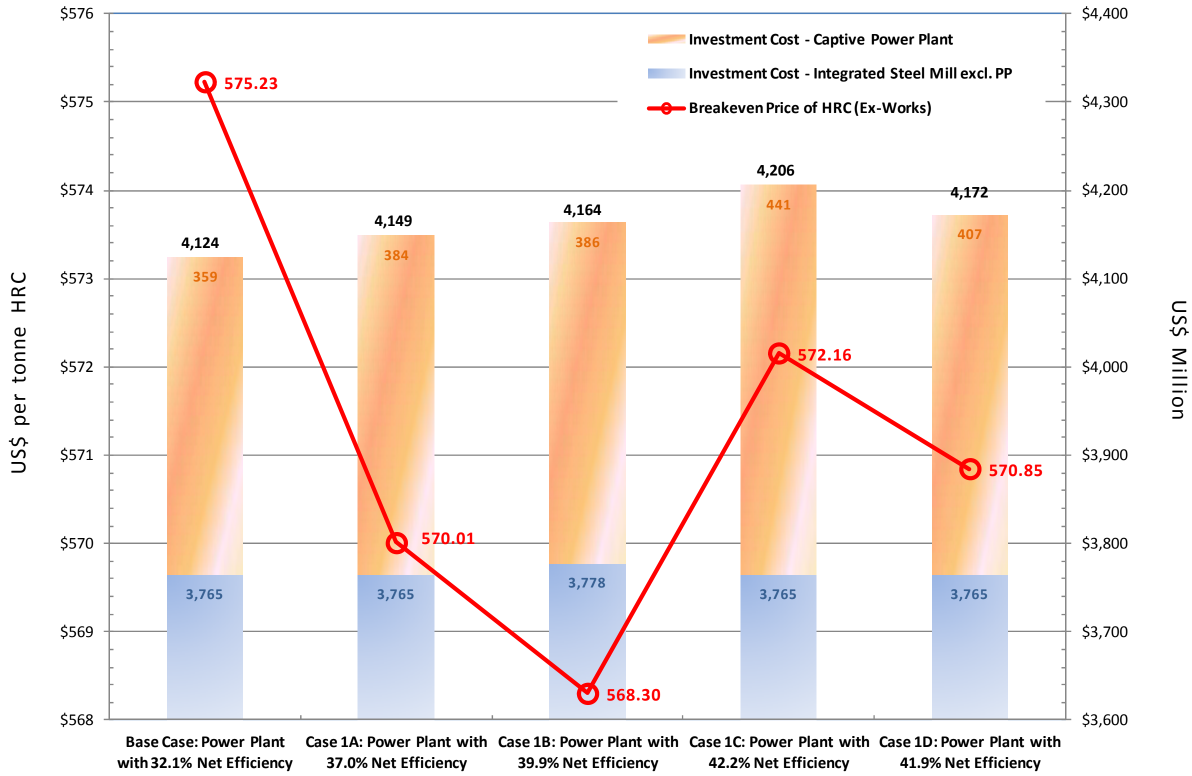

Figure F-10: Breakdown of Total Investment Cost between the Integrated Steel Mill and the Captive Power Plant

Annual Operating Expense

Changes made to the annual operating cost (also indicated in Figure F-8) as compared to the Base Case are:

- Annual fuel and reductant cost – particularly, the change on this cost item is due to the reduction of natural gas consumption by the captive power plant (Unit 1200) for each step-off case.
- Annual maintenance cost – most of the changes are in the maintenance of the captive power plants (Unit 1200), except for Case 1B, where there is slight increase on the annual maintenance bill of the Reheating and Rolling Mills (Unit 800 & 900).
- Other raw materials and consumables – most of the changes are due to the cost item of chemicals and consumables for the captive power plant (Unit 1200) which cover chemicals used for treatment of seawater cooling and the polishing of the make-up water.

These changes are summarised in this report.

a.) Annual fuel and reductant cost

Table F-11 summarises the annual reduction of the fuel cost as compared to the Base Case – attributed to the reduction of natural gas consumption by the steel mill.

Table F-11: Annual Fuel Bill for Natural Gas of the "REFERENCE" Steel Mill with Different Power Plant Options

	Annual Consumption of NG by the Steel Mill (GJ/t HRC)	Annual Fuel Bill for NG (US$ Million)	Annual Fuel Cost Saved (US$ Million)
Base Case	0.8496	$33.203	-
Case 1A	0.2579	$10.079	$23.124
Case 1B	0.0000	-	$33.203
Case 1C	0.0000	-	$33.203
Case 1D	0.0000	-	$33.203

b.) Annual maintenance cost

Table F-12 presents a summary of the breakdown of the annual maintenance cost of the processes of the "REFERENCE" Steel Mill.

Table F-12: Annual Maintenance Cost of the "REFERENCE" Steel Mill with Different Power Plant Options

Unit No.	Plant Section	Base Case		Case 1A		Case 1B		Case 1C		Case 1D	
		(% CAPEX)	Maintenance Cost	(% CAPEX)	Maintenance Cost	(% CAPEX)	Maintenance Cost	(% CAPEX)	Maintenance Cost	(% CAPEX)	Maintenance Cost
100	Coke Production	5.0%	20.000	5.0%	20.000	5.0%	20.000	5.0%	20.000	5.0%	20.000
200	Sinter Production	5.0%	11.000	5.0%	11.000	5.0%	11.000	5.0%	11.000	5.0%	11.000
300 & 400	Hot Metal Production	4.0%	24.880	4.0%	24.880	4.0%	24.880	4.0%	24.880	4.0%	24.880
500 & 600	Liquid Steel Production	5.0%	22.950	5.0%	22.950	5.0%	22.950	5.0%	22.950	5.0%	22.950
700	Continuous Slab Caster	8.0%	15.636	8.0%	15.636	8.0%	15.636	8.0%	15.636	8.0%	15.636
800 & 900	Reheating & Hot Rolling Mills	8.0%	36.000	8.0%	36.000	8.1%	37.203	8.0%	36.000	8.0%	36.000
1000	Lime Production	8.0%	1.280	8.0%	1.280	8.0%	1.280	8.0%	1.280	8.0%	1.280
1100	Air Separation Unit	2.5%	3.250	2.5%	3.250	2.5%	3.250	2.5%	3.250	2.5%	3.250
1200	Power Plant	2.5%	7.000	2.5%	7.560	2.5%	7.630	4.5%	15.973	4.5%	14.580
Annual Maintenance Cost (US$ Million/y)			**141.996**		**142.556**		**143.829**		**150.969**		**149.576**

c.) Chemical and Consumables

The changes in the annual cost for the "Other Raw Materials & Consumables" is predominantly related to the chemical consumptions used by the captive power plant as summarised in Table F-13. For these cases, the assumptions used in determining the cost of chemicals and consumables are summarised below:

- Reduction of "Chemical and Consumables" cost for the captive power plant of Case 1A and Case 1B as compared to the Base Case is predominantly due to the lesser amount of steam needed to generate each kWh of electricity, leading to lower amounts of makeup boiler feed water and seawater to be chemically treated and polished.

- Nominal cost added to the "Chemical and Consumable" of the captive power plant for Case 1C and Case 1D also includes the budget for natural gas as start up fuel.

- Chemicals and consumables used in the operation of the waste heat boilers attached to the Slab Reheating (Unit 800) for Case 1B and the polishing of the boiler feed water were included in the annual maintenance cost of the Reheating and HRM (See Table F-9).

Table F-13: Annual Cost for the Chemicals and Consumable of the Captive Power Plant of the "REFERENCE" Steel Mill

	Annual Bill for Chemicals & Consumables (US$ Million/y)	Annual Cost Saved or Added (US$ Million/y)
Base Case	$7.880	-
Case 1A	$6.304	($1.576)
Case 1B	$6.349	($1.531)
Case 1C	$8.230	$0.350
Case 1D	$8.230	$0.350

Cost of Electricity for the Steel Mill (Internal Price)

The cumulative effect of the changes made to the Annual O&M cost as compared to the Base Case could be reflected on the cost of electricity paid for by the "REFERENCE" Integrated Steel Mill. This is presented in Figure F-11.

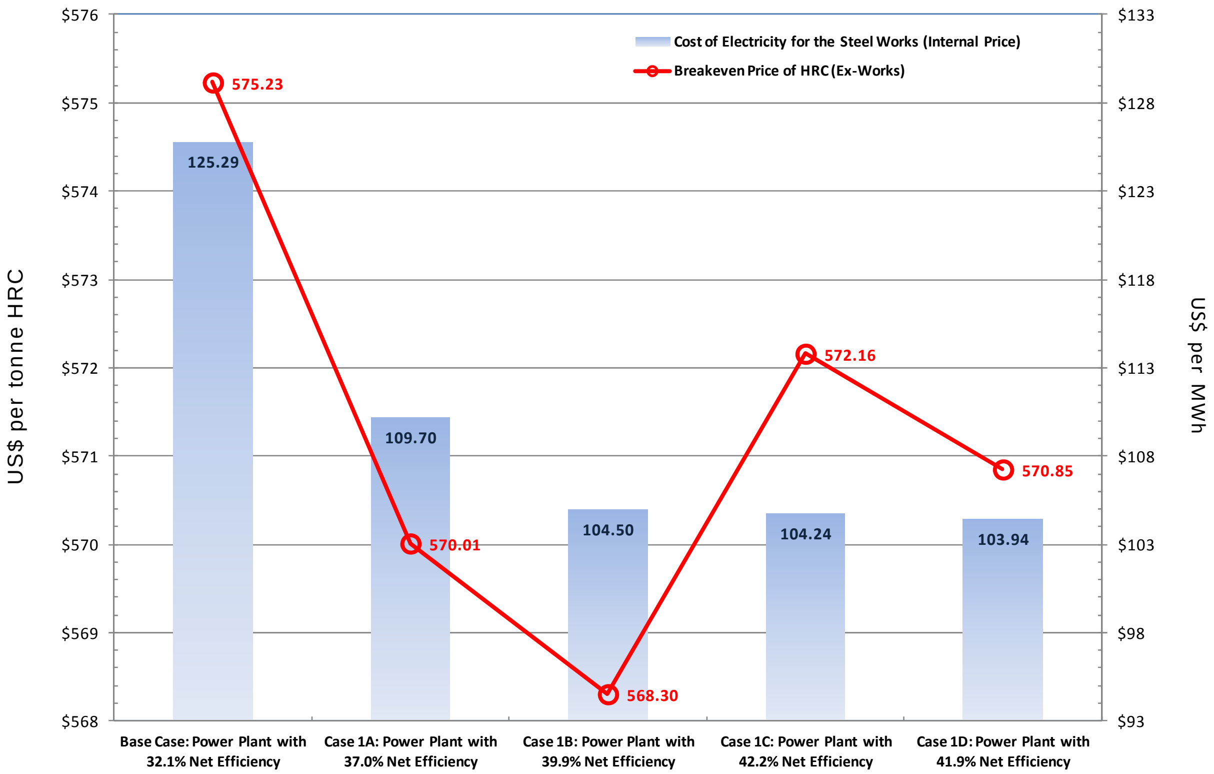

Figure F-11: Cost of Electricity (Internal Price) for the REFERENCE Steel Mill with Different Captive Power Plant Options

4.3. Summary of Results

Table F-14 summarised the key changes to cost of steel production from the "REFERENCE" Steel Mill with three different captive power plants scenarios as compared to the Base Case.

Table F-14: Cost Analysis (CAPEX and OPEX) of the "REFERENCE" Steel Mill – Summary of Results

	Base Case	Case 1A	Case 1B	Case 1C	Case 1D
Total Investment Cost	US$ 4.124 Billion	US$ 4.149 Billion	US$ 4.164 Billion	US$ 4.206 Billion	US$ 4.176 Billion
Notes – Total Installed Cost	Base Case	Increase in investment cost to the Power Plant (Unit 1200), Spare Parts/First Fill.	Increase in investment cost to the Power Plant (Unit 1200), Reheating and HRM (Unit 800/900), Spare Parts/First Fill.	Increase in investment cost to the Power Plant (Unit 1200), Spare Parts/First Fill.	Increase in investment cost to the Power Plant (Unit 1200), Spare Parts/First Fill.
Notes - Contingency	US$ 196 Million	Increase by US$ 2 Million	Increase by US$ 2 Million	Increase by US$ 4 Million	Increase by US$ 3 Million
Fuel Bill – Natural Gas	US$ 33.2 Million/y	Reduced by $23.1 Million/y	Reduced by US$ 33.2 Million	Reduced by US$ 33.2 Million	Reduced by US$ 33.2 Million
Annual Maintenance Cost	US$ 142.0 Million/y	US$ 142.6 Million/y	US$ 143.8 Million/y	US$ 151.0 Million/y	US$ 149.6 Million/y
Notes – Maintenance Cost	Base Case	Increased Maintenance Cost in the power plant (Unit 1200)	Increased Maintenance Cost in the power plant (Unit 1200) and slab reheating (Unit 800)	Increased Maintenance Cost in the power plant (Unit 1200)	Increased Maintenance Cost in the power plant (Unit 1200)
Chemicals and Consumables	US$ 7.9 Million/y	Reduced by US$ 1.58 Million	Reduced by US$ 1.53 Million	Increased by $ 0.350 Milion	Increased by $ 0.350 Milion
Notes – Chemicals and Consumables	Base Case	Reduction due to lower steam required per kWh electricity generated	Reduction due to lower steam required per kWh electricity generated	Increased in cost to include budget for NG as start-up fuel	Increased in cost to include budget for NG as start-up fuel
Cost of Electricity (Internal Price)	US$ 125.29 per MWh	US$ 109.70 per MWh	US$ 104.50 per MWh	US$ 104.24 per MWh	US$ 103.94 per MWh

5. COST IMPACT OF CO_2 EMISSIONS TRADING ON STEEL PRODUCTION

To demonstrate the impact of CO_2 ETS Price to the Breakeven Price of the HRC, nominal prices of $20, $40 and $60 per tonne CO_2 were included in the cost calculations for all cases.

Table F-13 presents the sensitivity of the breakeven price of the HRC produced from various cases to the ETS price of CO_2 emissions.

It should be noted that most of the burden of the CO_2 emissions is transferred to the captive power plant since they are the major users of the by-product gases for fuel (as shown in Figure E-7). This is again illustrated in Figure F-12 and also shows how the price of CO_2 in the ETS would impact the operating cost of the power plant (Unit 1200) for all cases.

Figure 12 also demonstrates how excess energy (BFG not used by the captive power plant due to higher efficiency) that was flared off in Case 1C and Case 1D would shift part of the cost of CO_2 emission to another process within the steel mill.

Table F-13: Sensitivity Analysis: Breakeven Price of HRC and CO_2 ETS Price

	CO_2 ETS Price ($/tonne CO_2)			
	$ 0.00	**$20.00**	**$40.00**	**$60.00**
Base Case: Power Plant with 32.1% Efficiency	$575.23	$617.08	$658.93	$700.77
Case 1A: Power Plant with 37.0% Efficiency	$570.01	$611.17	$652.33	$693.50
Case 1B: Power Plant with 39.9% Efficiency	$568.30	$609.31	$650.31	$691.31
Case 1C: Power Plant with 42.2% Efficiency	$572.16	$613.16	$654.17	$695.17
Case 1D: Power Plant with 41.9% Efficiency	$570.85	$611.85	$652.86	$693.86

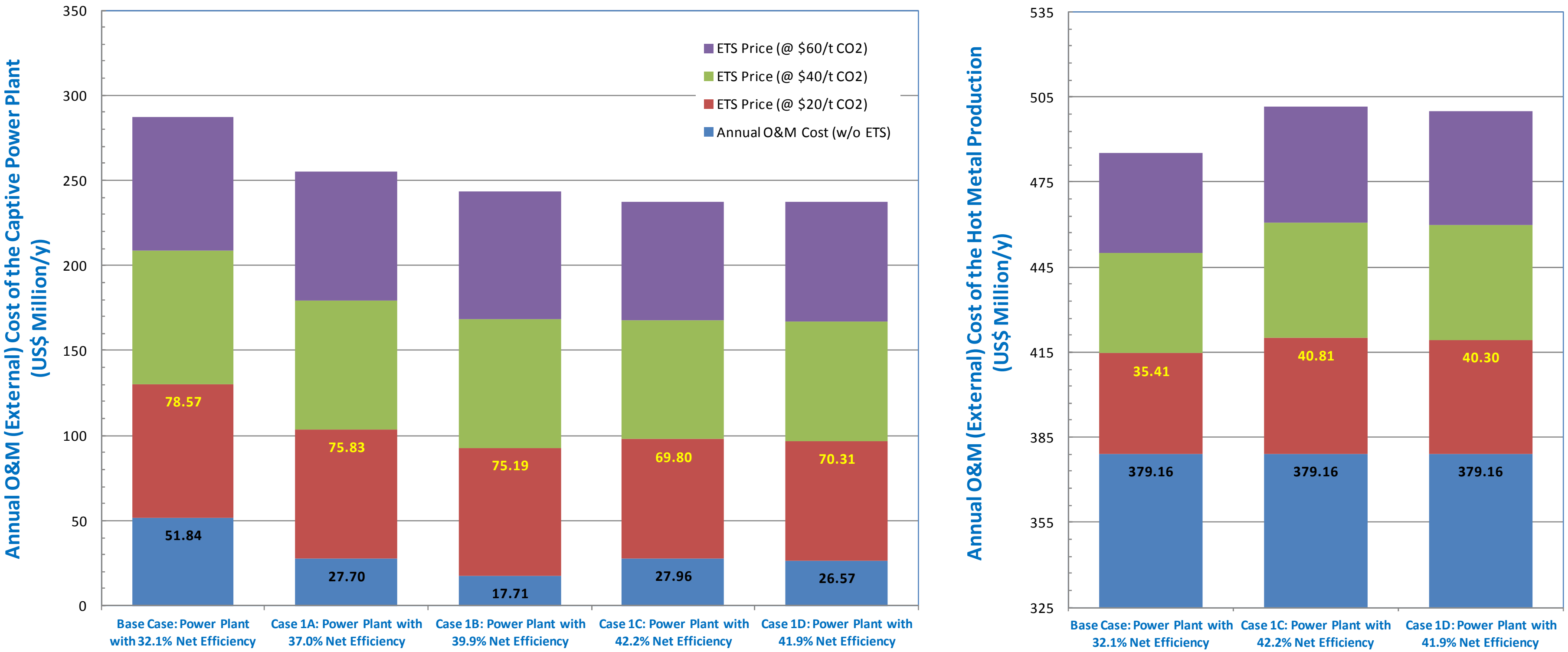

Figure F-12: Annual O&M (External Sourced) Cost of the Captive Power Plant and Hot Metal Production of the Reference Steel Mill with Different Captive Power Plant

6. ACKNOWLEDGEMENT

The cost analysis presented in this section of the report was done in-house solely by IEA Greenhouse Gas R&D Programme (IEAGHG).

We would like to thank to the contribution and support provided by the Steering Committee of this project and the comments given by Tata Steel Consulting and Alstom.

The objective of this section is to provide information that could help better understand cost impacts when implementing CO_2 capture in an integrated steel mill. This study has demonstrated that the choice of captive power plant could affect the reporting of the CO_2 avoidance cost.

Finally, it should be noted that significant care and diligence were undertaken in determining the accuracy of the information provided. However, the use of any information or its consequences should not be the responsibility of the authors or the organisation issuing this report.

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume I: Estimating the Cost of Steel Production from an Integrated Steel Mill (Reference Case)

Annex 1

Discounted Cash Flow for Each Major Processes (REFERENCE Integrated Steel Mill)

INDEX

APPENDIX 1-A: ANNUAL CASH FLOW (COKE PRODUCTION)

COKE PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (REFERENCE CASE)

ANNUAL PRODUCTION:

			1	2	3	4	5	6	7	8	9	10	11	12	13
Coke	To: Blast Furnace	tonnes	704,120	1,056,180	1,267,417	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241
Coke Breeze	To: Sinter Plant	tonnes	111,139	166,708	200,050	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278
Total			815,259	1,222,889	1,467,467	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519

			14	15	16	17	18	19	20	21	22	23	24	25
Coke	To: Blast Furnace	tonnes	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241
Coke Breeze	To: Sinter Plant	tonnes	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278
Total			1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519

Period		1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Hard Coking Coal		$119,579	$179,369	$215,243	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159
Semi-soft Coking Coal		$61,042	$91,564	$109,876	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085
Sub-Total		**$180,622**	**$270,933**	**$325,119**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**
Consummables and Other Utilities (US$ '000)														
Raw Water		$166	$250	$300	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333
Sub-Total		**$166**	**$250**	**$300**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Coke Oven Gas	(for Export)	($45,139)	($67,709)	($81,251)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)
Blast Furnace Gas	(for Oven Underfire Heating)	$11,519	$17,278	$20,733	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037
Electricity		$3,773	$5,462	$6,475	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150
Steam		$1,333	$1,999	$2,399	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666
Sub-Total		**($28,515)**	**($42,970)**	**($51,644)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS														
By-Products (US$ '000)														
Crude Tar		($5,903)	($8,854)	($10,625)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)
Benzole (BTX)		($4,599)	($6,898)	($8,278)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)
Sulphur		($210)	($315)	($378)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)
Sub-Total		**($10,711)**	**($16,067)**	**($19,281)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour		$12,784	$17,672	$20,605	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560
Maintenance & Spares		$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
Sub-Total		**$32,784**	**$37,672**	**$40,605**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**
Misc. O&M (US$ '000)														
Misc. Works Expenses		$4,900	$7,351	$8,821	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801
Misc. Operational Expenses		$1,851	$2,777	$3,332	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703
Sub-Total		**$6,752**	**$10,127**	**$12,153**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**
ANNUAL OPERATING COST (COKE PRODUCTION) - $'000		**$181,098**	**$259,944**	**$307,252**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**

Period		14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Hard Coking Coal		$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159
Semi-soft Coking Coal		$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085
Sub-Total		**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**
Consummables and Other Utilities (US$ '000)													
Raw Water		$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333
Sub-Total		**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Coke Oven Gas	(for Export)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)	($90,279)
Blast Furnace Gas	(for Oven Underfire Heating)	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037
Electricity		$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150	$7,150
Steam		$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666	$2,666
Sub-Total		**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**	**($57,426)**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS													
By-Products (US$ '000)													
Crude Tar		($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)
Benzole (BTX)		($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)
Sulphur		($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)
Sub-Total		**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**
FIXED O&M COST & MISC. OPEX													
Fixed O&M (US$ '000)													
Labour		$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560
Maintenance & Spares		$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
Sub-Total		**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**
Misc. O&M (US$ '000)													
Misc. Works Expenses		$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801
Misc. Operational Expenses		$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703
Sub-Total		**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**
ANNUAL OPERATING COST (COKE PRODUCTION) - $'000		**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**	**$338,791**

APPENDIX 1-B: ANNUAL CASH FLOW (SINTER PRODUCTION)

SINTER PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (REFERENCE CASE)

				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
ANNUAL PRODUCTION:																												
Sinter	To: Blast Furnace	Tonnes		2,222,779	3,334,169	4,001,003	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559
			Total	2,222,779	3,334,169	4,001,003	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																												
Raw Materials (US$ '000)																												
Sinter Fines (Brazil)				$117,244	$175,866	$211,039	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488
Sinter Fines (Australia)				$14,575	$21,862	$26,234	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149
Sinter Fines (Sweden)				$10,473	$15,709	$18,851	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945
Limestone				$6,020	$9,030	$10,836	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040
Quartzite				$480	$720	$864	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960
Olivine				$768	$1,152	$1,382	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536
			Sub-Total	**$149,559**	**$224,338**	**$269,206**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**
Consummables and Other Utilities (US$ '000)																												
Raw Water				$75	$113	$135	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150
			Sub-Total	**$75**	**$113**	**$135**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																												
Energy and Reductants (US$ '000)																												
Coke Breeze	(ex Coke Plant)			$24,688	$35,437	$41,886	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185	$46,185
Reclaimed Coke	(ex BF Screens)			$422	$634	$760	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845
Coke Oven Gas	(for Sinter Plant Ignition Fuel)			$1,585	$2,378	$2,854	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171
Electricity				$9,406	$13,615	$16,140	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824	$17,824
			Sub-Total	**$36,102**	**$52,063**	**$61,640**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**	**$68,024**
Raw Materials and Recycled Materials (US$ '000)																												
Lime	(ex Lime Plant)			$2,309	$3,353	$3,980	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397	$4,397
Screenings (excl. Coke)	(ex BF Screens)			$939	$1,409	$1,691	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879
BF Dust	(ex Blast Furnace)			$893	$1,339	$1,607	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786
HM Losses + Desulph. Slag	(ex HM Desulphurisation)			$468	$701	$842	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935
LD Slag	(ex BOF)			$2,053	$3,080	$3,696	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107
LD Dust & Sludge	(ex BOF)			$1,945	$2,918	$3,502	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891
Mill Scale	(ex Continuous Caster)			$368	$552	$662	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735
Mill Scale	(ex HRM)			$594	$891	$1,069	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188
			Sub-Total	**$9,570**	**$14,244**	**$17,048**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**	**$18,918**
FIXED O&M COST & MISC. OPEX																												
Fixed O&M (US$ '000)																												
Labour				$14,335	$19,858	$23,171	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380
Maintenance & Spares				$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000
			Sub-Total	**$25,335**	**$30,858**	**$34,171**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**
Misc. O&M (US$ '000)																												
Misc. Works Expenses				$1,603	$2,404	$2,885	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206
Misc. Operational Expenses				$801	$1,202	$1,443	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603
			Sub-Total	**$2,404**	**$3,606**	**$4,328**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**
ANNUAL OPERATING COST (SINTER PRODUCTION) - $'000				**$223,045**	**$325,222**	**$386,528**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**	**$427,399**

APPENDIX 1-C: ANNUAL CASH FLOW (HOT METAL PRODUCTION)

HOT METAL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (REFERENCE CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Hot Metal	To: Steelmaking	Tonnes		1,947,131	2,920,697	3,504,836	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263
			Total	1,947,131	2,920,697	3,504,836	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coal (PCI)			$44,745	$67,118	$80,542	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491
		Sub-Total	**$44,745**	**$67,118**	**$80,542**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**
Raw Materials (US$ '000)																											
Lump Ore (Australia)			$25,534	$38,301	$45,962	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069
Pellets (Brazil)			$77,013	$115,520	$138,624	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026
Limestone			$610	$915	$1,098	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220
Quartzite			$388	$582	$699	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776
Calcium Carbide Powder			$5,084	$7,626	$9,151	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168
		Sub-Total	**$108,630**	**$162,944**	**$195,533**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**
Consummables and Other Utilities (US$ '000)																											
Refractories (excl. Blast Furnace)			$2,076	$3,113	$3,736	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151
Raw Water			$198	$297	$356	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396
		Sub-Total	**$2,273**	**$3,410**	**$4,092**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Lump Coke	(ex Coke Plant)		$156,410	$224,508	$265,367	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606	$292,606
Reclaimed Coke	(to Sinter Plant)		($418)	($627)	($753)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)
Coke Oven Gas	(for Hot Stove Heating)		$2,438	$3,657	$4,389	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876
Coke Oven Gas	(for Ancilliary Users)		$1,262	$1,894	$2,272	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525
Blast Furnace Gas	(for Export)		($69,675)	($104,513)	($125,415)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)
Electricity	(for Iron Making incl. HM Desulphurisation & Slag Granulation)		$25,933	$37,536	$44,498	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140	$49,140
Electricity	(for Ancilliary Users)		$1,274	$1,844	$2,187	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415	$2,415
Steam			$172	$258	$310	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344	$344
		Sub-Total	**$117,397**	**$164,558**	**$192,855**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**	**$211,719**
Raw Materials and Recycled Materials (US$ '000)																											
Sinter	(ex Sinter Plant)		$223,045	$325,222	$386,528	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399	$427,399
Oxygen	(ex ASU)		$6,864	$9,095	$10,434	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326	$11,326
Screenings (excl. Coke)	(to Sinter Plant)		($930)	($1,395)	($1,674)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)
BF Dust	(to Sinter Plant)		($884)	($1,326)	($1,591)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)
HM Losses + Desulph. Slag	(to Sinter Plant)		($463)	($694)	($833)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)
		Sub-Total	**$227,633**	**$330,903**	**$392,865**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**	**$434,173**
Waste Processing and Disposal Cost																											
Waste Processing Fee (US$ '000)																											
Slag Processing Fee (De-S Slag)			$248	$372	$446	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496
BF Sludge Disposal Fee			$159	$238	$286	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318
De-S Slag Disposal Fee			$144	$216	$259	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288
		Sub-Total	**$551**	**$826**	**$991**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																											
By-Products (US$ '000)																											
Granulated BF Slag			($8,890)	($13,335)	($16,002)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)
		Sub-Total	**($8,890)**	**($13,335)**	**($16,002)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$17,155	$23,665	$27,570	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174
Maintenance & Spares			$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880
		Sub-Total	**$42,035**	**$48,545**	**$52,450**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$5,202	$7,803	$9,363	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403
Misc. Operational Expenses			$650	$975	$1,170	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300
		Sub-Total	**$5,852**	**$8,778**	**$10,533**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**	**$11,704**
ANNUAL OPERATING COST (HOT METAL PRODUCTION) - $'000			**$540,226**	**$773,747**	**$913,860**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**	**$1,007,269**

LIQUID STEEL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (REFERENCE CASE)

Item	Note	Unit	1	2	3	4	5	6	7	8	9	10	11	12
ANNUAL PRODUCTION:														
Liquid Steel	To: Casting	Tonnes	2,172,614	3,258,921	3,910,706	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228
		Total	2,172,614	3,258,921	3,910,706	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228
		Period	1	2	3	4	5	6	7	8	9	10	11	12
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Raw Materials (US$ '000)														
Pellets			$1,188	$1,783	$2,139	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377
Merchant Scrap (Rotterdam - Mixed)			$57,626	$86,439	$103,727	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252
FeMnC			$33,534	$50,301	$60,361	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068
FeSi75			$10,756	$16,134	$19,361	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513
Desox Al			$7,198	$10,796	$12,956	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395
Burnt Dolomite			$2,170	$3,254	$3,905	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339
		Sub-Total	**$112,472**	**$168,708**	**$202,450**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**
Consummables and Other Utilities (US$ '000)														
Refractories (Steelmaking)			$6,441	$9,661	$11,593	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881
Electrodes (Ladle Metallurgy)			$2,644	$3,966	$4,760	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289
Raw Water			$95	$143	$171	$190	$190	$190	$190	$190	$190	$190	$190	$190
		Sub-Total	**$9,180**	**$13,770**	**$16,524**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Coke Oven Gas	(for Ladle Metallurgy)		$4,536	$6,804	$8,165	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073
Basic Oxygen Furnace Gas	(for Export)		($12,891)	($19,336)	($23,203)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)
Electricity	(for Steelmaking incl. Ladle Metallurgy)		$12,900	$18,672	$22,135	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444
Steam	(for Export)		($1,664)	($2,496)	($2,995)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)
		Sub-Total	**$2,882**	**$3,644**	**$4,102**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**
Raw Materials and Recycled Materials (US$ '000)														
Hotmetal	(ex Iron Making)		$540,226	$773,747	$913,860	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269
Lime	(ex Lime Plant)		$15,686	$22,776	$27,030	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866
Oxygen	(ex ASU)		$8,384	$11,109	$12,744	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834
Scrap (Internal)	(ex Ladle Metallurgy, Caster, HRM)		$26,853	$40,280	$48,335	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706
LD Dust & Sludge	(to Sinter Plant)		($1,925)	($2,888)	($3,466)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)
LD Slag	(to Sinter Plant)		($2,032)	($3,048)	($3,658)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)
		Sub-Total	**$587,191**	**$841,976**	**$994,846**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**
Waste Processing and Disposal Cost														
Waste Processing Fee (US$ '000)														
Slag Processing Fee (LD Slag)			$1,440	$2,160	$2,592	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880
Slag Processing Fee (Ladle Slag)			$101	$152	$182	$203	$203	$203	$203	$203	$203	$203	$203	$203
LD Slag Disposal Fee			$345	$517	$621	$690	$690	$690	$690	$690	$690	$690	$690	$690
Ladle Slag Disposal Fee			$1,520	$2,280	$2,736	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040
		Sub-Total	**$3,406**	**$5,109**	**$6,131**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS														
By-Products (US$ '000)														
LD Slag			($225)	($337)	($405)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)
		Sub-Total	**($225)**	**($337)**	**($405)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour			$20,727	$28,976	$33,925	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224
Maintenance & Spares			$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950
		Sub-Total	**$43,677**	**$51,926**	**$56,875**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**
Misc. O&M (US$ '000)														
Misc. Works Expenses			$5,369	$8,053	$9,664	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738
Misc. Operational Expenses			$1,422	$2,133	$2,560	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844
		Sub-Total	**$6,791**	**$10,186**	**$12,223**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**
ANNUAL OPERATING COST (LIQUID STEEL PRODUCTION) - $'000			**$765,374**	**$1,094,981**	**$1,292,746**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**

Item	Note	Unit	13	14	15	16	17	18	19	20	21	22	23	24	25
ANNUAL PRODUCTION:															
Liquid Steel	To: Casting	Tonnes	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228
		Total	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228
		Period	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Raw Materials (US$ '000)															
Pellets			$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377
Merchant Scrap (Rotterdam - Mixed)			$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252
FeMnC			$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068
FeSi75			$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513
Desox Al			$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395
Burnt Dolomite			$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339
		Sub-Total	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**
Consummables and Other Utilities (US$ '000)															
Refractories (Steelmaking)			$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881
Electrodes (Ladle Metallurgy)			$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289
Raw Water			$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190
		Sub-Total	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Coke Oven Gas	(for Ladle Metallurgy)		$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073
Basic Oxygen Furnace Gas	(for Export)		($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)
Electricity	(for Steelmaking incl. Ladle Metallurgy)		$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444	$24,444
Steam	(for Export)		($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)	($3,328)
		Sub-Total	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**	**$4,407**
Raw Materials and Recycled Materials (US$ '000)															
Hotmetal	(ex Iron Making)		$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269	$1,007,269
Lime	(ex Lime Plant)		$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866	$29,866
Oxygen	(ex ASU)		$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834	$13,834
Scrap (Internal)	(ex Ladle Metallurgy, Caster, HRM)		$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706
LD Dust & Sludge	(to Sinter Plant)		($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)
LD Slag	(to Sinter Plant)		($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)
		Sub-Total	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**	**$1,096,760**
Waste Processing and Disposal Cost															
Waste Processing Fee (US$ '000)															
Slag Processing Fee (LD Slag)			$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880
Slag Processing Fee (Ladle Slag)			$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203
LD Slag Disposal Fee			$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690
Ladle Slag Disposal Fee			$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040
		Sub-Total	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS															
By-Products (US$ '000)															
LD Slag			($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)
		Sub-Total	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**
FIXED O&M COST & MISC. OPEX															
Fixed O&M (US$ '000)															
Labour			$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224
Maintenance & Spares			$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950
		Sub-Total	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**
Misc. O&M (US$ '000)															
Misc. Works Expenses			$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738
Misc. Operational Expenses			$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844
		Sub-Total	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**
ANNUAL OPERATING COST (LIQUID STEEL PRODUCTION) - $'000			**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**	**$1,424,589**

APPENDIX 1-E: ANNUAL CASH FLOW (SLAB CASTING)

CONTINUOUS CASTING

Application of CO_2 Capture to an Integrated Steelworks (REFERENCE CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Slab	To: Reheat Furnaces	Tonnes		0	0	0	2,105,263	3,157,895	3,789,474	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526
			Total	0	0	0	2,105,263	3,157,895	3,789,474	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Consummables and Other Utilities (US$ '000)																											
Refractories (Casters)			$2,785	$4,178	$5,013	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571
Casting Powder			$1,128	$1,693	$2,031	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257
Raw Water			$208	$311	$374	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415
		Sub-Total	**$4,121**	**$6,182**	**$7,418**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Tundish Heating etc...)		$383	$575	$690	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766
Electricity			$2,873	$4,159	$4,930	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444	$5,444
		Sub-Total	**$3,256**	**$4,733**	**$5,620**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**	**$6,211**
Raw Materials and Recycled Materials (US$ '000)																											
Liquid Steel	(ex Steelmaking)		$765,374	$1,094,981	$1,292,746	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589	$1,424,589
Oxygen	(ex ASU)		$314	$416	$477	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518	$518
Scrap (Internal)	(to BOS Furnace)		($10,509)	($15,764)	($18,917)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)
Mill Scales	(to Sinter Plant)		($362)	($543)	($652)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)
		Sub-Total	**$754,816**	**$1,079,090**	**$1,273,654**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**	**$1,403,364**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$19,646	$26,743	$31,001	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840
Maintenance & Spares			$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636
		Sub-Total	**$35,282**	**$42,379**	**$46,637**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$2,953	$4,429	$5,315	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905
Misc. Operational Expenses			$478	$717	$860	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956
		Sub-Total	**$3,431**	**$5,146**	**$6,175**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**
ANNUAL OPERATING COST (CONTINUOUS CASTING) - $'000			**$800,906**	**$1,137,530**	**$1,339,505**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**	**$1,474,154**

LIME PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (REFERENCE CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Lime	To: Steelmaking	Tonnes		150,978	226,467	271,761	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956
	To: Sinter Plant	Tonnes		22,228	33,342	40,010	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456
			Total	173,206	259,809	311,771	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412

			Period	14	15	16	17	18	19	20	21	22	23	24	25
Lime	To: Steelmaking	Tonnes		301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956
	To: Sinter Plant	Tonnes		44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456
			Total	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Raw Materials (US$ '000)															
Limestone			$6,805	$10,208	$12,250	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611
		Sub-Total	**$6,805**	**$10,208**	**$12,250**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Coke Oven Gas	(for Lime Kiln)		$6,138	$9,207	$11,049	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277
Electricity			$687	$995	$1,179	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302
		Sub-Total	**$6,825**	**$10,202**	**$12,228**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**
FIXED O&M COST & MISC. OPEX															
Fixed O&M (US$ '000)															
Labour			$1,786	$2,491	$2,914	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196
Maintenance & Spares			$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280
		Sub-Total	**$3,066**	**$3,771**	**$4,194**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**
Misc. O&M (US$ '000)															
Misc. Works Expenses			$1,299	$1,949	$2,338	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598
		Sub-Total	**$1,299**	**$1,949**	**$2,338**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**
ANNUAL OPERATING COST (LIME PRODUCTION) - $'000			**$17,996**	**$26,130**	**$31,010**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**

		Period	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Raw Materials (US$ '000)														
Limestone			$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611
		Sub-Total	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Coke Oven Gas	(for Lime Kiln)		$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277	$12,277
Electricity			$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302	$1,302
		Sub-Total	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**	**$13,579**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour			$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196
Maintenance & Spares			$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280
		Sub-Total	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**	**$4,476**
Misc. O&M (US$ '000)														
Misc. Works Expenses			$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598
		Sub-Total	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**	**$2,598**
ANNUAL OPERATING COST (LIME PRODUCTION) - $'000			**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**	**$34,263**

OXYGEN PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (REFERENCE CASE)

ANNUAL PRODUCTION:

			Period 1	2	3	4	5	6	7	8	9	10	11	12	13
Oxygen	To: Blast Furnace	nm³	95,046,031	142,569,046	171,082,856	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062
	To: Steelmaking	nm³	116,092,839	174,139,259	208,967,111	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679
	To: Continuous Caster	nm³	4,345,228	6,517,843	7,821,411	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457
	To: HRM	nm³	5,263,158	7,894,737	9,473,684	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316
	Buffer Requirements	nm³	22,074,726	33,112,088	39,734,506	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451
	Total		242,821,982	364,232,973	437,079,568	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965

			Period 14	15	16	17	18	19	20	21	22	23	24	25
Oxygen	To: Blast Furnace	nm³	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062
	To: Steelmaking	nm³	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679
	To: Continuous Caster	nm³	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457
	To: HRM	nm³	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316
	Buffer Requirements	nm³	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451
	Total		485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965

	Period 1	2	3	4	5	6	7	8	9	10	11	12	13
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Electricity	$17,661	$25,563	$30,305	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466
Steam	$159	$238	$286	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318
Sub-Total	**$17,820**	**$25,802**	**$30,591**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS													
By-Products (US$ '000)													
Liquid Argon	($7,009)	($10,513)	($12,616)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)
Sub-Total	**($7,009)**	**($10,513)**	**($12,616)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**
FIXED O&M COST & MISC. OPEX													
Fixed O&M (US$ '000)													
Labour	$1,880	$2,585	$3,008	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290
Maintenance & Spares	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250
Sub-Total	**$5,130**	**$5,835**	**$6,258**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**
ANNUAL OPERATING COST (OXYGEN PRODUCTION) - $'000	**$15,941**	**$21,123**	**$24,233**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**

	Period 14	15	16	17	18	19	20	21	22	23	24	25
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS												
Energy and Reductants (US$ '000)												
Electricity	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466	$33,466
Steam	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318
Sub-Total	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**	**$33,783**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS												
By-Products (US$ '000)												
Liquid Argon	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)
Sub-Total	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**
FIXED O&M COST & MISC. OPEX												
Fixed O&M (US$ '000)												
Labour	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290
Maintenance & Spares	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250
Sub-Total	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**
ANNUAL OPERATING COST (OXYGEN PRODUCTION) - $'000	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**	**$26,306**

APPENDIX 1-H: ANNUAL CASH FLOW (POWER PLANT)

ELECTRICITY PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (REFERENCE CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Electricity	To: Coke Plant	MWh		28,534	42,801	51,361	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068
	To: Sinter Plant	MWh		71,129	106,693	128,032	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258
	To: Iron Making & Ancilliary	MWh		205,739	308,608	370,330	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478
	To: Steelmaking	MWh		97,549	146,323	175,588	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097
	To: Continuous Casting	MWh		21,726	32,589	39,107	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452
	To: Reheat Furnaces & HRM	MWh		210,526	315,789	378,947	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053
	To: Lime Plant	MWh		5,196	7,794	9,353	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392
	To: Oxygen Plant	MWh		133,552	200,328	240,394	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104
	To: Off-Sites & Losses	MWh		26,280	39,420	47,304	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560
			Total	800,231	1,200,347	1,440,416	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463

			Period	14	15	16	17	18	19	20	21	22	23	24	25
Electricity	To: Coke Plant	MWh		57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068
	To: Sinter Plant	MWh		142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258
	To: Iron Making & Ancilliary	MWh		411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478
	To: Steelmaking	MWh		195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097
	To: Continuous Casting	MWh		43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452
	To: Reheat Furnaces & HRM	MWh		421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053
	To: Lime Plant	MWh		10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392
	To: Oxygen Plant	MWh		267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104
	To: Off-Sites & Losses	MWh		52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560
			Total	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463	1,600,463

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Natural Gas		$16,602	$24,902	$29,883	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203
	Sub-Total	**$16,602**	**$24,902**	**$29,883**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**
Consummables and Other Utilities (US$ '000)														
Chemicals & Consummables		$3,940	$5,910	$7,092	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880
	Sub-Total	**$3,940**	**$5,910**	**$7,092**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Basic Oxygen Furnace Gas		$12,891	$19,336	$23,203	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782
Blast Furnace Gas		$58,157	$87,235	$104,682	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313
	Sub-Total	**$71,047**	**$106,571**	**$127,885**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour		$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760
Maintenance & Spares		$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000
	Sub-Total	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**
ANNUAL OPERATING COST (ELECTRICITY PRODUCTION) - $'000		**$102,349**	**$148,143**	**$175,620**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**

	Period	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Natural Gas		$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203	$33,203
	Sub-Total	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**	**$33,203**
Consummables and Other Utilities (US$ '000)													
Chemicals & Consummables		$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880
	Sub-Total	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Basic Oxygen Furnace Gas		$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782
Blast Furnace Gas		$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313
	Sub-Total	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**	**$142,095**
FIXED O&M COST & MISC. OPEX													
Fixed O&M (US$ '000)													
Labour		$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760	$3,760
Maintenance & Spares		$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000	$7,000
	Sub-Total	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**	**$10,760**
ANNUAL OPERATING COST (ELECTRICITY PRODUCTION) - $'000		**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**	**$193,938**

APPENDIX 1-I: ANNUAL CASH FLOW (REHEATING AND HOT ROLLING MILLS)

HOT ROLLED COIL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (REFERENCE CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Hot Rolled Coil	To: Sales	Tonnes		2,000,000	3,000,000	3,600,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000
			Total	2,000,000	3,000,000	3,600,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Consummables and Other Utilities (US$ '000)																											
Works Back Up Rolls	(for HSM)		$4,500	$6,750	$8,100	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000
Banding	(for Finish Products)		$180	$270	$324	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360
Raw Water			$454	$681	$817	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908
		Sub-Total	**$5,134**	**$7,701**	**$9,241**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Reheating Furnace)		$28,796	$43,194	$51,832	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592
Electricity			$27,840	$40,297	$47,771	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754	$52,754
		Sub-Total	**$56,636**	**$83,491**	**$99,604**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**	**$110,346**
Raw Materials and Recycled Materials (US$ '000)																											
Slab	(ex Continuous Casting)		$800,906	$1,137,530	$1,339,505	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154	$1,474,154
Oxygen	(ex ASU)		$380	$504	$578	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627	$627
Scrap (Internal)	(to BOS Furnace)		($16,294)	($24,441)	($29,329)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)
Mill Scales	(to Sinter Plant)		($585)	($877)	($1,052)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)
		Sub-Total	**$784,408**	**$1,112,716**	**$1,309,701**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**	**$1,441,024**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$25,539	$35,348	$41,233	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157
Maintenance & Spares			$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000
		Sub-Total	**$61,539**	**$71,348**	**$77,233**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$3,874	$5,810	$6,973	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747
Misc. Operational Expenses			$721	$1,082	$1,298	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443
		Sub-Total	**$4,595**	**$6,892**	**$8,271**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**
ANNUAL OPERATING COST (HOT ROLLED COIL PRODUCTION) - $'000			**$912,313**	**$1,282,149**	**$1,504,051**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**	**$1,651,985**

Synthesis Report:

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

Project Partners:

Swedish Energy Agency | swerea MEFOS | ieaghg

SSAB | LKAB

Project Management, Implementation and Delivery:

swerea MEFOS | TATA STEEL | SINTEF

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- Swedish Energy Agency
- LKAB
- SSAB
- Members of Swerea MEFOS

The project is managed by a Steering Committee whose members represent the different project partners mentioned above. This committee is chaired by Nils Edberg of SSAB.

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- Swerea MEFOS (lead organisation)
- Tata Steel Consulting
- Sintef Materials and Chemistry

Disclaimer:

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Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

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LIST OF ABBREVIATIONS

ASU	air separation unit (also known as oxygen plant)
BAT	best available technology
BF	blast furnace
BFG	blast furnace gas
BOF	basic oxygen furnace (also known LD or converter)
BOFG	basic oxygen furnace gas (also known as LDG or CG)
BOP	balance of plant
BOS	basic oxygen steelmaking
BREF	Best available technology reference document
BTX	benzene, toluene and xylene (also known as Benzole)
CAPEX	capital expenditure
CDQ	coke dry quenching
CG	converter gas (also known as BOFG or LDG)
COG	coke oven gas
De-S	desulphurised
dmtu	dry metric tonne unit
DRR	direct reduction rate
EAF	electric arc furnace
EBITDA	earnings before interest, tax, depreciation and amortisation
EOP	"End of Pipe" (refer to Cases 2A and 2B – capture of CO_2 from various flue gases)
EOS	emission optimised sintering process
ESP	electrostatic precipitator
EU27	European Union (27 member countries)
FeMnC	ferromanganese carbide
FeSi75	ferromanganese silicon (at least 75% silica content)
GAN	gaseous nitrogen
GAR	gaseous argon
GBFS	granulated blast furnace slag
GGBFS	granulated ground blast furnace slag
GOX	gaseous oxygen
GTCC	gas turbine combined cycle
HM	hot metal (also known as pig iron)
HRC	hot rolled coil
HRM	hot rolling mill (also known as HSM)
HS	hot stove
HSM	hot strip mill
IEAGHG	IEA Greenhouse Gas R&D Programme
IPPC	integrated pollution prevention control
JCR	jumbo coke reactor (also known as SCS)
LAR	liquid argon
LDG	Lint-Donawitz gas (also known BOFG or CG)
LIN	liquid nitrogen
LM	ladle metallurgy
LOX	liquid oxygen
MAC	main air compressor
MEA	mono-ethanol amine
MDEA	methyldiethanol amine
MDEA/Pz	blend of MDEA and piperazine
mtpy	million tonnes per year

NG	natural gas
NGCC	natural gas combined cycle
OBF	oxy-blast furnace (oxygen blown blast furnace)
OBF-PG	OBF processed gas
OBF-TG	OBF raw top gas
OHF	open hearth furnace
OPEX	operation expenditure
PCI	pulverized coal injection
PFD	process flow diagram
PFR kiln	parallel flow regenerative kiln
Pz	piperazine
RAR	reducing agent rate
RHF	rotary hearth furnace
SCS	single chamber system (also known as JCR)
SCR	selective catalytic reactor (for NOx removal from flue gases)
SM	secondary metallurgy
SOACT	state of the art clean technology for steel production (REFERENCE Handbook)
tcs	tonne of crude steel
TGR	top gas recycle
thm	tonne of hot metal
tls	tonne of liquid steel
TRT	top gas recycle turbine
WBF	walking beam furnace

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture

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Section A

Introduction and Study Objectives

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1. INTRODUCTION

The Executive Committee of IEA Greenhouse Gas R&D Programme (IEA GHG) has requested a study to be made evaluating the potential for CO_2 capture to reduce greenhouse gas emissions from an integrated steel mill and its associated cost.

In collaboration with Swerea MEFOS AB, this project was developed with co-funding support from the Swedish Energy Agency, SSAB, LKAB and Swerea MEFOS member companies. The project was initiated in January 2010.

Swerea MEFOS AB has retained the service of Corus Consulting PLC (now TATA Steel Consulting) to undertake the cost evaluation and financial modelling and also engaged SINTEF Materials and Chemistry to undertake the evaluation of post-combustion capture CO_2 modelling.

The primary goal of this project is to specify a **"REFERENCE"** integrated steel mill producing hot rolled coil and evaluate the cost and performance of the plant with and without CO_2 capture.

This document is a synthesis of the report submitted by Swerea MEFOS [1] to IEA Greenhouse Gas R&D Programme (IEA GHG) evaluating the cost of steel production from an integrated steel mill equipped with Post-Combustion CO_2 Capture using conventional MEA Solvent.

2. OBJECTIVES OF THE STUDY

The project team was requested by the Steering Committee to specify and evaluate the cost and performance of an integrated steel mill producing 4 million tonnes of hot rolled coil per year. The "REFERENCE" integrated steel mill without CO_2 capture would be designed based on specifications typical of average Western European Steel Mills.

Specifically, the study aims:

- To specify a conceptual "REFERENCE" integrated steel mill typical of Western European configurations and to evaluate its techno-economic performance with and without CO_2 capture.

- To determine the techno-economic performance, CO_2 emissions and CO_2 avoidance cost of the following cases:
  - A conceptual integrated steel mill typical to Western Europe as the "REFERENCE Case".
  - An end of pipe CO_2 capture using conventional MEA solvent at two different levels of CO_2 capture rate
  - An Oxygen Blast Furnace (OBF) and using MDEA/Pz solvent for CO_2 capture from the raw blast furnace top gas.

3. SCOPE OF THE REPORT

This report presents the techno-economic analysis of the cost of steel production of an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 capture technology situated in Coastal Region of

Western Europe producing 4 million tonnes of Hot Roll Coil (HRC) per year. The CO_2 Capture process is based on chemical absorption technology using conventional Mono Ethanol Amine (MEA) as solvent.

The study presents in detail the evaluation of two levels of CO_2 capture rate from an integrated steel mill as described below:

- *EOP-L1 Case (Case 2A)*
  For the End of Pipe Level 1 Case, the CO_2 is captured from the flue gases of the Hot Stoves (UNIT 300) and the Steam Generation Plant (UNIT 2000) resulting to ~50% CO_2 avoided.

- *EOP-L2 Case (Case 2B)*
  For the End of Pipe Level 2 Case, the CO_2 is captured from the flue gases of the Underfire Heaters of the Coke Oven Batteries (UNIT 100), the Hot Stoves (UNIT 300), the Lime Kiln (UNIT 1000), and the Steam Generation Plant (UNIT 2000) resulting to ~60% CO_2 avoided.

The scope of Volume 2 of this report is to define the assumptions used in the techno-economic evaluation of the study; and present the main results of the study. These include description of:

- Plant Location
- Battery Limit
- Raw materials, product, and by-products
- Process description
- Material balance
- Process gas network
- CO_2 balance

This report presents and highlights the methodology of the Techno-Economic Evaluation, the key assumptions used to estimate CAPEX and OPEX and the key results of the study for the Cases 2A and 2B (i.e. post-combustoin capture cases). It should be noted that it is no intention of this report to present the full engineering detail and design concept, as these are presented in the main report submitted by Swerea MEFOS [1].

4. NOTES TO THE READER

The intention of this study is to simulate the different techno-economic parameters of an average performing integrated steel mill. Therefore, it should be noted that the "REFERENCE" Steel Mill specified in this study is not necessarily to have the best performing steel mill that applies all the Best Available Technologies that are commercially available. Nonetheless, this will be based on a typical configuration that could be found in many European steel mills.

In choosing the technology for CO_2 capture, one of the selection criteria was based on the availability of performance and cost data that could be used for this assessment. In this regard, the choice of using MEA for Cases 2A and 2B, and MDEA/Pz for Case 3 as solvent to capture CO_2 are considered appropriate to demonstrate the cost of an integrated steel mill with CO_2 capture.

Additionally, it is not the objective of this study to optimise the integration of CO_2 capture plant into a steel mill as this could be very site specific. It should be emphasised that this study is focused on establishing a cost evaluation methodology to advance the understanding of the cost implications of deploying CO_2 capture in an integrated steel mill.

Finally, it is the intention of the authors to present every volumes of this report to be self containing. Therefore, all assumptions and the discussion of the background to them are presented in details in Volume 1. However, some of these discussions will be repeated within the text of Volumes 2 and 3 to ensure that these volumes could be read separately.

To summarise, Volume 1 of the report presents the design, assumptions, performance and economic details of a hypothetical steel mill which can be used as a basis to explore and comparing options for CO_2 emission reduction. Volume 2 of the report presents the analysis of a steel mill with conventional post-combustion capture options (i.e. capture of CO_2 from the different flue gases within the steel mill). Volume 3 presents an option where further efficiency could be gained through the use of novel technology – i.e. using oxy-blast furnace with top gas recycle; that could improve the economics of the capture of CO_2 from an integrated steel mill.

5. REFERENCE

[1] Hooey, L., Boden, A., and Larsson, M. (2011). **"CO_2 Capture Applied to the Integrated Steelmaking".** *MEFOS Report – 560025*

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Section B

Design Basis, Assumptions and Nomenclature

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1. BOUNDARY LIMIT

The definition of the boundary (battery) limit of the integrated steel mill is essential to formulate a clear account of the overall energy requirements and direct CO_2 emissions per tonne of steel produced (For this study – this should define the total CO_2 emitted per tonne of hot rolled coil).

A schematic representation of the boundary limit, material inputs and outgoing products, by-products and waste is illustrated in Figure B-1.

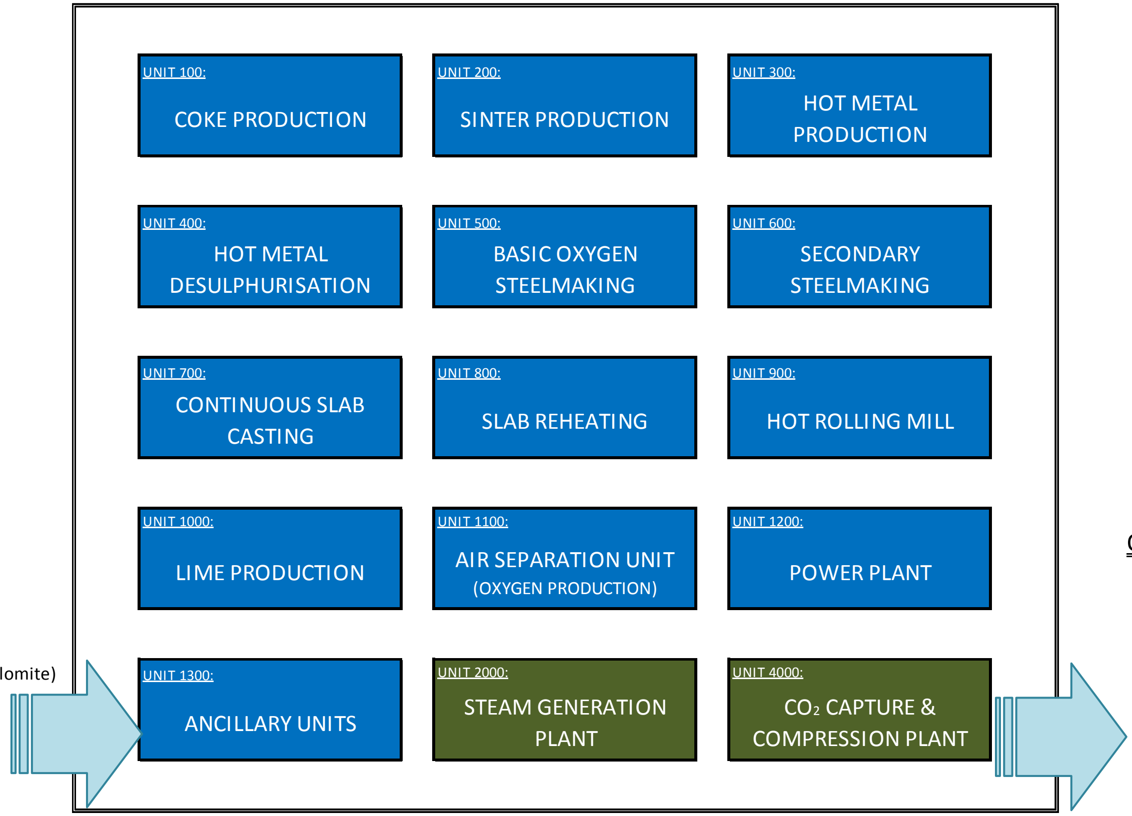
The steering committee agreed that the boundary limit should include the following unit processes:

- UNIT 100: Coke Plant
- UNIT 200: Sinter Plant
- UNIT 300: Blast Furnace and Hot Stoves (Iron Making Process)
- UNIT 400: Hot Metal Desulphurisation Plant
- UNIT 500: Basic Oxygen Steelmaking
- UNIT 600: Ladle Metallurgy
- UNIT 700: Continuous Casting
- UNIT 800: Reheating Furnace
- UNIT 900: Hot Rolling Mill
- UNIT 1000: Lime Plant
- UNIT 1100: Air Separation Unit – High Purity Oxygen Production
- UNIT 1200: Power Plant
- UNIT 1300: Ancillaries
- UNIT 2000: Steam Generation Plant
- UNIT 4000: CO_2 Capture and Compression Plant

Raw material handling, utilities, waste water treatment plant and other auxiliary equipment are assumed to be included in each unit.

INCOMING:

- Iron Ore Burdens (Fines, Lump & Pellet)
- Merchant Scrap
- Ferro Alloys (FeMnC, FeSi-75, Aluminium)
- Fluxes (Limestone, Quartzite, Olivine, CaC2, Burnt Dolomite)
- Coking Coal (Hard and Semi-Soft)
- PCI Coal
- Natural Gas
- Other Consummables and Additives



OUTGOING:

- Hot Rolled Coil
- Coking By-Products (Coal Tar, BTX and Sulphur)
- Slag (BF Granulated Slag, De-S Slag, BOF Slag, LM Slag)
- BF Sludge and Dust, MEA Sludge
- Liquid Argon
- Compressed Carbon Dioxide

- Emissions (Flue Gases, Diffuse and Fugitive)
- Vent Gases (Waste Nitrogen and Oxygen)

Figure B-1: Schematic representation of the Boundary Limit of the Steel Mill with Post-Combustion CO_2 Capture. [1]

The major raw materials for the steel production considered in the study are:

- Iron Ore Fines
- Iron Ore Pellets
- Lump Iron Ore
- Coking Coal
- PCI Coal
- Fluxes (Limestone, Quartzite, Olivine, Calcium Carbide, Burnt Dolomite)
- External Scrap (also referred to Merchant or Purchased Scrap)
- Ferro Alloys and Aluminium
- Natural Gas
- Other consumables (as specified in Annex I).

The product and by-products that are sold outside the boundary limit include:

- Hot Rolled Coil
- Crude Tar
- Benzole
- Sulphur
- Granulated BF Slag
- BOS Slag (also referred to LD Slag)
- Argon

The site will be handling several intermediate products used in the production of steel and these include:

- Coke
- Sinter
- Lime
- Hot Metal
- Liquid Steel
- Slab

Materials that are accounted as waste that goes to the landfill are:

- BF Sludge
- de-S Slag
- BOS Slag (also referred to LD Slag)
- LM Slag (also referred to SM Slag)
- MEA Sludge

Industrial gases and off-gases handled by the site include:

- Blast Furnace Gas
- Basic Oxygen Furnace Gas
- Coke Oven Gas
- Oxygen
- Nitrogen
- Argon
- Carbon Dioxide

Utilities that are available or produced within the boundary limit include:

- Steam
- Electricity
- Water (i.e. sea water, potable, machinery cooling water, condensates)

2. PLANT LOCATION AND LAYOUT

The steel mill is located along the Coastal Region of Western Europe. It should be noted that this location is representative to several integrated steel mills close to the Atlantic Coast of Europe.

The site is assumed to have:

- access to an existing port capable of handling all incoming raw materials
- access to natural gas via a pipeline connected to the main grid
- access to existing rail line adjacent to the steel mill

It is assumed that the steel mill is situated where there are no exceptional ground conditions that would lead to higher than normal construction costs. It is also assumed to be close to a deep sea, thus limiting the length of the sea water line (both submarine and sea water pump discharge line).

The site will have adequate road and rail network for delivery of raw materials, intermediate and products from stockyards to various points of the steel mill.

The site layout for the REFERENCE Steel Mill without CO_2 Capture and Steel Mills with Post-Combustion CO_2 Capture (for Cases EOP-L1 and EOP-L2) are shown in Figures B-2(a), B-2(b) and B-2(c). It should be noted that these figures are a conceptual representation of the steel mill, and the purpose of which is only to illustrate the minimum land footprint required by the steel mill and obtain a preliminary estimates for the pipeline length needed for transporting CO_2 within the site.

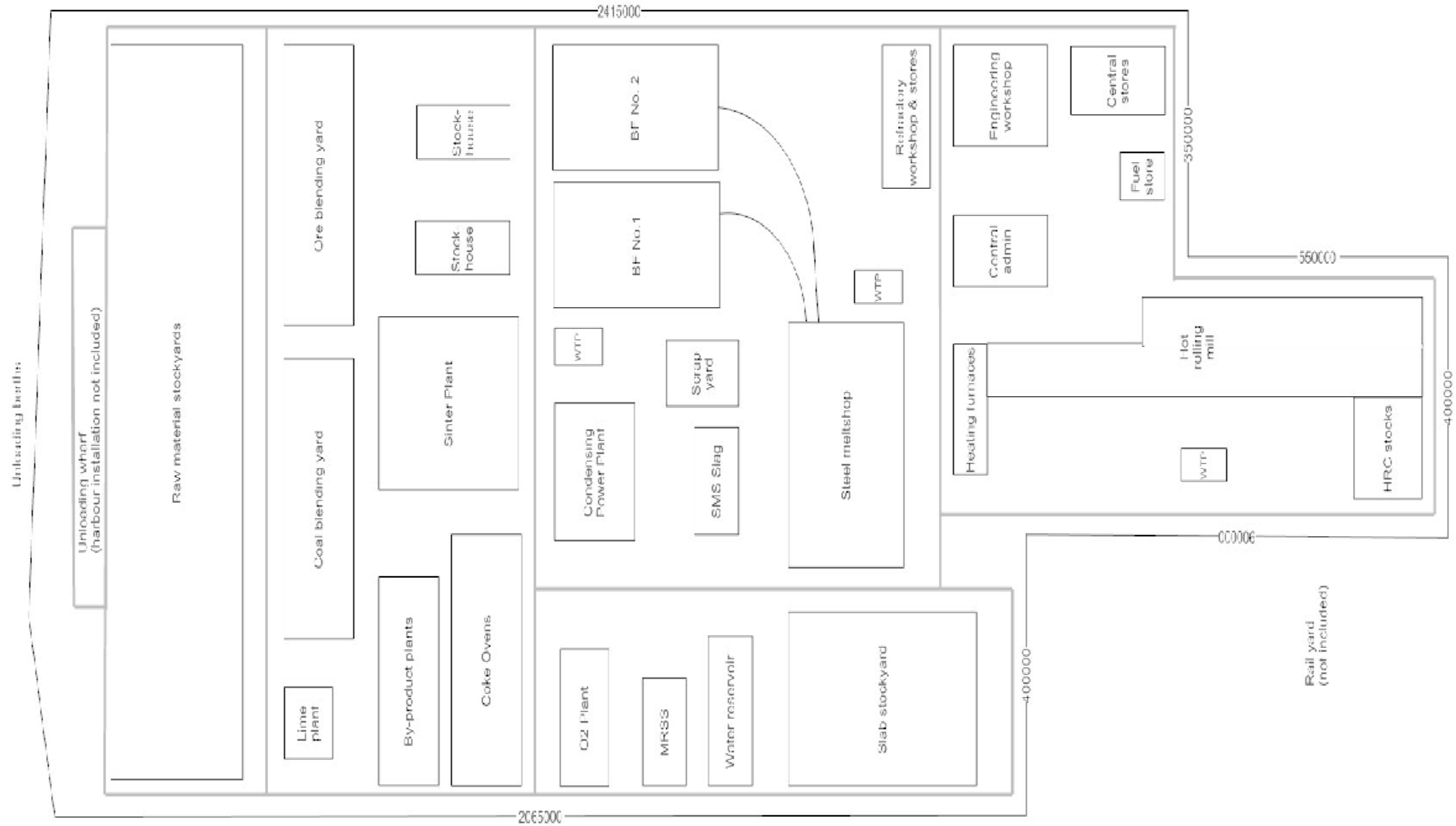


Figure B-2(a): Overview – Plant Layout of the REFERENCE Steel Mill

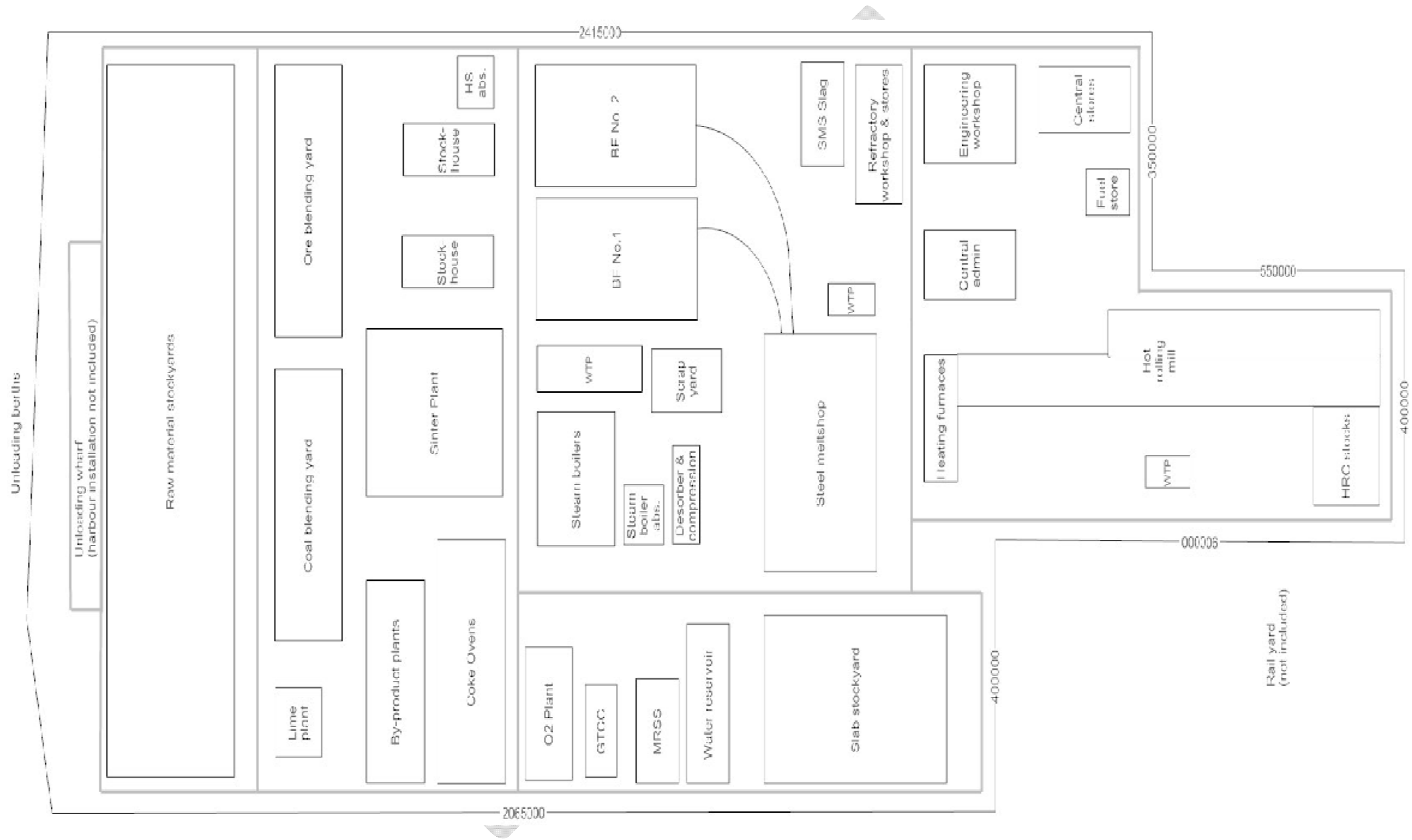


Figure B-2(b): Overview – Plant Layout of the Integrated Steel Mill with Post-Combustion CO_2 Capture (EOP-L1 Case)

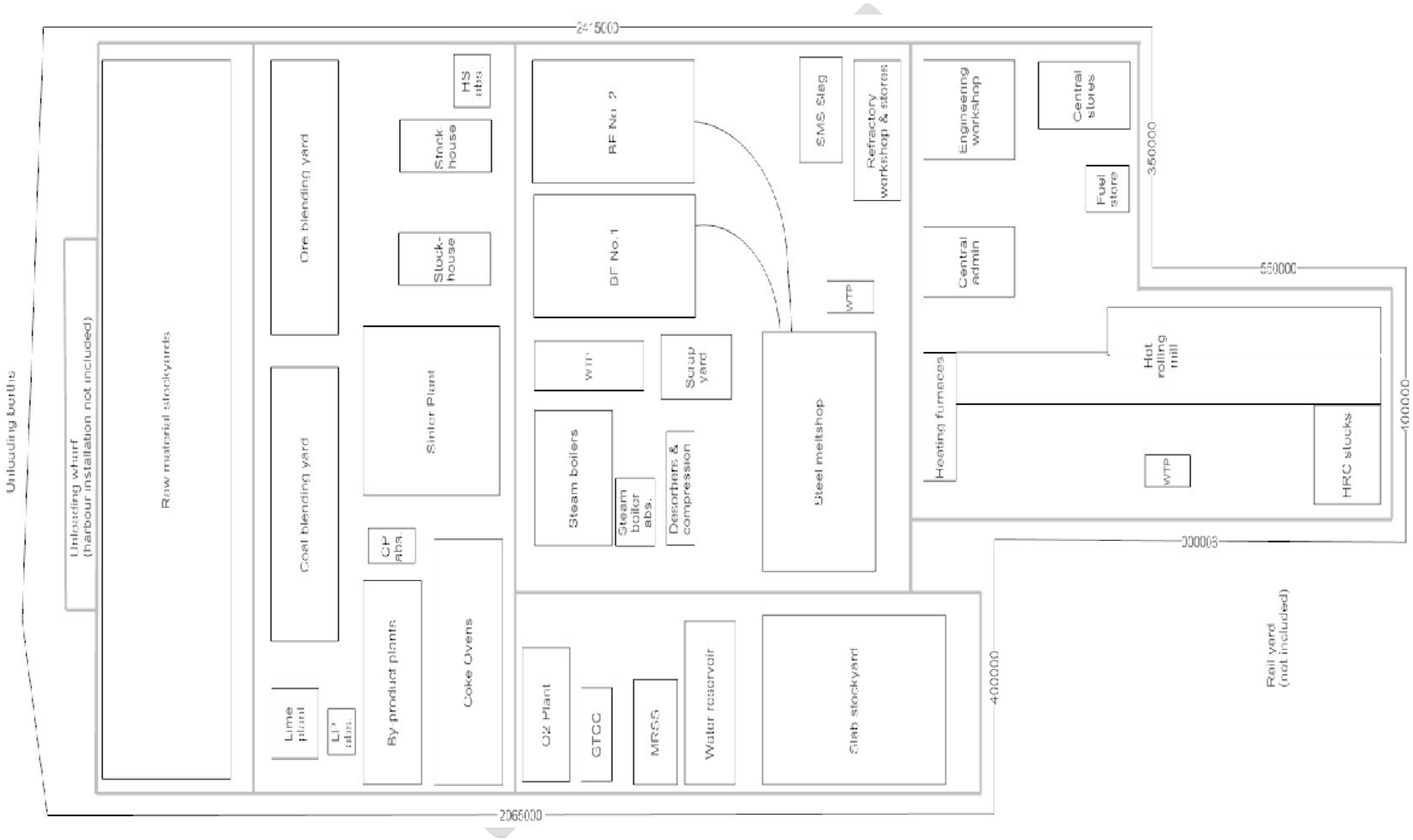


Figure B-2(c): Overview – Plant Layout of the Integrated Steel Mill with Post-Combustion CO_2 Capture (EOP-L2 Case)

3. ASSUMPTIONS: STEEL MILL WITH POST-COMBUSTION (END OF PIPE) CO_2 CAPTURE

The general assumptions used to evaluate the cost of the REFERENCE Steel Mill were also adopted for the evaluation of the cost of the integrated steel mill with Post-Combustion CO_2 Capture. This section summarises these assumptions. A more detailed description of these assumptions is presented in Annex 1.

3.1. Extra-Ordinary Assumptions

The following extra-ordinary assumptions used in the study include:

a) Only one type of steel product produced and sold.

It was assumed in the study that a standard grade hot rolled coil will be the only main product to be sold by the steel mill.

b) Balanced coke production

The study assumed that coke plant (UNIT 100) produces lump coke and coke breeze that are sufficient to meet the demands of the steel mill – i.e. there will be no export or import of coke.

c) Balanced electricity production

The captive power plant is assumed to produce electricity that is enough to supply the requirements of the whole steel mill. For the steel mills with post-combustion CO_2 capture (i.e. for Cases 2A and 2B), the study assumed that natural gas imported into the boundary limit is the primary fuel of the captive power plant. There will no import or export of electricity into or out of the defined boundary limit.

d) Plant ownership structure

The study assumed captive ownership of the lime plant (UNIT 1000), oxygen plant (UNIT 1100), power plant (UNIT 1200) and steam generation plant (UNIT 2000).

e) Utilisation of the off-gases

For all cases, the study assumed that all off-gases produced by the coke ovens (UNIT 100), blast furnace (UNIT 300) and basic oxygen steelmaking furnaces (UNIT 500) are recovered based on industry norm and used within the steel mill. There will be no export of off-gases or other form of energy (i.e. steam or hot water) from the steel mill.

For Cases EOP-L1 (Case 2A) and EOP-L2 (Case 2B) – i.e. steel mills with post-combustion CO_2 capture, all the excess off-gases not used by the integrated steel mill are delivered to the captive steam generation plant (UNIT 2000) to serve as its primary fuel.

In case of any surplus off-gas produced, this will be assumed to be flared. This should be in addition to flared off-gases which are normal to any operating steel mills. All off-gases that are considered lost or not recovered will also be accounted for as "flared".

Any deficit to the off-gas will be supplemented by the natural gas imported into the boundary limit.

f) Other operating considerations

- CO_2 emissions due to purchased pellets, burnt dolomites and merchant scrap will not be accounted as direct CO_2 emissions of the steel mill.

- Granulated BF Slag will not be given CO_2 emission credit – even if this could be considered as substitute clinker for the cement industry.

3.2. Key Assumptions

Key technical assumptions used in determining the heat and mass balances of individual processes are presented in Annex 1. These include the assumptions used in defining the operating parameters for the coke production (UNIT 100), ironmaking (UNIT 300) and steelmaking (UNIT 500).

For Cases EOP-L1 and EOP-L2, the study assumed the following with regard to the utilisation of the off-gases from the steel mill:

- COG would supply fuel to the following:
    - coke plant (UNIT 100)
    - sinter plant (UNIT 200)
    - hot stoves (UNIT 300)
    - reheating furnace (UNIT 800) and
    - lime plant (UNIT 1000)

- BFG would supply fuel to the following:
    - hot stoves (UNIT 300) and
    - steam generation plant (UNIT 2000)

- BOFG would supply fuel to the steam generation plant (UNIT 2000).

4. DESIGN BASIS - SITE SPECIFIC CONDITIONS

The engineering design basis for this study is presented in Annex 1. These include the definition for the following:

(a.) Ambient Conditions
(b.) Raw Water and Seawater properties that are available to the site
(c.) Steam Conditions supplied to the site
(d.) Electricity Grid within the Steel Mill

5. MATERIAL SPECIFICATIONS – RAW MATERIALS, PRODUCTS, INTERMEDIATE PRODUCTS, BY-PRODUCTS AND WASTE

All the materials – as enumerated in Section B-1 - involved in the production of the hot rolled coil are described in Volume 1, Section C of the report. The specifications of these materials are presented in Annex 2.

6. UNIT PROCESS NOMENCLATURE AND UNITS ARRANGEMENTS

With reference to the different PFD presented in this study, the list below presents the arrangements and nomenclatures used for each processes.

- Unit 100: Coke Production
  - 105: Coal Handling and Blending Facility
  - 110: Coke Oven Batteries
  - 120: Coke Quenching
  - 125: Coke Screening
  - 130: COG Cooling and Tar Separation
  - 131: Primary Gas Cooler
  - 132: Tar ESP
  - 133: Tar Recovery Unit and Tar Dehydrator
  - 140: Naphthalene Scrubber
  - 150: H_2S and NH_3 Scrubber
  - 155: H_2S and NH_3 Stripper
  - 160: Combine Claus Plant and NH_3 Cracker
  - 170: BTX Scrubber
  - 175: BTX Distillation
  - 180: Gas Exhauster and Gas Holder

- Unit 200: Sinter Production
  - 210: Raw Materials Handling and Blending Station
  - 220: Sinter Plant
  - 230: Gas Cleaning (from Sinter Strand) – Fabric Filter and ESP
  - 240: Sinter Crusher, Cooler and Screening
  - 250: Gas Cleaning (from Sinter Cooler) - ESP

- Unit 300: Hot Metal Production
  - 310: Raw Materials Handling, Blending and Feeding
  - 320: Blast Furnace
  - 330: BF Slag Granulation Plant
  - 340: Hot Stoves
  - 350: Recuperators
  - 360: Main Air Compression Plant
  - 370: BF Gas Cleaning - Cyclone and Scrubber
  - 380: Gas Holder
  - 1310: PCI Coal Preparation (Coal Mill) and Drying – part of ancillary unit

- Unit 400: Hot Metal Desulphurisation
  - 410: Hot Metal Desulphurisation Station
  - 420: Slag & HM Spillage Processing Unit

- Unit 500: Primary Steelmaking
  - 510: Basic Oxygen Furnace
  - 520: Slag Processing Unit
  - 530: Gas Recovery Hood and Waste Heat Boiler
  - 540: BOF Gas Cleaning – Cyclone and Scrubber
  - 550: Gas Holder

- Unit 600: Secondary Steelmaking (Ladle Metallurgy)
  - 610: Ladle Station

- Unit 700: Continuous Casting
  - 710: Continuous Slab Caster

- Unit 800 & 900: Reheating and Rolling Mills
  - 810: Reheating Furnaces
  - 820: Recuperators
  - 910: Hot Rolling Mill

- Unit 1000: Lime Production
  - 1010: Lime Kiln
  - 1020: Gas Cleaning – ESP
  - 1030: Screening

- Unit 1100: Air Separation Unit – Oxygen Production
  - 1110: Main Air Compressor
  - 1120: Air Pre-Cooling and Treatment
  - 1130: Main Heat Exchanger and Cryogenic Separation Plant
  - 1140: Liquid Product Storage
  - 1150: Product Evaporation and Compression Plant

- Unit 1200: Captive Power Plant
  - 1210: Gas Turbine Island
  - 1220: Electricity Generators
  - 1230: Heat Recovery Steam Generator
  - 1240: Steam Turbine Island

- Unit 2000: Steam Generation Plant
  - 1110: Boiler Island
  - 1120: Steam Delivery Manifolds

- Unit 4000: CO_2 Capture and Compression Plant
  - 3010: Flue Gas FD Fans
  - 3020: Direct Contact Coolers
  - 3030: Gas Holder
  - 3110: Absorber Column
  - 3120: Heat Integration and Exchange Networks
  - 3130: Flash Columns
  - 3140: Stripper Columns
  - 3200: CO_2 Compression Train

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Section C

Process Overview & Energy Performance of the Steel Mill

I N D E X

1. INTRODUCTION

The study assumed an integrated steel mill situated in the Coastal Region of the Western Europe producing 4 million tonnes of hot rolled coil per year. This steel works would be equipped with Post-Combustion (End of Pipe) CO_2 capture Technology based on conventional MEA solvent to reduce its greenhouse gas emissions.

This study evaluated two different cases for integrated steel mill with post-combustion CO2 capture; these cases involved the following:

- *EOP-L1 Case (Case 2A)*
  For the End of Pipe Level 1 Case, the CO_2 are captured from the flue gases of the Hot Stoves (UNIT 300) and the Steam Generation Plant (UNIT 2000) resulting in ~50% CO_2 avoided.
- *EOP-L2 Case (Case 2B)*
  For the End of Pipe Level 2 Case, the CO_2 are captured from the flue gases of the Underfire Heaters of the Coke Oven Batteries (UNIT 100), the Hot Stoves (UNIT 300), the Lime Kiln (UNIT 1000), and the Steam Generation Plant (UNIT 2000) resulting in ~60% CO_2 avoided.

The production of the hot rolled coil and incorporating post-combustion CO_2 capture technology to the steel mill should consist of the following processes:

- Unit 100: Coke Production — based on 3 batteries of coke ovens
- Unit 200: Sinter Production — based on a single fixed bed sintering machine
- Unit 300: Hot Metal Production — based on 2 trains of oxy-blast furnaces
- Unit 400: Hot Metal Desulphurisation — based on 2 stations of HM desulphurisation
- Unit 500: Primary Steelmaking — based on 2 trains of basic oxygen furnaces
- Unit 600: Secondary Steelmaking — based on 2 stations of ladle metallurgy process
- Unit 700: Continuous Casting — based on 2 trains of double strand slab casters
- Unit 800: Slab Reheating — based on 2 furnaces per line of HSM
- Unit 900: Hot Rolling Mills — based on 2 lines of hot strip mills (HSM)
- Unit 1000: Lime Production — based on 2 trains of PFR lime kilns
- Unit 1100: HP Oxygen Production — based on 1 train of Air Separation Unit
- Unit 1200: Electricity Production — based on 1 captive power plant
- Unit 2000: Steam Production — based on multi-train packaged water tube boilers
- Unit 4000: CO_2 Capture Plant — based on 2 trains of absorbers & 1 stripper column
- Ancillaries, off-sites, utilities and balance of plant

This section of the report describes the various changes made to the integrated steel mill equipped with Post-Combustion CO_2 capture as compared to the REFERENCE Steel Mill without CO_2 capture.

This section of the report focuses on providing information to the changes made to the following:

- Captive Power Plant (UNIT 1200)
- Steam Generation Plant (UNIT 2000)
- CO_2 Capture and Compression Plant (UNIT 4000)

Additionally, this section presents in detail the following information for:

- Process flow diagram of the CO_2 Capture & Compression Plant (UNIT 4000).
- Summary of Electricity and Steam Demand for EOP-L1 and EOP-L2 Cases

The different process flow diagrams and mass balances of the major processes relevant to the hot rolled coil production should not have any modification as compared to the REFERENCE Steel Mill. These information are presented in Annex IV of this report.

2. MODIFICATION TO THE INTEGRATED STEEL MILL

The incorporation of the post-combustion capture technology into the integrated steel mill increases the electricity and steam demand as compared to the REFERENCE steel mill.

For the EOP-L1 (Case 2A) and EOP-L2 (Case 2B), there will be no other changes to the steel production side except for the Captive Power Plant (UNIT 1200) and the addition of a Steam Generation Plant (UNIT 2000). This section of the report describes the details of these changes.

2.1. UNIT 1200: Power Plant

The incorporation of the Post-Combustion CO_2 Capture Technology increases the electricity demand of the steel mill by 43% and 55% for EOP-L1 and EOP-L2 Cases respectively as compared to the REFERENCE Steel Mill without CO_2 Capture. Table C-3 presents the breakdown of the electricity demand for all cases.

To maintain a like for like analysis for the steel mill without and with CO_2 capture, it was agreed that the use of the steel mill's off-gases should be switched from providing electricity in the REFERENCE Steel Mill case, to providing steam for the steel mill with CO_2 capture.

To provide the additional electricity required by the steel mill, a natural gas combine cycle (NGCC) based power plant was assumed.

The NGCC power plant used for this study providing electricity to the Steel Mill with Post-Combustion CO_2 capture are based on the following features:

- E-Class Gas turbine fired with NG in a single shaft arrangement delivering between ~192MWe (EOP-L1 Case) and ~208 MWe (EOP-L2 Case).

- Heat from the flue gas of the gas turbine will be recovered by the heat recovery steam generation (HRSG) unit. This will deliver steam to the steam turbine at 3 different pressure levels and IP reheated steam.

- Steam turbine is based on triple pressure and single reheat arrangement delivering about ~100MWe.

It should be noted that for both EOP-L1 and EOP-L2 Cases, the gas turbine selected for the NGCC power plant will be the same type of machine. However, the gas turbine used by the NGCC power plant of EOP-L2 case will have features that will allow for an extended operating hours (i.e. operating with high electricity output) to meet the required availability of the steel mill. This will result in higher maintenance costs due to more frequent services required over its lifetime.

Table C-3: Electricity Demand and Supply of the Steel Mill without and with CO_2 Capture

UNIT 1200	REFERENCE Steel Mill (Base Case)		Steel Mill with CO_2 Capture (EOP-L1 Case)		Steel Mill with CO_2 Capture (EOP-L2 Case)	
Electricity Production (Total)	**1,600,463 MWh/y (400.1 kWh/t HRC)**		**2,290,444 MWh/y (572.6 kWh/t HRC)**		**2,486,979 MWh/y (621.7 kWh/t HRC)**	
Power Plant Type	Gas Fired Boiler Power Plant		Natural Gas Combine Cycle		Natural Gas Combine Cycle	
Fuel Type	BFG (66%), BOFG (15%), NG (19%)		NG (100%)		NG (100%)	
Nominal Capacity	215 MWe		292 MWe		308 MWe	
Average Daily Net Power Output	183 MWe		262 MWe		284 MWe	
Net Efficiency (Fuel Input – LHV)	32.2%		56.6%		57.0%	
Load Factor	85%		90%		92%	
Electricity Demand						
100: Coke Production	57,068 MWh/y	14.3 kWh/t HRC	57,068 MWh/y	14.3 kWh/t HRC	57,068 MWh/y	14.3 kWh/t HRC
200: Sinter Plant	142,258 MWh/y	35.6 kWh/t HRC	142,258 MWh/y	35.6 kWh/t HRC	142,258 MWh/y	35.6 kWh/t HRC
300/400: Iron Making	392,206 MWh/y	98.1 kWh/t HRC	392,206 MWh/y	98.1 kWh/t HRC	392,206 MWh/y	98.1 kWh/t HRC
500/600: Steelmaking	195,097 MWh/y	48.8 kWh/t HRC	195,097 MWh/y	48.8 kWh/t HRC	195,097 MWh/y	48.8 kWh/t HRC
700: Continuous Casting	43,452 MWh/y	10.9 kWh/t HRC	43,452 MWh/y	10.9 kWh/t HRC	43,452 MWh/y	10.9 kWh/t HRC
800/900: Reheating and Rolling	421,053 MWh/y	105.3 kWh/t HRC	421,053 MWh/y	105.3 kWh/t HRC	421,053 MWh/y	105.3 kWh/t HRC
1000: Lime Production	10,392 MWh/y	2.6 kWh/t HRC	10,392 MWh/y	2.6 kWh/t HRC	10,392 MWh/y	2.6 kWh/t HRC
1100: ASU - HP Oxygen	267,104 MWh/y	66.8 kWh/t HRC	267,034 MWh/y	66.8 kWh/t HRC	267,104 MWh/y	66.8 kWh/t HRC
1300: Ancillary (Unit: 300/400)	19,272 MWh/y	4.8 kWh/t HRC	19,272 MWh/y	4.8 kWh/t HRC	19,272 MWh/y	4.8 kWh/t HRC
2000: Steam Generation Plant	- MWh/y	- kWh/t HRC	82,654 MWh/y	20.7 kWh/t HRC	101,269 MWh/y	25.3 kWh/t HRC
4000: CO2 Capture & Compression	- MWh/y	- kWh/t HRC	607,402 MWh/y	151.9 kWh/t HRC	785,251 MWh/y	196.3 kWh/t HRC
Off Site Users and Losses	52,560 MWh/y	13.1 kWh/t HRC	52,557 MWh/y	13.1 kWh/t HRC	52,557 MWh/y	13.1 kWh/t HRC

2.2. UNIT 2000: Steam Generation Plant

The introduction of the post-combustion CO_2 capture plant to the integrated steel mill should consequently increase the steam demand by 3.77 and 4.68 GJ/t HRC for EOP-L1 and EOP-L2 respectively as compared to 0.21 GJ/t HRC for the REFERENCE steel mill without CO_2 capture. Table C-4 presents the breakdown of the steam demand for all cases.

Table C-4: Steam Demand and Supply of the Steel Mill without and with CO_2 Capture

UNIT 2000	REFERENCE Steel Mill (Base Case)	Steel Mill with CO_2 Capture (EOP-L1 Case)	Steel Mill with CO_2 Capture (EOP-L2 Case)
Steam Production (Total)	**846,756 GJ/y (211.7 MJ/t HRC)**	**15,913,486 GJ/y (3,978.4 MJ/t HRC)**	**19,566,496 GJ/y (4,891.6 MJ/t HRC)**
500: BOF Waste Heat Boilers	211.7 MJ/t HRC	224.8 MJ/t HRC	224.8 MJ/t HRC
2000: Steam Generation Plant	-	3753.5 MJ/t HRC	4666.8 MJ/t HRC
Steam Demand (Total)			
100: Coke Production	169.6 MJ/t HRC	169.6 MJ/t HRC	169.6 MJ/t HRC
300/400: Iron Making	21.9 MJ/t HRC	21.9 MJ/t HRC	21.9 MJ/t HRC
1100: ASU - HP Oxygen	20.2 MJ/t HRC	20.2 MJ/t HRC	20.2 MJ/t HRC
4000: CO2 Capture & Compression	- MJ/t HRC	3,766.7 MJ/t HRC	4,679.9 MJ/t HRC

As mentioned in the previous section, to maintain a like for like assessment between steel mill without and with CO_2 capture, the utilisation of the works' off-gases would be changed from providing electricity to the steel mill for the REFERENCE Case, to providing steam for the steel mill with CO_2 capture.

To provide the extra steam demand by the CO_2 capture plant, a separate steam generation plant (SGP) was assumed.

This is based on multiple trains of packaged water tube boilers each with a capacity of 60 tph delivering 9 Bar_a saturated steam. These boilers will be fuelled by the BFG and BOFG; and supplemented by the natural gas. Table C-5 summarised the key operating parameter of the steam generation plant for EOP-L1 and EOP-L2 Cases respectively.

Table C-5: Steam Generation Plant Specification (Unit 2000)

UNIT 2000: SGP	Steel Mill with CO_2 Capture (EOP-L1 Case)	Steel Mill with CO_2 Capture (EOP-L2 Case)
Steam Production (Total)	**15,014,125 GJ/y**	**18,667,135 GJ/y**
Steam Generation Plant	Packaged Water Tube Boilers (@ 60 tph per boiler)	Packaged Water Tube Boilers (@ 60 tph per boiler)
Boiler Efficiency	89.2%	89.3%
Fuel Type (Thermal Input)	BFG (70.7%), BOFG (14.7%) and NG (13.6%)	BFG (56.9%), BOFG (12.6%) and NG (30.4%)
Steam Output to CO_2 Capture Plant	3.75 GJ/t HRC (Steam @ 9 Bar_a, saturated)	4.67 GJ/t HRC (Steam @ 9 Bar_a, saturated)

3. CO_2 CAPTURE AND COMPRESSION PLANT

To establish a baseline cost for capturing CO_2 from various flue gases generated by the different processes of the integrated steel mill, this study has selected MEA as solvent for the post-combustion CO_2 capture option. The selection of this solvent is due to the fact that MEA solvent is well studied, with cost and performance data that are publicly available.

This section of the report presents the details of the CO_2 capture and compression plant for both cases where steel mills are incorporated with post-combustion CO_2 capture using MEA solvent.

The simplified block flow diagrams used in this study are presented in Figures C-1 to C-2; and the PFD of the CO_2 compression plant is presented in Figure C-3. The study assumed that CO_2 from flue gases was captured by individual absorbers and that the rich amine solution is pumped back to a central stripper unit.

For EOP-L1 Case, two absorber columns were used to capture CO_2 from the flue gases of the hot stoves and steam generation plant; and a single stripper column was used to regenerate the rich amine solvent.

For the EOP-L2 Case, in addition to the absorbers and stripper columns used for EOP-L1 Case, two more absorber columns were added to capture CO_2 from the flue gases of the underfire heaters of the coke oven batteries and the lime kilns, and an additional stripper column was also added to the central stripper unit to regenerate the rich amine solution.

This study assumed 90% capture rate for all the CO_2 absorbers regardless of varying CO_2 concentration.

It should be noted that energy requirements of the CO_2 capture plant using MEA as solvent has been optimised by using a Split Flow Configuration as illustrated in Figure C-4.

With the split flow configuration a fraction of the rich amine solution from the absorber columns is preheated against the incoming lean amine solution from the reboiler of the stripper column. The preheated rich amine solution is then introduced to a flash column to separate the CO_2 rich vapour and a semi-lean amine solution. The vapour fraction from the flash column is sent to the stripper's condenser whilst the semi-lean amine solution is sent to the intercooler section of the absorber column. This reduces the amount of rich amine solution to be regenerated by the stripper column.

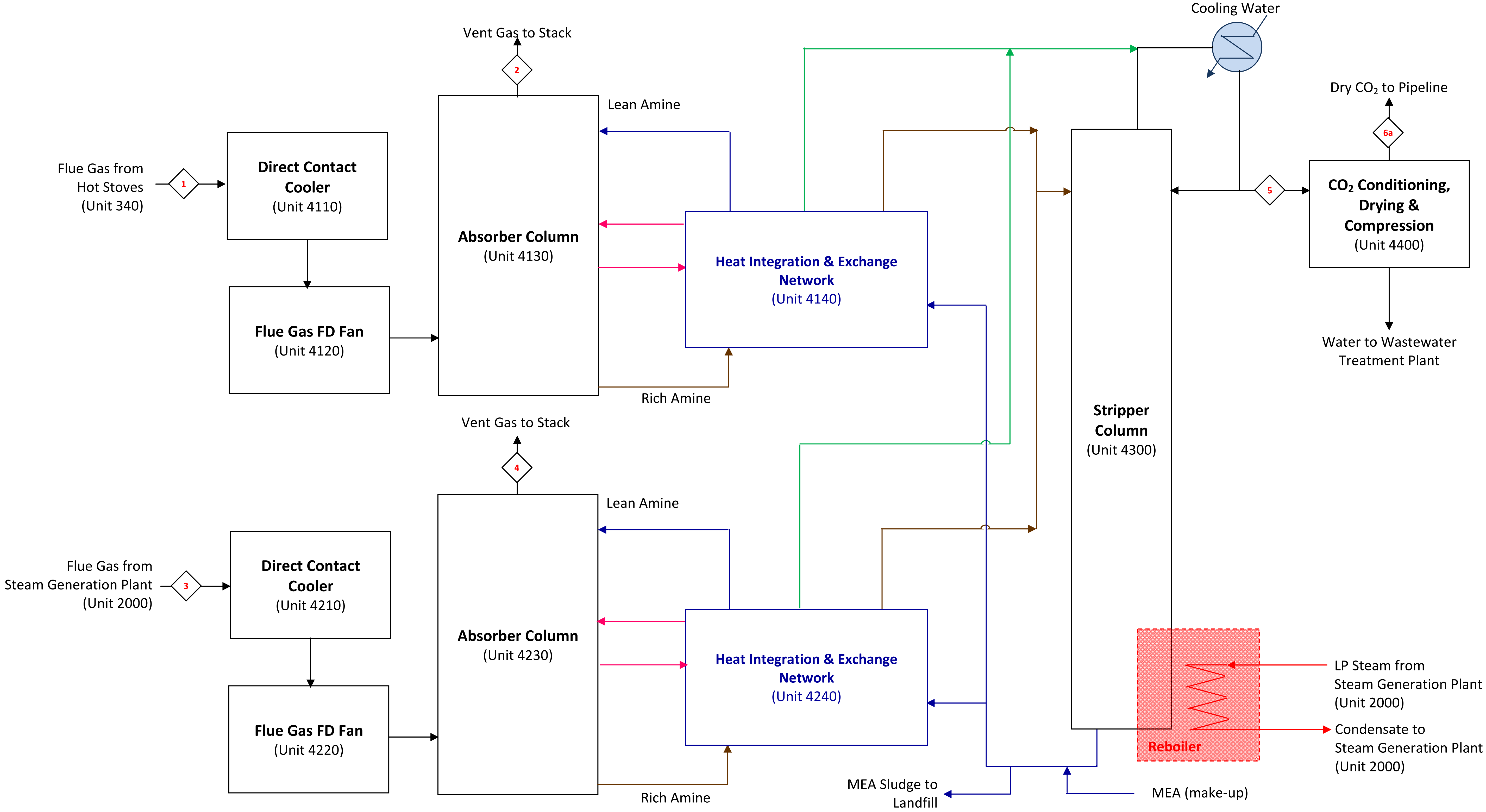

Figure C-1: Process Flow Diagram – CO_2 Capture and Compression Plant – Steam Generation Plant and Hot Stoves (EOP-L1 and EOP-L2 Case)

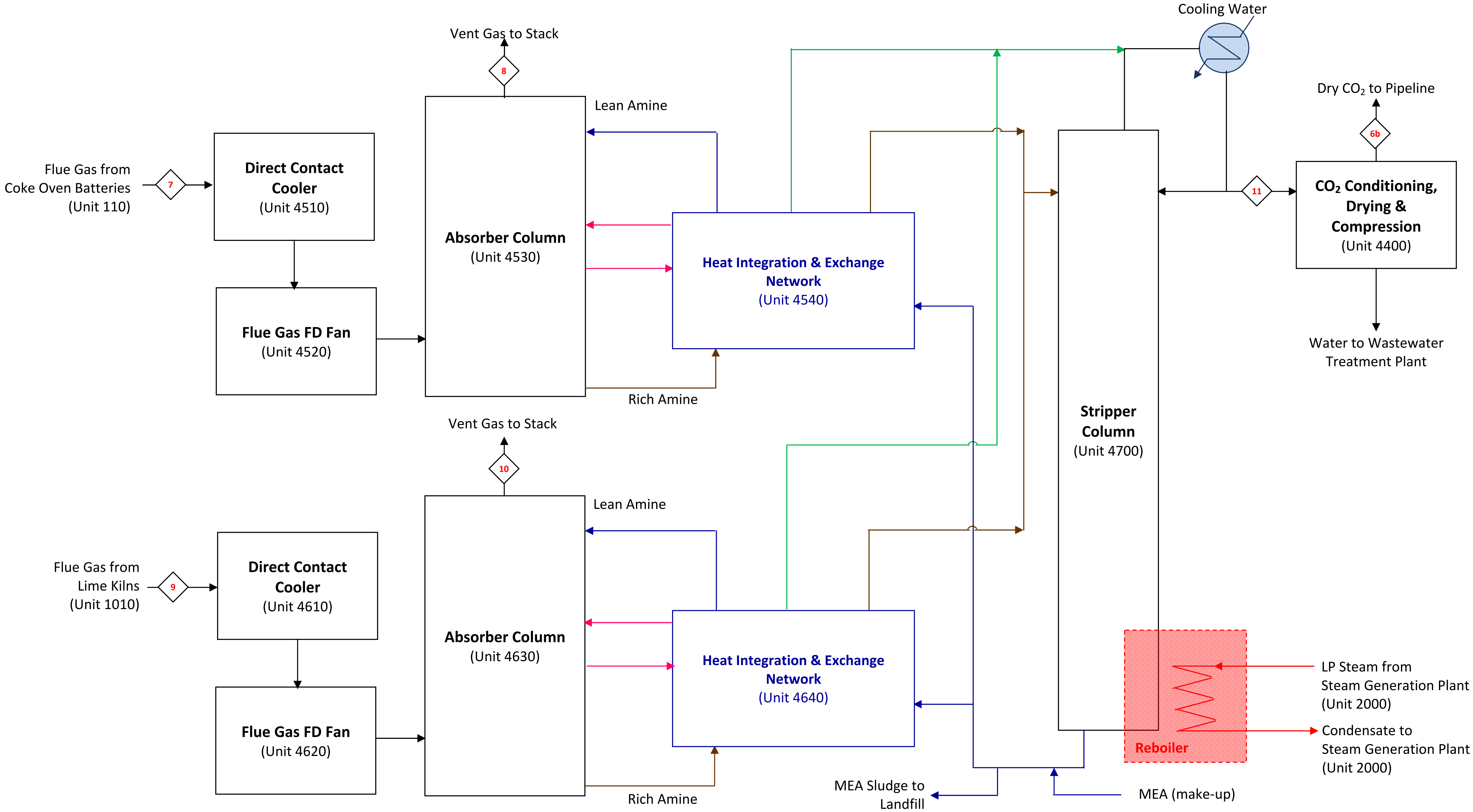

Figure C-2: Process Flow Diagram – CO_2 Capture and Compression Plant – Coke Oven Batteries and Lime Plant (EOP-L2 Case)

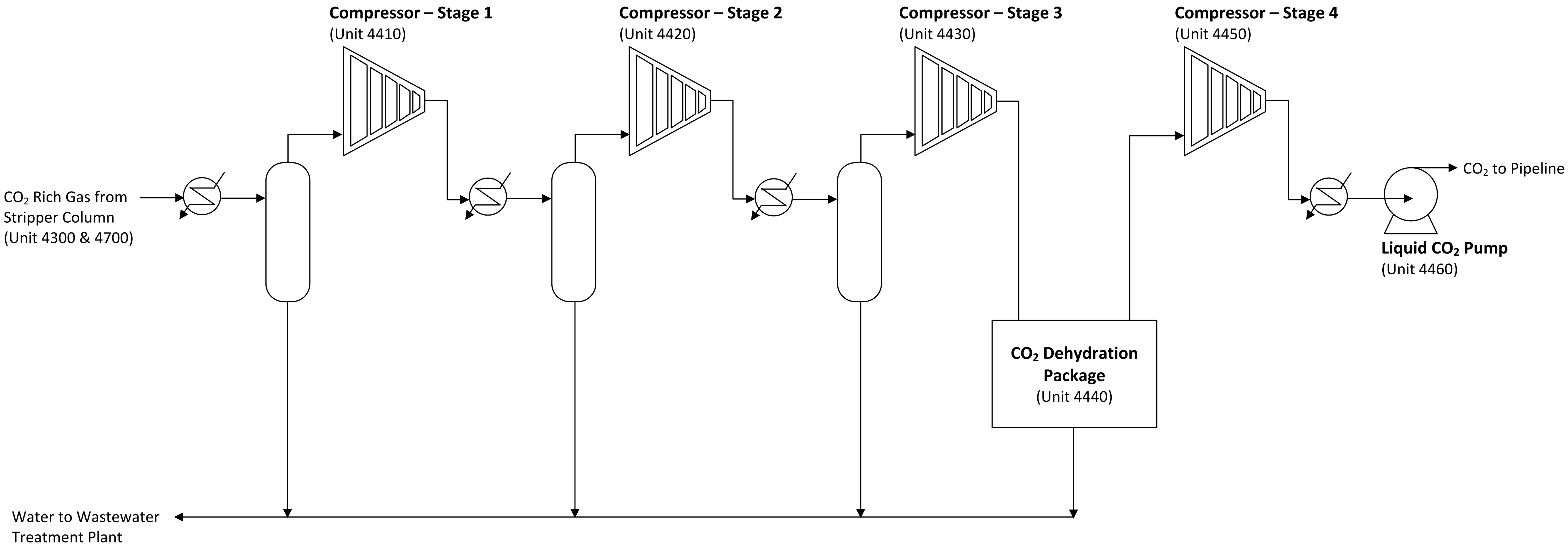

Figure C-3: PFD – CO_2 Compression Plant

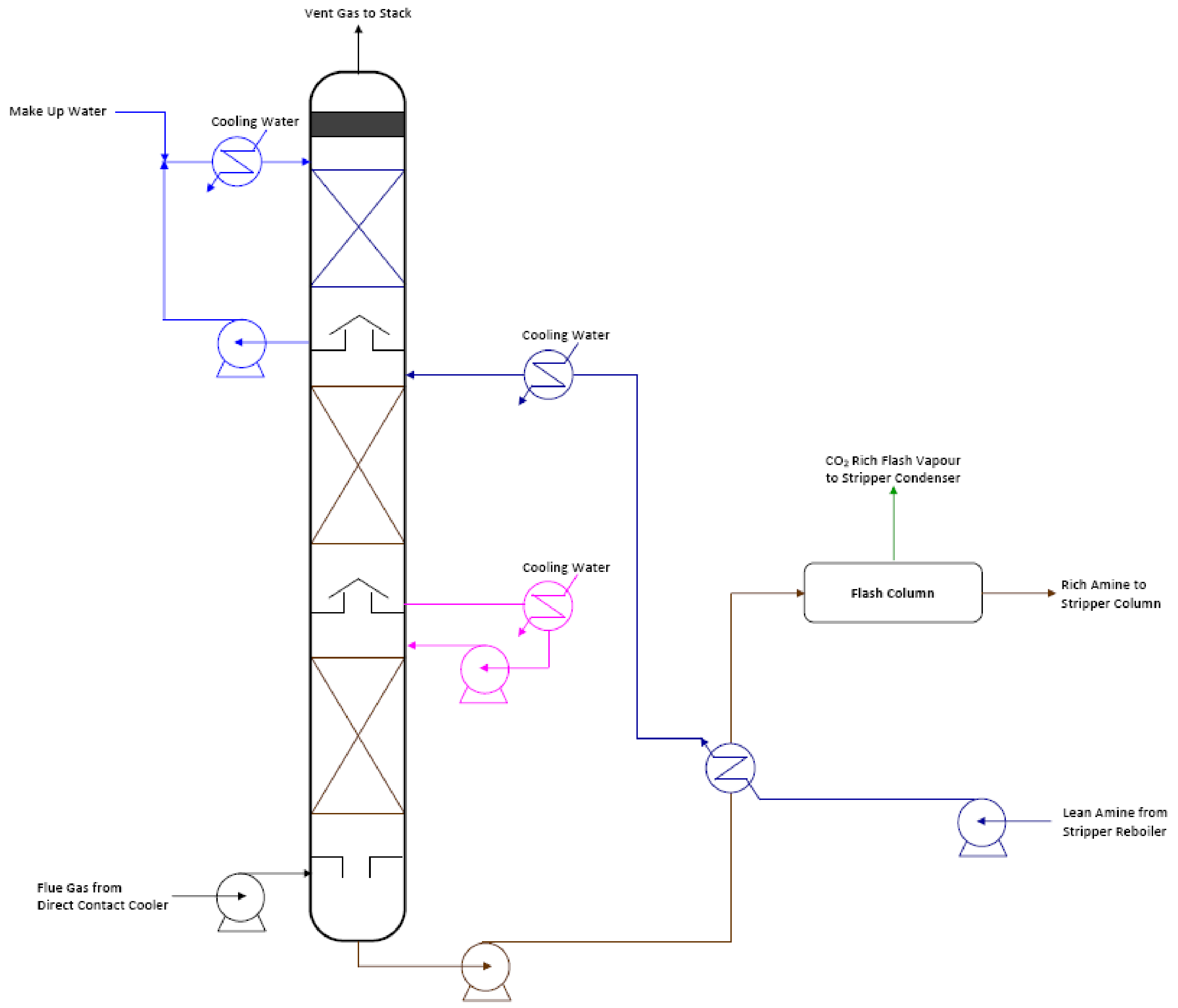

Figure C-4(a): Conventional MEA Absorber and Heat Integration Configuration

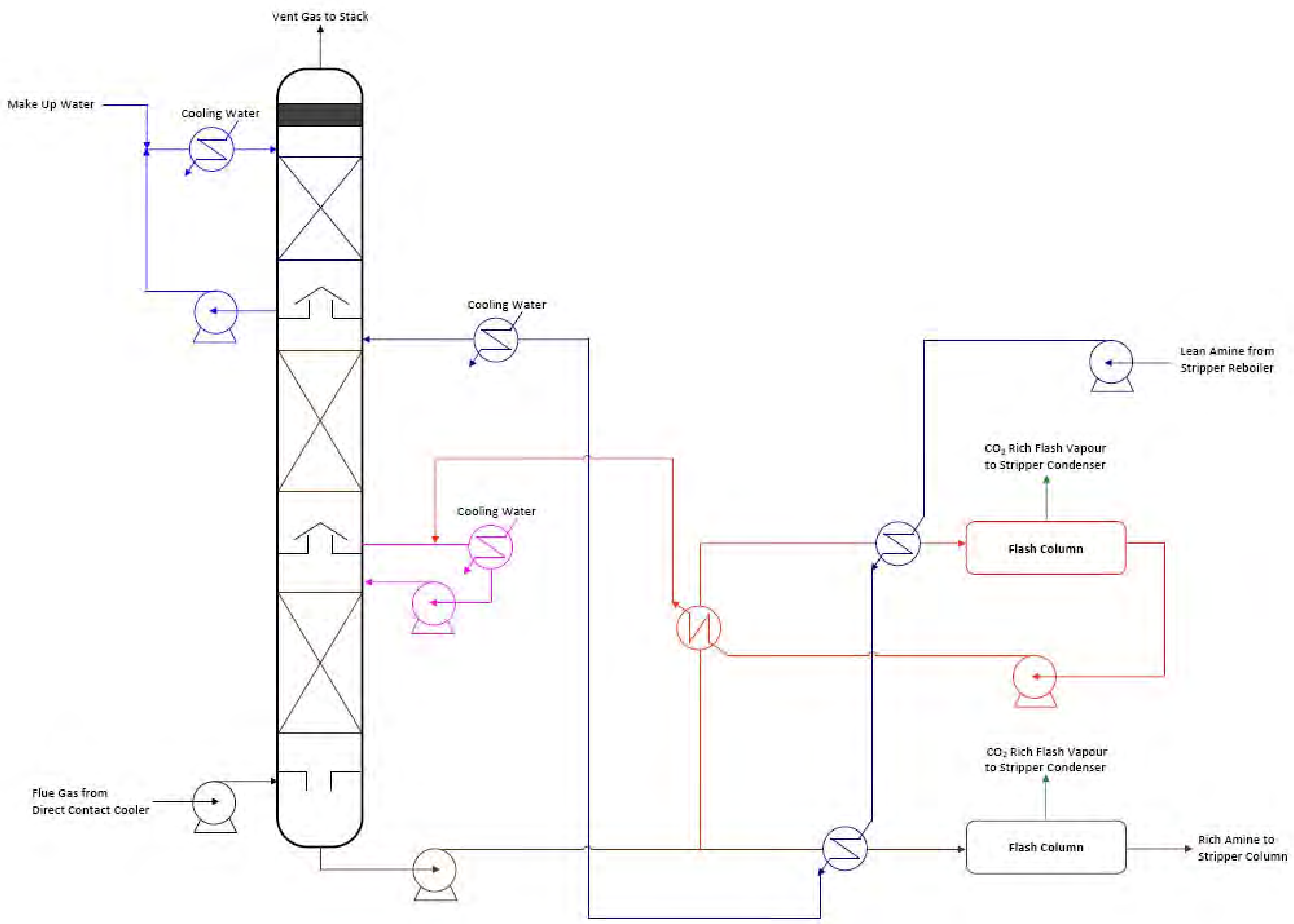

Figure C-4(b): Conventional MEA Absorber and Heat Integration with Split Flow Configuration

3.1. Study Specification

EOP-L1 Case

Table C-1 summarised the key operating and design parameters used to establish the mass and energy balance of the CO_2 capture plant for the EOP-L1 Case.

Table C-1: EOP-L1 Case Specification (Unit 4000: CO_2 Capture Plant)

Absorber Column (2 Trains)	**unit**	**Steam Boiler**	**Hot Stoves**
Flow Rate: Flue Gas	Nm^3/t HRC	1807.4	774.3
CO_2 Concentration	%	27.2	27.3
Total CO_2 Captured (per column)	kg/t HRC	869.5	373.6
CO_2 Recovery	%	90.0	90.0
Column Diameter	m	11.3	8.3
Absorber Height (Total)	m	40.3	40.3
Linear Gas Velocity (Design Basis)	m/s	2.48	2.49
Flow Rate: Lean Amine Solution[1]	t/t CO_2 captured	10.7	10.6
Temperature: Lean Amine Solution (Inlet)	^oC	30	30
Flow Rate: Rich Amine Solution[1]	t/t CO_2 captured	11.7	11.6
Temperature: Rich Amine Solution (Outlet)	^oC	41	41
Split Flow Fraction (% Rich Amine Solution)	%	40	40
Intercooler Temperature	^oC	30	30

Stripper Column (1 Common Train)		Unit 4300
Flow Rate: CO_2 to Compression Plant (wet)	Nm^3/t HRC	644.5
Column Diameter	m	11.7
Stripper Height (Total)	m	23.1
Flow Rate: Lean amine solution[2]	t/t CO_2 captured	10.6
Flow Rate: Rich amine solution[2]	t/t CO_2 captured	11.6
Steam demand[2]	MJ/t CO_2 captured	3.03
Reboiler Pressure	Bar_a	1.85
Reboiler Temperature	^oC	120

Electricity Demand		
CO_2 Capture Plant[2]	kWh/t HRC	50.78
CO_2 Compression Plant[2]	kWh/t HRC	101.07

Other Utilities		
Total Water Demand[2]	t/t CO_2 captured	80.9
Make Up Water[2]	t/t CO_2 captured	4.0
MEA Make Up[2]	kg/t CO_2 captured	1.0
MEA Sludge[2]	kg/t CO_2 captured	1.0

[1] Based on per tonne of CO2 captured per column
[2] Based on per tonne of CO2 captured (total)

EOP-L2 Case

Table C-2 summarised the key operating and design parameters used to establish the mass and energy balance of the CO_2 capture plant for the EOP-L2 Case.

Table C-2: EOP-L2 Case Specification (Unit 4000: CO_2 Capture Plant) [3]

Absorber Column (4 Trains)	**Unit**	**Steam boiler**	**Hot stoves**	**Coke Plant**	**Lime Plant**
Flow Rate: Flue Gas	Nm^3/t HRC	2118.4	774.3	660.0	187.0
CO_2 Concentration	%	24.6	27.3	14.8	19.5
Total CO_2 Captured (per column)	kg/t HRC	922.5	373.6	172.2	64.4
CO_2 Recovery	%	90.0	90.0	90.0	90.0
Column Diameter	m	12.3	8.3	6.2	3.5
Absorber Height (Total)	m	40.3	40.3	38.6	38.6
Linear Gas Velocity (Design Basis)	m/s	2.48	2.49	3.05	2.75
Flow Rate: Lean Amine Solution	t/t CO_2 captured	11.4	10.6	13.1	13.2
Temperature: Lean Amine Solution (Inlet)	^oC	30	30	30	30
Flow Rate: Rich Amine Solution	t/t CO_2 captured	12.4	11.6	14.1	14.2
Temperature: Rich Amine Solution (Outlet)	^oC	41	41	46	46
Split Flow Fraction (% Rich Amine Solution)	%	40	40	30	30
Intercooler Temperature	^oC	30	30	30	30

Stripper Column (2 Trains)		Unit 4300	Unit 4700
Flow Rate: CO_2 to Compression Plant (wet)	Nm^3/t HRC	671.9	122.7
Column Diameter	m	12.2	5.5
Stripper Height (Total)	m	23.1	23.1
Lean amine solution[1]	t/t CO_2 captured	11.2	13.1
Rich amine solution[1]	t/t CO_2 captured	12.2	14.1
Steam demand[1]	MJ/t CO_2 captured	3.03	3.18
Reboiler Pressure	Bar_a	1.85	1.85
Reboiler Temperature	^oC	120	119

Electricity Demand		
CO_2 Capture Plant	kWh/t HRC	71.7
CO_2 Compression Plant	kWh/t HRC	124.6

Other Utilities		
Total Water Demand	t/t CO_2 captured	87.3
Total Water Demand	t/t CO_2 captured	4.4
MEA Make Up	kg/t CO_2 captured	1.0
MEA Sludge	kg/t CO_2 captured	1.0

[3] See Footnote in Table C-1

3.2. Mass Balance - CO_2 Capture Plant

EOP-L1 Case

Table C-1 presents a summary of the mass balance for the CO_2 capture and compression plant of the integrated steel mill with Post-Combustion CO_2 Capture (EOP-L1 Case); for the Stream Number, please refer to Figure C-1.

Table C-1: Mass Balance (Unit 4000: CO_2 Capture and Compression Plant)

		1	2	3	4	5	6
Stream		**Flue Gas from Hot Stoves**	**Vent Gas from Absorber (Unit 4130)**	**Flue Gas from SGP**	**Vent Gas from Absorber (Unit 4230)**	**Wet CO2 from Stripper Column (Unit 4300)**	**CO2 to Pipeline**
Total Mass Flow (wet)	**t/y**	**4,390,584**	**2,806,294**	**10,241,478**	**6,572,694**	**5,009,212**	**4,972,575**
Total Mass Flow (dry)	**t/y**	**4,231,794**	**2,731,277**	**9,866,392**	**6,396,951**	**4,972,525**	**4,972,540**
Specific Mass Flow (wet)	kg/t CO2 captured[4]	882.9	564.3	2059.6	1321.8	1007.4	1000.0
Specific Mass Flow (dry)	kg/t CO2 captured	851.0	549.3	1984.1	1286.4	1000.0	1000.0
Pressure	Bara	1.02	1.09	1.02	1.09	1.81	110.01
Temperature	oC	148	30	150	30	148	148
Phase		gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/t CO2 Captured	622.82	447.84	1453.90	1049.16	518.46	509.29
Average MW		31.8	28.2	31.8	28.2	43.5	44.0
Gas Composition (wet basis)							
CO2	%v.	27.30	3.79	27.22	3.78	98.23	100.00
O2	%v.	0.80	1.11	0.70	0.97	-	-
N2	%v.	65.52	90.91	65.62	91.06	-	-
H2O	%v.	6.38	4.19	6.45	4.19	1.77	0.002

[4] This is based on the total CO_2 captured.

EOP-L2 Case

Table C-2 presents a summary of the mass balance for the CO_2 capture and compression plant of the integrated steel mill with Post-Combustion CO_2 Capture (EOP-L2 Case); for the Stream numbers, please refer to Figures C-1 and C-2.

Table C-2: Mass Balance (Unit 4000: CO_2 Capture and Compression Plant)

		1	2	3	4	5	6
Stream		**Flue Gas from Hot Stoves**	**Vent Gas from Absorber (Unit 4130)**	**Flue Gas from SGP**	**Vent Gas from Absorber (Unit 4230)**	**Wet CO2 from Stripper Column (Unit 4300)**	**CO2 to Pipeline (Total)**
Total Mass Flow (wet)	**t/y**	**4,390,584**	**3,219,336**	**11,781,328**	**8,858,289**	**5,222,423**	**6,131,310**
Total Mass Flow (dry)	**t/y**	**4,231,794**	**3,133,244**	**11,222,429**	**8,620,817**	**5,184,604**	**6,131,267**
Specific Mass Flow (wet)	kg/t CO2 captured	716.1	525.1	1921.6	1444.8	851.8	1000.0
Specific Mass Flow (dry)	kg/t CO2 captured	690.2	511.0	1830.4	1406.1	845.6	1000.0
Pressure	Bara	1.02	1.09	1.02	1.09	1.81	110.01
Temperature	oC	148	30	150	30	25	25
Phase		gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/t CO2 Captured	505.13	416.68	1382.07	1149.37	438.34	509.31
Average MW		31.8	28.2	31.2	28.2	43.6	44.0
Gas Composition (wet basis)							
CO2	%v.	27.30	3.79	24.64	3.39	98.25	100.00
O2	%v.	0.80	1.11	0.70	0.96	-	-
N2	%v.	65.52	90.91	66.45	91.45	-	-
H2O	%v.	6.38	4.19	8.20	4.19	1.75	0.002

		7	8	9	10	11
Stream		**Flue Gas from Coke Oven Batteries**	**Vent Gas from Absorber (Unit 4530)**	**Flue Gas from Lime Kiln**	**Vent Gas from Absorber (Unit 4630)**	**Wet CO2 from Stripper Column (Unit 4700)**
Total Mass Flow (wet)	**t/y**	**3,474,713**	**2,627,278**	**1,006,794**	**684,944**	**953,635**
Total Mass Flow (dry)	**t/y**	**3,246,246**	**2,556,767**	**931,180**	**666,561**	**946,662**
Specific Mass Flow (wet)	kg/t CO2 captured	566.7	428.5	164.2	111.7	155.5
Specific Mass Flow (dry)	kg/t CO2 captured	529.5	417.0	151.9	108.7	154.4
Pressure	Bara	1.02	1.09	1.02	1.09	1.81
Temperature	oC	250	30	150	30	25
Phase		gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/t CO2 Captured	430.62	341.27	121.99	88.97	80.05
Average MW		29.5	28.1	30.2	28.1	43.6
Gas Composition (wet basis)						
CO2	%v.	14.77	1.86	19.41	1.86	98.23
O2	%v.	5.00	6.31	7.77	6.31	-
N2	%v.	69.47	87.64	60.24	87.64	-
H2O	%v.	10.76	4.19	12.58	4.19	1.77

4. PERFORMANCE OF THE STEEL MILL WITH POST-COMBUSTION CO_2 CAPTURE – SYSTEM ENERGY ANALYSIS

4.1. Overall Energy Consumption of the Steel Mill

Based on the assumption where there will be no import or export of energy in or out of the defined boundary limit, this therefore should simplify the calculation of the total energy consumed by the steel mill.

Table C-6 presents the difference of the total energy consumed by the REFERENCE Steel Mill without CO_2 Capture and the Steel Mill with Post-Combustion CO_2 Capture (EOP-L1 and EOP-L2 Cases) based on the difference between the energy content of the coking coal, PCI coal and natural gas as input; and the energy content of the coking by-products as output.

Table C-6: Overall Energy Consumption - Steel Mill without and with CO_2 Capture

	REFERENCE Steel Mill without CO_2 Capture		Steel Mill with Post-Combustion Capture (EOP-L1 Case)		Steel Mill with Post-Combustion Capture (EOP-L2 Case)	
Energy Input						
Coking Coal	16.292	GJ/t HRC	16.292	GJ/t HRC	16.292	GJ/t HRC
PCI Coal	5.032	GJ/t HRC	5.032	GJ/t HRC	5.032	GJ/t HRC
Natural Gas	0.849	GJ/t HRC	4.216	GJ/t HRC	5.518	GJ/t HRC
Energy Out						
Coking By-Products	0.903	GJ/t HRC	0.903	GJ/t HRC	0.903	GJ/t HRC
Total Energy Consumption	**21.270**	**GJ/t HRC**	**24.637**	**GJ/t HRC**	**25.939**	**GJ/t HRC**

4.2. Breakdown of Natural Gas Consumption

	REFERENCE Steel Mill without CO_2 Capture		Steel Mill with Post-Combustion Capture (EOP-L1 Case)		Steel Mill with Post-Combustion Capture (EOP-L2 Case)	
Annual NG Consumption						
Power Plant	0.849	GJ/t HRC	3.642	GJ/t HRC	3.927	GJ/t HRC
Steam Generation Plant	-	GJ/t HRC	0.574	GJ/t HRC	1.591	GJ/t HRC
Total Consumption	0.849	GJ/t HRC	4.216	GJ/t HRC	5.518	GJ/t HRC

4.3. CO_2 Emissions of the Steel Mill

The breakdown of the CO_2 emissions from the different major processes of the Integrated Steel Mill without and with CO_2 Capture is summarised in Table C-7.

Table C-7: Breakdown of CO_2 Emissions - Steel Mill without and with CO_2 Capture

UNIT	CO_2 Emissions Breakdown – Major Processes	REFERENCE Steel Mill without CO_2 Capture		Steel Mill wih OBF/MDEA CO_2 Capture		Steel Mill with OBF/MDEA CO_2 Capture	
		Emissions (kg/t HRC)	Annual Emission (t/y)	Emissions (kg/t HRC)	Annual Emission (t/y)	Emissions (kg/t HRC)	Annual Emission (t/y)
100	Flue Gas – Coke Oven	191.37	765,495	191.37	765,495	19.14	76,550
100	Flare – Coke Oven	3.30	13,196	3.30	13,196	3.30	13,196
200	Flue Gas – Sinter Plant (incl. CO emissions as CO2)	289.46	1,157,825	289.44	1,157,757	289.44	1,157,757
300	Flue Gas – Hot Stoves	415.19	1,660,769	41.51	166,051	41.51	166,051
400/1300	Diffuse Emissions - HM Desulph. & Ancillaries (PCI Drying et. al.)	7.76	31,042	7.76	31,042	7.76	31,042
300	Flare – Blast Furnace	19.73	78,931	19.73	78,931	19.73	78,931
500/600	Flare (incl. losses) - BOF, Diffuse Emissions from SM	51.02	204,089	51.02	204,089	51.02	204,089
700	Diffuse Emissions – Continuous Casting	0.80	3,188	0.80	3,188	0.80	3,188
800	Flue Gas – Reheating Furnaces	57.71	230,833	57.71	230,833	57.71	230,833
900	Diffuse Emissions – Hot Rolling Mills	0.04	179	0.04	179	0.04	179
1000	Flue Gas – Lime Plant	71.62	286,493	71.62	286,493	7.16	28,649
1200	Flue Gas – Power Plant	982.13	3,928,513	210.80	843,211	227.31	909,221
2000	Flue Gas - Steam Generation Plant	-	-	96.61	386,456	102.50	410,008
1300	Ancillaries transport fuel emissions (trucks and rails)	4.00	16,000	4.00	16,000	4.00	16,000
Total Emissions		**2094.14**	**8,376,554**	**1045.73**	**4,182,921**	**831.42**	**3,325,694**
Total CO_2 Captured		**NA**	**NA**	**1243.13**	**4,972,525**	**1532.82**	**6,131,267**

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture

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Section D

Economic Evaluation of the Integrated Steel Mill with Post-Combustion CO_2 Capture (End of Pipe Cases)

I N D E X

1. INTRODUCTION

This section of the report describes the assessment of the CAPEX and OPEX of the Integrated Steel Mill equipped with Post-Combustion CO_2 capture technology. The cost model was developed by Tata Steel Consulting based on the information regarding material usage, specification and capacity of individual processes as presented in Annex II and Annex III for EOP-L1 and EOP-L2 Cases respectively.

The main results for the cost of the producing HRC from steel mill with CO_2 capture were compared to the results of the REFERENCE Integrated Steel Mill. The breakdowns of the individual cost calculations are presented in Annex 5 and Annex 6 for both EOP Cases.

2. FINANCIAL ASSUMPTIONS

The assumptions used in evaluating the cost of HRC production from the REFERENCE Steel Mill are also adopted in estimating the cost of HRC production from the Integrated Steel Mills with Post-Combustion CO_2 capture (i.e. Case 2A and 2B).

All the information necessary in defining the parameters (as enumerated below) are presented in Annex 4.

- Plant Location
- Plant Life
- Design and Construction Period
- Commissioning
- Decommissioning
- Capital Charges
- Recurring Capital Expenditure
- Working Capital
- Currency
- Inflation
- Depreciation
- Estimate Accuracy

3. FINANCIAL COST MODEL

3.1. Cost Model Overview

The cost model developed by Tata Steel Consulting is shown schematically in Figures D-1 and D-2 illustrating the evaluation methodology for the direct cost of the steel production with CO_2 capture for EOP-L1 and EOP-L2 Cases.

The model for the Integrated Steel Mill with Post-Combustion CO_2 capture was adapted from model developed for the REFERENCE Integrated Steel Mill. This is based on a transfer cost model wherein the operating cost of each major unit is transferred to the users of the intermediate raw materials, finally leading to the direct cost of the hot rolled coil.

The cost of the CO_2 capture and compression plant is transferred to the major units where CO_2 from flue gas or process gas is captured. For example in the EOP-L1 Case, CO_2 from the hot metal production and steam generation plant are captured. Therefore, the direct cost of the CO_2 capture and compression unit is paid for by the hot metal production (Unit 300/400) and steam generation plant (Unit 2000) respectively in proportion to the amount of CO_2 captured from each unit.

3.2. Database and Input Data

3.2.1. Price Database

The study has made extensive use of various databases from relevant publications and actual steel mill operational data (including information from Tata Steel Consulting Internal Database) to establish the key price inputs of the raw materials, consumables, disposal cost, and by-products – adjusted to reflect long term European price trends.

3.2.2. Summary - Key Price Inputs

Table D-1 presents the key price inputs for the raw materials, consumables, disposal costs, and by-products used in the cost evaluation of the operating expense of the Integrated Steel Mill with CO_2 Capture (EOP-L1 and EOP-L2 Cases).

Table D-2 presents the key price inputs for the internally traded by-products.

3.2.3. Summary – Annual Operating Data

The operating data used in the evaluation of the annual operating expenses of the Integrated Steel Mill with CO_2 Capture is based on the mass balance of each plant/process as presented in Annex II and Annex III. The mass flow is expressed as per unit product of the plant/process or as mass flow per unit of hot rolled coil.

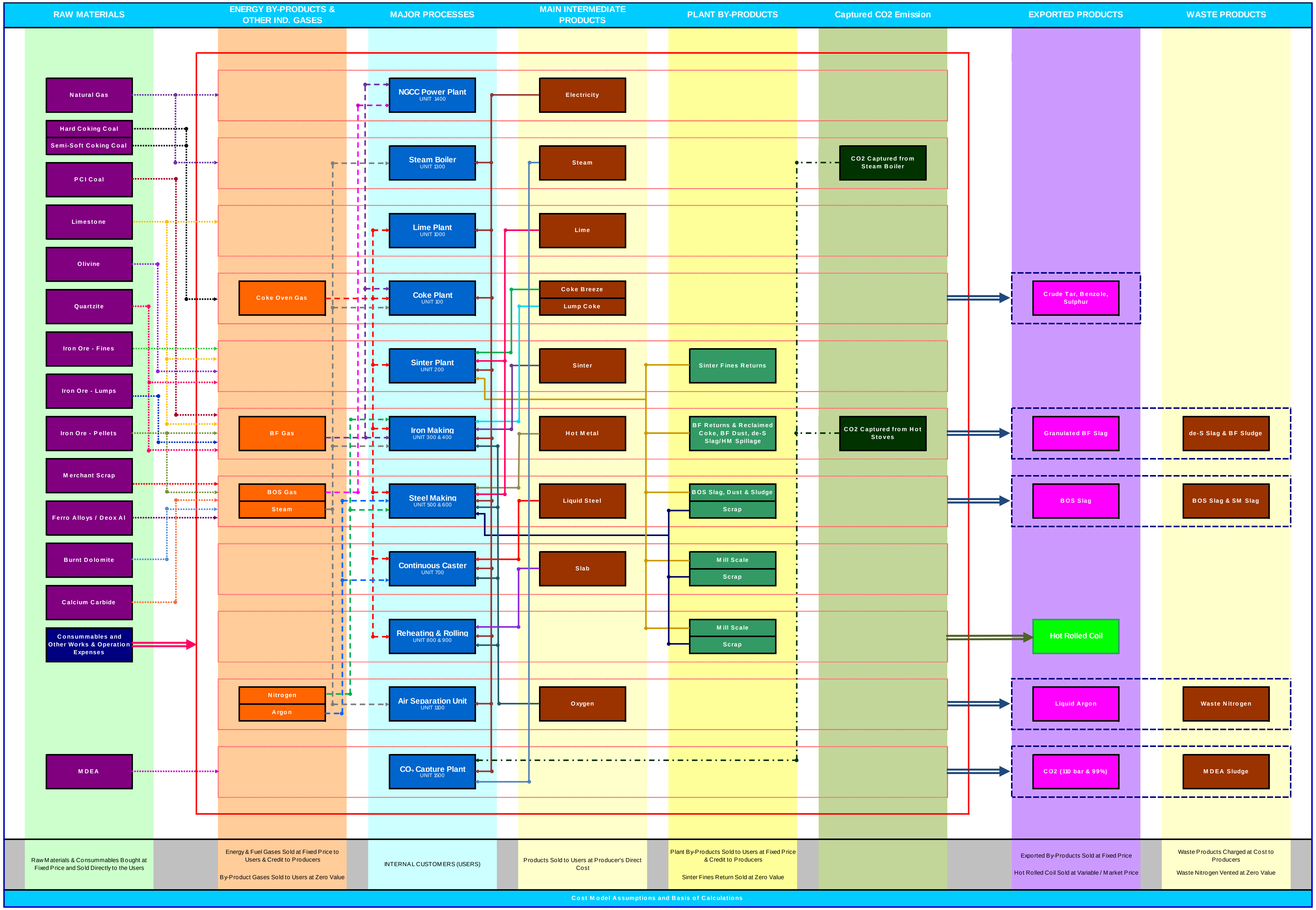

Figure D-1: Schematic representation of the cost model showing the evaluation of the direct cost of the integrated steel mill with post-combustion CO2 Capture (EOP-L1 Case).

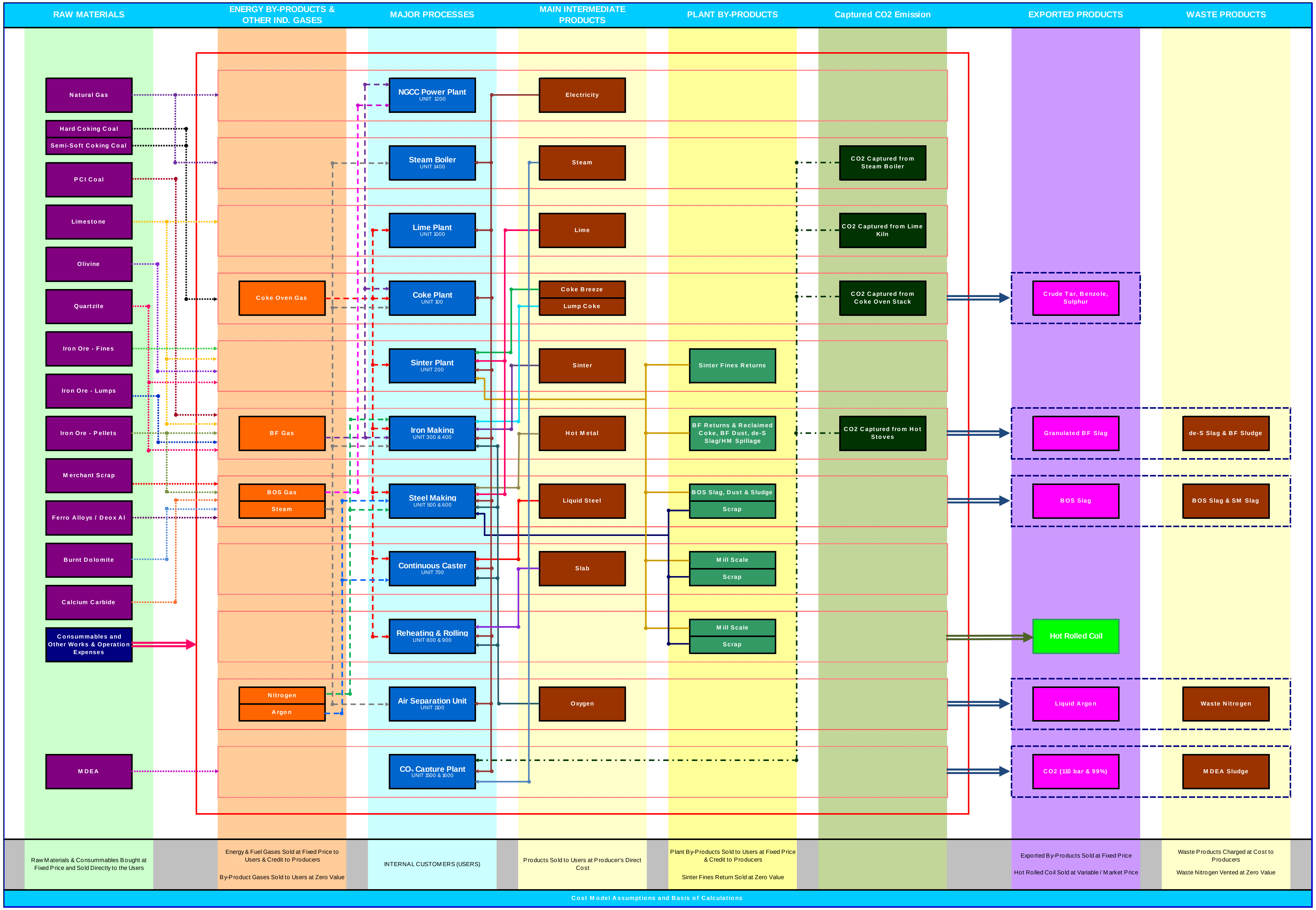

Figure D-2: Schematic representation of the cost model showing the evaluation of the direct cost of the integrated steel mill with post-combustion CO2 Capture (EOP-L2 Case).

Table D-1: Summary of Key Price Inputs of Raw Materials, Consumables, Disposal and By-Products Integrated Steel Mill with CO_2 Capture (OBF/MDEA Case)

	Unit	Unit Price
Iron Ore		
Fines (fob Brazil) – dry	dmtu of Fe	$0.97
Fines (fob Sweden) – dry	dmtu of Fe	$1.06
Fines (fob Australia) – dry	dmtu of Fe	$0.95
Pellets (fob Brazil) – dry	dmtu of Fe	$1.44
Lump (fob Australia) – dry	dmtu of Fe	$1.23
Energy		
Natural Gas (delivered)	GJ	$9.77
Coal		
Hard Coking Coal (fob Australia)	Tonne	$148.00
Semi-Soft Coking Coal (fob Australia)	Tonne	$107.00
PCI Coal (fob Australia)	Tonne	$109.48
Scrap		
Scrap – Rotterdam (Mixed)	Tonne	$228.00
Freight & Handling		
Voyage Rate - Iron Ore (Brazil - Netherlands)	Tonne	$10.00
Voyage Rate - Iron Ore (Scandinavia - Netherlands)	Tonne	$5.00
Voyage Rate - Iron Ore (Australia - Netherlands)	Tonne	$22.00
Voyage Rate - Coal (Australia - Netherlands)	Tonne	$21.00
Handling Charges - Iron Ore	Tonne	$6.00
Handling Charges - Coal	Tonne	$6.00
Fluxes and Ferro Alloys		
Limestone	Tonne	$23.25
Quartzite	Tonne	$18.00
Olivine	Tonne	$17.00
Burnt Dolomite (Dolomet)	Tonne	$92.00
Powder Calcium Carbide (CaC2)	Tonne	$800.50
FeMnC	Tonne	$1,403.17
FeSi75	Tonne	$1,650.29
Deox Al	Tonne	$2,208.58
By Products		
Crude Tar	Tonne	$176.00
Benzole/BTX	Tonne	$466.17
Sulphur	Tonne	$85.00
Slag (Blast Furnace)	Tonne	$16.00
Slag (BOS Furnace)	Tonne	$2.00
Argon (Sale)	Nm^3	$0.93
Other Consumables, Utilities and Disposal		
Water	m^3	$0.11
Refractories (Iron Making Production) – excl. Blast Furnace	Tonne	$820.00
Refractories (Steelmaking Production)	Tonne	$847.00
Refractories (Continuous Caster)	Tonne	$630.00
Electrodes (Secondary Steelmaking)	Tonne	$4,057.00
Casting Powder	kg	$0.67
Work Rolls - HRM	per tonne	$2.25
Banding	Tonne	$0.09
MEA	Tonne	$1,685.00
Slag Processing	Tonne	$5.89
Slag Tip / Quench & Dig	Tonne	$1.55
BOS Slag Land Fill Tax	Tonne	$3.87
SM (Ladle) Slag Land Fill Tax	Tonne	$86.79
BF Sludge Disposal Charge	Tonne	$20.00
MEA Sludge Disposal Charge	Tonne	$634.00
Site Haulage	Tonne	$0.31

Table D-2: Summary of Key Price Inputs of Raw Materials, Consumables, Disposal and By-Products Integrated Steel Mill with Post Combustion CO_2 Capture (EOP-L1 and EOP-L2 Cases)

	Unit	Unit Price
Energy		
Coke Oven Gas	GJ	**$9.77**
Blast Furnace Gas	GJ	**$9.77**
BOF Gas	GJ	**$9.77**
Scrap		
Scrap - Internal Arising (@ 85% of purchased scrap price)	Tonne	**$193.80**
Others		
Nitrogen (Internally Used)	Nm^3	**$0.00**
Argon (Internally Used)	Nm^3	**$0.00**
BF Undersize and Reclaimed Coke	Tonne	**$30.00**
BF/BOS Sludges & Dusts, HM Spillage, De-S Slag, etc.	Tonne	**$30.00**
Mill Scales	Tonne	**$20.00**
Slag Processing	Tonne	**$5.89**
Site Haulage	Tonne	**$0.31**

4. INVESTMENT COST

The basis of estimating the total investment cost accounts for the following:

- Total installed cost for plant and equipment
- Site Development and Construction
- Recurring Capital Expenditure
- Contingency

4.1. Plant and Equipment – Major Processes

The capital cost of the major plant and equipment considered for the Integrated Steel Mill with CO_2 Capture are estimated based on the process specification as described in Section C.

The cost estimates are subdivided according to the following Units or Block of Units:

- UNIT 100: Coke Production
- UNIT 200: Sinter Production
- UNIT 300 & 400: Blast Furnace, Hot Stoves and HM Desulphurisation
- UNIT 500 & 600: Steelmaking, Ladle Metallurgy
- UNIT 700: Continuous Caster
- UNIT 800 & 900: Reheating Furnace and Hot Rolling Mills
- UNIT 1000: Lime Production
- UNIT 1100: High Purity Oxygen Production
- UNIT 1200: Power Plant
- UNIT 2000: Steam Generation Plant
- UNIT 4000: CO_2 Capture and Compression Plant

The total installed cost for each plant or process accounts for (but is not limited to):

- Direct material – including plant, equipment and bulk materials
- Plant Construction
  - o Installation cost includes the mechanical erection, piping installation, etc...;
  - o instrumentation, process control automation and electrical installation;
  - o civil works, and where necessary other site preparation.
- EPC Services – including contractor's home office and construction supervision.
- Other Costs - including temporary buildings, training and plant start up (excl. spare parts and first fill).

The equipment cost was estimated from quoted prices from equipment suppliers and database of Tata Steel Consulting, adjusted to 2010 prices. All capital cost estimates are within ±30% accuracy.

Table D-3 summarizes the investment breakdown and the total figures for each major Units or Block of Units considered within the boundary limit of Steel Mill with Post-Combustion CO_2 capture and this is compared with the capital cost of the "REFERENCE" Integrated Steel Mill without CO_2 Capture (as shown in Table D-3).

A list of major plant components accounting for the majority of the total equipment cost reported for each Unit or Block of Units is enumerated for illustration purposes only. A detailed list of the plant and equipment is not provided as this is not part of the scope of this study.

Table D-3: Capital Cost Allocation of the Major Processes
Integrated Steel Mill with CO_2 Capture (OBF and MDEA CO_2 Capture)

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)
100	**Coke Production** • No other changes to the list – See Vol. 1, Section E (Table E-4)	**1.7 million tpy**	**400**
200	**Sinter Production** • No changes to the list – See Vol. 1, Section E (Table E-4)	**4.5 million tpy**	**220**
300	**Blast Furnace / Hot Stoves (Iron Making)** • No changes to the list – See Vol. 1, Section E (Table E-4)	**3.9 million tpy**	**622** (estimate incl. Unit 400)
400	**Hot Metal Desulphurization Plant** • No changes to the list – See Vol. 1, Section E (Table E-4)		**See Unit 300**
500	**Basic Oxygen Steelmaking Plant** • No changes to the list – See Vol. 1, Section E (Table E-4)	**4.4 million tpy**	**459** (estimate incl. Unit 600)
600	**Ladle Metallurgy (Secondary Steel Refining)** • No changes to the list – See Vol. 1, Section E (Table E-4)		**See Unit 500**
700	**Continuous Slab Caster** • No changes to the list – See Vol. 1, Section E (Table E-4)	**4.3 million tpy**	**195**
800 / 900	**Reheating Furnace & Hot Rolling Mills** • No changes to the list – See Vol. 1, Section E (Table E-4)	**4.0 million tpy**	**450**
1000	**Lime Production** • No changes to the list – See Vol. 1, Section E (Table E-4)	**0.4 million tpy**	**16**
1100	**ASU – Oxygen Production** • No changes to the list – See Vol. 1, Section E (Table E-4)	**1900 tpd O_2**	**130**

Table D-3 (cont'd): Capital Cost Allocation of the Major Processes
Integrated Steel Mill with CO_2 Capture (OBF and MDEA CO_2 Capture)

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)

1200	**Power Plant (NGCC – Single Shaft Arrangement)**
	• Gas Turbine Island
	• Heat Recovery Steam Generation (Triple Pressure & IP Reheat)
	• Steam Turbine Island
	  o Steam Turbines and Condenser
	  o Cooling Water Pumps (seawater once through cooling)
	• Generator Set
		292/308 MWe	362

2000	**Steam Generation Plant**
	• Boiler Island
	  o Packaged Water Tubes LP Steam Boilers @ 60 tph each
	  o Combustion Air Blowers, FD and ID Fans
	  o Boiler Feed Water and Condensate Pumps
	• Steam Drum and Manifold
			139/160

4000	**CO_2 Capture and Compression Plant**
	• Direct Contact Coolers (2x)
	• Absorber Columns (2x) – diameter & packing height: See Section C
	  o Rich/Lean MEA Heat Exchangers
	  o Lean Amine Coolers & Intercoolers, Cooling Water Pumps
	  o Flash Drums
	  o Amine Pumps
	• Stripper Column (1x) - diameter & packing height: See Section C
	  o Reboiler, Condensate Pumps
	  o Reflux drum
	  o Reflux pump
	  o Condenser, Cooling Water Pumps
	• CO_2 Compression Trains (2x)
	  o CO_2 Compressors (4 Stages)
	  o TEG Dehydration Unit
	• Water Treatment Plant and Cooling Water System
		5.0/6.2 million tpy	590/797

4.2. Plant and Equipment – Raw Materials Handling and Spare Parts

There are no changes to this investment category as compared to the REFERENCE Steel Mill. For details, see Volume 1 Section E of the report.

The total investment cost for these items include the following:

- raw materials handling equipments was estimated at US$ 128 Million.
- primary spare parts, tools, refractories for various furnaces, first fill and consumables used during the commissioning and plant start up were estimated at US$ 116 Million.

4.3. Plant and Equipment – Auxiliary, Utilities and BOP

There are no changes to this category as compared to the REFERENCE Steel Mill. For details, see Volume 1 Section E of the report.

The total investment cost for the auxiliary plant and equipment should be the same and was estimated at US$ 350 Million.

4.4. Site Development, Construction and Project Engineering

There are no changes to this category as compared to the REFERENCE Steel Mill. For details, see Volume 1 Section E of the report.

The overall project engineering and management, site construction, civil works and plant commissioning of the Steel Mill with CO_2 capture were estimated at a total cost of US$562 Million.

This cost breakdown of this capital expenditure includes the following:

• Pre-operating Expenses	US$	21 Million
• Land Preparation, Site Development & Waste Disposal		144 Million
• Project Engineering		201 Million
• Buildings and Site Infrastructure		196 Million

4.5. Recurring Capital Expenditure

The relining of the refractory and the replacement of cooling stave is the only recurring capital expenditure accounted for in this study. It was estimated at US$232 Million and disbursement will be made on every 15th year of the operation.

The study assumed that relining of the blast furnace should not affect the overall steel production capacity. This assumption is made for simplification purpose only.

4.6. Contingency

Contingency is a provisional sum to take into account of any possibility of cost overruns which is meant to cover any estimating errors or omissions.

The contingency has been estimated at US$ 208 and US$ 209 Million for EOP-L1 and EOP-L2 respectively (which is approximately 5% of the total installed cost – excluding CAPEX for CO_2 Capture and Compression Plant and Blast Furnace Reline – Recurring CAPEX).

The contingency for the CO_2 capture and compression plant was estimated at US$ 89 and US$120 Million for EOP-L1 and EOP-L2 cases respectively (which is about 15% of the installed cost of CO_2 capture and compression plant).

4.7. Summary of Results

Table D-5 presents the summary of the total investment cost for the Integrated Steel Mill with CO_2 Capture and this is compared against the total investment cost for the REFERENCE Steel Mill.

Table D-4: Summary of Results - Total Investment Cost

Unit No.	Plant Section	REFERENCE Case		Steel Mill w/CO_2 Capture EOP-L1 Case		Steel Mill w/CO_2 Capture EOP-L2 Case	
		Cost Breakdown	CAPEX (US$ Million)	Cost Breakdown	CAPEX (US$ Million)	Cost Breakdown	CAPEX (US$ Million)
Plant and Equipment – Major Processes			$ 2,772		$ 2,993		$ 3,014
100	Coke Production	400		400		400	
200	Sinter Production	220		220		220	
300 & 400	Blast Furnace and Hot Metal Desulphurisation	622		622		622	
500 & 600	Basic Oxygen Steelmaking and Ladle Metallurgy	459		459		459	
700	Continuous Slab Caster	195		195		195	
800 & 900	Reheating Furnace & Hot Rolling Mills	450		450		450	
1000	Lime Production	16		16		16	
1100	ASU – O_2 Production	130		130		130	
1200	Power Plant	280		362		362	
2000	Steam Generation Plant	-		139		160	
Plant and Equipment – Material Handling & Spare Parts			244		247		247
	Raw Material Handling	128		128		128	
	Spare Parts and First Fill	116		119		119	
Plant and Equipment – Auxiliary, Utilities and BOP			350		350		350
Site Development, Construction and Project Engineering			562		562		562
	Pre-operating Expenses	21		21		21	
	Land Preparation, Site Development & Waste Disposal	144		144		144	
	Buildings and Site Infrastructure	196		196		196	
	Project Engineering	201		201		201	
Total Installed Cost - Steel Mill (US$ Million)			3,928		4,152		4,173
Contingency @ 5% of Total Installed Cost - Steel Mill			196		208		209
CO_2 Capture and Compression Plant			-		679		917
4000	Plant & Equipment, First Fill, Spare Parts, BOP, Site Dev.	-		590		797	
	Contingency (15% of Installed Cost – CO_2 Capture Plant)	-		89		120	
Total Investment Cost – excl. Recurring CAPEX (US$ Million)			4,124		5,038		5,321
Recurring CAPEX (Blast Furnace Reline – Every 15th Year)			232		232		232
Specific Investment Cost – excl. Recurring CAPEX (US$/tHRC)			1,031		1,259		1,330

5. ANNUAL OPERATING AND MAINTENANCE COST

The basis of calculation of the annual operating and maintenance cost accounts for the following:

- Fixed Cost
  - Maintenance Cost
  - Direct Labour Cost
  - Indirect Labour, Management and Overhead Cost

- Variable Cost
  - Energy and Reluctant
  - Raw Materials
  - Fluxes
  - Consumables
  - Utilities

- Other Cost
  - Miscellaneous Works Expenses
  - Other Operational Expense (Environmental Clean Up, etc...)
  - On-Site Haulage Fee
  - Slag Processing Fee
  - Disposal and Landfill Cost

The calculation of these cost are described in Volume 1 of this report. The breakdown of these cost for the Steel Mill with Post-Combustion CO_2 capture are presented in Annex 5 and Annex 6.

This section will only highlight the summary of results for the Integrated Steel Mill with Post-Combustion CO_2 Capture for EOP-L1 and EOP-L2 Cases and compared against the annual O&M cost of the REFERENCE Steel Mill without CO_2 capture.

Table D-5 presents the breakdown of the Annual O&M Cost for the Steel Mill with Post-Combustion Capture.

The differences in the cost of annual O&M as compared to the REFERENCE Case involve the following items:

- Annual Maintenance Cost
- Direct Labour Cost
- Fuel Cost (Natural Gas)
- Chemical and Consumables (Power Plant and Steam Generation Plant)
- Annual Water Consumption
- Disposal and Landfill Cost (MEA Sludge Disposal)

The breakdown of these differences are summarised in Tables D-6 to D-10.

Table D-5: Summary of Results – Annual O&M Cost

Cost Item	REFERENCE Case Cost Breakdown (US$ Million/y)	REFERENCE Case Annual OPEX (US$ Million/y)	Steel Mill w/CO_2 Capture EOP-L1 Case Cost Breakdown (US$ Million/y)	Steel Mill w/CO_2 Capture EOP-L1 Case Annual OPEX (US$ Million/y)	Steel Mill w/CO_2 Capture EOP-L2 Case Cost Breakdown (US$ Million/y)	Steel Mill w/CO_2 Capture EOP-L2 Case Annual OPEX (US$ Million/y)
Fixed O&M Cost		**422.717**		**454.290**		**464.759**
Maintenance	141.996		169.903		179.996	
Direct Labour	204.581		208.247		208.623	
Indirect Labour	76.140		76.140		76.140	
Variable O&M Cost		**1288.650**		**1438.355**		**1492.620**
Fuel and Reductant	483.938		615.481		666.362	
Iron Ore (Fines, Lumps and Pellets)	492.054		492.054		492.054	
Purchased Scrap and Ferroalloys	218.228		218.228		218.228	
Fluxes	44.650		44.650		44.650	
Consumables & Other Utilities	49.781		67.943		71.326	
Miscellaneous Expense		**62.247**		**62.247**		**62.247**
Miscellaneous Works Expense	50.398		50.398		50.398	
Other Misc. OPEX (incl. environmental clean up)	11.849		11.849		11.849	
Other O&M Cost		**8.181**		**11.334**		**12.069**
Slag Processing	3.578		3.578		3.578	
On-Site Haulage	0.268		0.268		0.268	
Disposal and Landfill	4.335		7.488		8.222	
Annual O&M Cost (US$ Million/y)		**1,781.795**		**1,966.226**		**2,031.694**

Table D-6: Summary of Results – Annual Maintenance Cost

Unit No.	Plant / Process	REFERENCE Case: Maintenance (% CAPEX)	REFERENCE Case: Maintenance Cost (US$ Million/y)	Steel Mill w/CO_2 Capture EOP-L1 Case: Maintenance (% CAPEX)	Steel Mill w/CO_2 Capture EOP-L1 Case: Maintenance Cost (US$ Million/y)	Steel Mill w/CO_2 Capture EOP-L2 Case: Maintenance (% CAPEX)	Steel Mill w/CO_2 Capture EOP-L2 Case: Maintenance Cost (US$ Million/y)
100	Coke Production	5.0%	20.000	5.0%	20.000	5.0%	20.000
200	Sinter Production	5.0%	11.000	5.0%	11.000	5.0%	11.000
300 & 400	Blast Furnace and Hot Metal Desulphurisation	4.0%	24.880	4.0%	24.880	4.0%	24.880
500 & 600	Basic Oxygen Steelmaking and Ladle Metallurgy	5.0%	22.950	5.0%	22.950	5.0%	22.950
700	Continuous Slab Caster	8.0%	15.636	8.0%	15.636	8.0%	15.636
800 & 900	Reheating Furnace & Hot Rolling Mills	8.0%	36.000	8.0%	36.000	8.0%	36.000
1000	Lime Production	8.0%	1.280	8.0%	1.280	8.0%	1.280
1100	Air Separation Unit	2.5%	3.250	2.5%	3.250	2.5%	3.250
1200	Power Plant	2.5%	7.000	4.0%	14.469	5.0%	18.087
2000	Steam Generation Plant	-	-	2.5%	3.475	2.5%	4.000
4000	CO2 Capture and Compression Plant	-	-	2.5%	16.963	2.5%	22.914
Annual Maintenance Cost (US$ Million/y)		**5.12%**	**141.996**	**4.63%**	**169.903**	**4.58%**	**179.996**

Table D-6: Summary of Results – Direct Labour Cost

Unit No.	Plant / Process	REFERENCE Case		Steel Mill w/CO_2 Capture EOP-L1 Case		Steel Mill w/CO_2 Capture EOP-L2 Case	
		No of Personnel	Direct Labour Cost (US$ Million/y)	No of Personnel	Direct Labour Cost (US$ Million/y)	No of Personnel	Direct Labour Cost (US$ Million/y)
100	Coke Production	240	22.560	240	22.560	240	22.560
200	Sinter Production	270	25.380	270	25.380	270	25.380
300 & 400	Blast Furnace and Hot Metal Desulphurisation	321	30.174	321	30.174	321	30.174
500 & 600	Basic Oxygen Steelmaking and Ladle Metallurgy	396	37.224	396	37.224	396	37.224
700	Continuous Slab Caster	360	33.840	360	33.840	360	33.840
800 & 900	Reheating Furnace & Hot Rolling Mills	480	45.157	480	45.157	480	45.157
1000	Lime Production	34	3.1960	34	3.1960	34	3.1960
1100	Air Separation Unit	35	3.290	35	3.290	35	3.290
1200	Power Plant	40	3.760	42	3.948	42	3.948
2000	Steam Generation Plant	-	-	15	1.410	17	1.598
4000	CO2 Capture and Compression Plant	-	-	22	2.068	24	2.256
Annual Maintenance Cost (US$ Million/y)		2176	$204.58 Million/y	2215	$208.25 Million/y	2219	$208.62 Million/y

Table D-8: Breakdown of Annual NG Bill

		REFERENCE Case		Steel Mill w/CO_2 Capture EOP-L1 Case		Steel Mill w/CO_2 Capture EOP-L2 Case	
Fuel and Reductant Cost (US$ Million/y)		**US$ 483.94 Million/y**		**US$ 615.48 Million/y**		**US$ 666.36 Million/y**	
Natural Gas Consumption and Cost							
1200	Power Plant	0.85 GJ/t HRC	33.20	3.64 GJ/t HRC	142.33	3.93 GJ/t HRC	153.46
2000	Steam Generation Plant	-	-	0.57 GJ/t HRC	22.42	1.59 GJ/t HRC	62.17
Annual NG Consumption Cost (US$ Million/y)		**US$ 33.20 Million/y**		**US$ 164.75 Million/y**		**US$ 215.63 Million/y**	

Table D-9: Breakdown of Chemical and Consumables

		REFERENCE Case		Steel Mill w/CO_2 Capture EOP-L1 Case		Steel Mill w/CO_2 Capture EOP-L2 Case	
Consumables and Other Utilities (US$ Million/y)		US$ 49.78 Million/y		US$ 67.94 Million/y		US$ 71.33 Million/y	
Chemical and Consumables							
1200	Power Plant		7.88		7.88		8.56
2000	Steam Generation Plant		-		7.50		7.50
4000	CO2 Capture & Compression Plant		-		8.38		10.33
Annual Water Bill							
	Annual Make Up Water Consumption (m3/y)	21,068,828	2.39	41,179,759	4.68	47,827,764	5.43
Total (US$ Million/y)		US$ 10.27 Million/y		US$ 28.43 Million/y		US$ 31.82 Million/y	

Table D-10: Breakdown of Disposal and Landfill Cost

		REFERENCE Case		Steel Mill w/CO_2 Capture EOP-L1 Case		Steel Mill w/CO_2 Capture EOP-L2 Case	
Disposal and Landfill Cost (US$ Million/y)		**US$ 4.34 Million/y**		**US$ 7.49 Million/y**		**US$ 8.22 Million/y**	
Natural Gas Consumption and Cost							
4000	CO2 Capture & Compression Plant (MEA Sludge)	-	-	4,973 t/y	3.15	6,131 t/y	3.89
Annual NG Consumption Cost (US$ Million/y)		**-**		**US$ 3.15 Million/y**		**US$ 3.89 Million/y**	

6. ANNUAL REVENUES FROM SALE OF STEEL MILL'S BY-PRODUCTS

The study assumed that only the following by-products were sold from the steel mill:

- Coke By-Products (Crude Tar, Benzole, Sulphur)
- Granulated BF Slag
- BOS Slag
- Argon

In the cost model developed and presented by Tata Steel Consulting, it was assumed that:

- All by-products are sold at fixed price (as shown in Table D-1)
- All sale of these by-products are credited to the producer

Table D-11 presents a summary of the annual revenues derived from the by-products sale of the integrated steel mill without and with CO_2 capture cases. As there is no change to the steel mill operation when incorporating the post-combustion CO_2 capture plant, thus the annual revenues from the steel mill's by-products for the EOP-L1 and EOP-L2 Cases are the same as compared to the REFERENCE Steel Mill case.

Table D-11: Revenues from Sale of Steel Mill's By-Products

Cost Items	All Cases	
	Tonnage (t/y)	Annual Sales (US$ Million/y)
100: Coke By-Products		
Crude Tar	67,080	**11.806**
Benzole	19,729	**9.197**
Sulphur	4,937	**0.420**
Steel Mill Slag		
300: Granulated BF Slag	1,111,252	**17.780**
500: BOS Slag (LD Slag)	224,903	**0.450**
1100: Liquid Argon	26,918	**14.018**
Annual Revenues (US$ Million/y)		**53.670**

7. SPECIFIC PRODUCTION COST – INTERMEDIATE PRODUCTS

The cost breakdown of all the different intermediate products for EOP-L1 and EOP-L2 Cases are presented in Annex 5 and Annex 6 respectively.

The most significant impact on the annual direct cost of the integrated steel mill with Post Combustion CO_2 capture is due to the additional electricity and steam consumption of the CO_2 capture plant.

The cost of CO_2 capture and the additional cost to produce electricity and steam required to operate the CO_2 capture plant are all charged to the users of these utilities. The increase in the cost of incorporating CO_2 capture plant is reflected in the cost of the different intermediate products. These are summarised in Table D-12.

Table D-12: Specific Production Cost of Various Intermediate Products of the Steel Mill without and with CO_2 Capture

(NOTE: The cost reported only accounts for the annual OPEX of each specific unit. This excludes CAPEX and indirect labour cost)

From / Intermediate Products	REFERENCE Case Specific Production Cost (US$ / unit product)	Steel Mill w/CO_2 Capture EOP-L1 Case Specific Production Cost (US$ / unit product)	Steel Mill w/CO_2 Capture EOP-L2 Case Specific Production Cost (US$ / unit product)	Notes and Remarks
100: Coke Production	$ 207.78 per tonne coke	$ 226.80 per tonne coke	$ 277.68 per tonne coke	For EOP-L1 Case, the increase in the coke production cost is due to the increase in the specific cost of steam supplied to the coke oven batteries. On the other hand, for EOP-L2, the increase in the coke price is the effect of the price increase due to the capture of CO_2 from the coke oven's underfire heaters.
200: Sinter Production	$ 96.14 per tonne sinter	$ 95.47 per tonne sinter	$ 99.02 per tonne sinter	For EOP-L1 Case, the cost reduction is due to the cheaper electricity price as compared to the REFERENCE case. Whilst the increase for EOP-L2 Case are due to the increase in the cost of lime and coke breeze delivered to the sinter plant. (This is the effect of the cost of capturing CO2 from the lime and coke plants).
300/400: Iron Making	$ 258.65 per tonne Hot Metal	$ 327.49 per tonne Hot Metal	$ 333.29 per tonne Hot Metal	For both cases, the increase is mostly due to the cost of CO2 capture from the hot stoves and the cost of steam supplied to the hot metal production.
500/600: Steelmaking	$ 327.85 per tonne Liquid Steel	$ 375.73 per tonne Liquid Steel	$ 390.78 per tonne Liquid Steel	The increase in the cost of liquid steel is mainly due to the effect of the increase in the hot metal cost delivered to the crude steel production plant. Nonetheless, it should be noted that the increase of credit gained from steam generated and the reduction of cost of oxygen are factored into this number.
700: Continuous Casting	$ 350.11 per tonne Slab	$ 398.96 per tonne Slab	$ 414.49 per tonne Slab	The increase in slab cost is primarily due to the increase in the liquid steel cost.
1000: Lime Production	$ 98.91 per tonne Lime	$ 96.15 per tonne Lime	$ 196.42 per tonne Lime	For EOP-L1 Case, the decrease in the price of lime is due to the lower electricity price delivered to the lime plant. On the other hand, for EOP-L2, the increase in the lime price is the effect of the price increase due to the capture of CO_2 from the lime kilns' flue gases.
1100: ASU High Purity O2	$ 0.05958 per Nm3 Oxygen	$ 0.03838 per Nm3 Oxygen	$ 0.03588 per Nm3 Oxygen	The cost of oxygen production is reduced due to the lower cost of electricity delivered by the power plant.
1200: Power Plant	$ 125.3 per MWh Electricity	$ 75.4 per MWh Electricity	$ 75.6 per MWh Electricity	The deployment of the NGCC in both EOP-L1 and EOP-L2 cases increases the efficiency of the captive power plant as compared to the REFERENCE case. This therefore lowers the cost of electricity produced.
2000: Steam Generation Plant	-	$ 53.20 per GJ Steam (9 bar sat.)	$ 38.68 per GJ Steam (9 bar sat.)	For the REFERENCE Case, the steam is produced from the waste heat boilers of the BOS plant. This is delivered at a cost of $3.63 /GJ. The cost of steam production for EOP-L1 and EOP-L2 also includes the cost of CO2 capture.
4000: CO2 Capture Plant	-	$ 177.01 per tonne CO2 captured	$ 134.70 per tonne CO2 captured	The differences in the operating cost of capture per tonne of CO2 reflects the impact of the economy of scale.

8. ANNUAL OPERATING COST OF THE INTEGRATED STEEL MILL WITH POST-COMBUSTION CO_2 CAPTURE TECHNOLOGY

The overall annual operating cost of the integrated steel mill with CO_2 capture was calculated using 2 methods.

- The first method is based on the difference between the overall annual O&M cost (as presented in Table D-5), and the revenues obtained from the sale of by-products (as presented in Table D-11).

- The second method is based on the sum of the annual production cost of the hot rolled coil (which represents the direct cost of the hot rolled coil production as presented in Annex II and Annex III for EOP-1 and EOP-L2 Cases Respectively), and the indirect cost of the steel mill (which mainly consists of the indirect labour cost (as presented in Table D-5).

Tables D-13 and D-14 summarised the results of the calculation of the annual operating cost of the Integrated Steel Mill using the two methods for the economic life of the steel mill (i.e. 25 years of operation).

8.1. Cost Base of the Major Plants and Processes (Distribution of Annual O&M Cost and Sale Revenues of By-Products)

Based on Accounting Method 01 (Tables D-13 and D-14), Figures D-3(a) and D3(b) illustrate the breakdown of the annual O&M cost and by-products sales revenues of the different major plants and processes for the steel mill with Post-Combustion CO_2 capture.

The following could be referred to with regard to the calculation of the cost distribution as presented in Figure D-3(a) and D-3(b):

- Energy and Reductants
    - Coking and PCI coal
    - Natural Gas (Tables D-8)
- Raw Materials
    - Iron Ore
    - Purchased Scrap and Ferroalloys
    - Fluxes
- Consumables and Other Utilities
- Direct Labour (Table D-7)
- Maintenance and Other OPEX
    - Annual Maintenance Cost (Table D-6)
    - Miscellaneous Cost
    - Other O&M Cost
- Revenues – Sale of By Products (Section D-6)

It should be noted that the costs presented in the figures do not include the indirect labour cost of the integrated steel mill. This figure should also demonstrate the cost base of each plants and processes by presenting the cost of externally sourced raw materials, energy and reductants, consumables and other utilities used by each business units (major plants and processes).

Table D-13: Annual Operating Cost of the Steel Mill with Post-Combustion CO_2 Capture (EOP-L1 Case)

Annual Operating Cost	Operating Period					Cost Reference (Year 4-25)
	1	2	3	4	5 … 25	
Annual HRC Production (t/y)	**2,000,000**	**3,000,000**	**3,600,000**	**4,000,000**	**4,000,000**	
Accounting Method 01						
Annual O&M Cost	1109.66	1537.94	1794.91	1966.23	1966.23	Table D-5
Revenues (By-Product Sales)	(26.84)	(40.25)	(48.30)	(53.67)	(53.67)	Table D-11
Annual Operating Cost (US$ Million/y)	**1082.82**	**1497.69**	**1746.61**	**1912.56**	**1912.56**	
Accounting Method 02						
Direct Cost of HRC Production	1020.31	1428.36	1673.20	1836.42	1836.42	Annex II – Page 11
Indirect Cost of Steel Mill	62.51	69.33	73.41	76.14	76.14	Table D-5
Annual Operating Cost (US$ Million/y)	**1082.82**	**1497.69**	**1746.61**	**1912.56**	**1912.56**	

Table D-14: Annual Operating Cost of the Steel Mill with Post-Combustion CO_2 Capture (EOP-L2 Case)

Annual Operating Cost	Operating Period					Cost Reference (Year 4-25)
	1	2	3	4	5 … 25	
Annual HRC Production (t/y)	**2,000,000**	**3,000,000**	**3,600,000**	**4,000,000**	**4,000,000**	
Accounting Method 01						
Annual O&M Cost	1147.63	1589.66	1854.88	2031.69	2031.69	Table D-5
Revenues (By-Product Sales)	(26.84)	(40.25)	(48.30)	(53.67)	(53.67)	Table D-11
Annual Operating Cost (US$ Million/y)	**1120.79**	**1549.41**	**1806.58**	**1978.02**	**1978.02**	
Accounting Method 02						
Direct Cost of HRC Production	1058.28	1480.08	1733.16	1901.88	1901.88	Annex III – Page 11
Indirect Cost of Steel Mill	62.51	69.33	73.41	76.14	76.14	Table D-5
Annual Operating Cost (US$ Million/y)	**1120.79**	**1549.41**	**1806.58**	**1978.02**	**1978.02**	

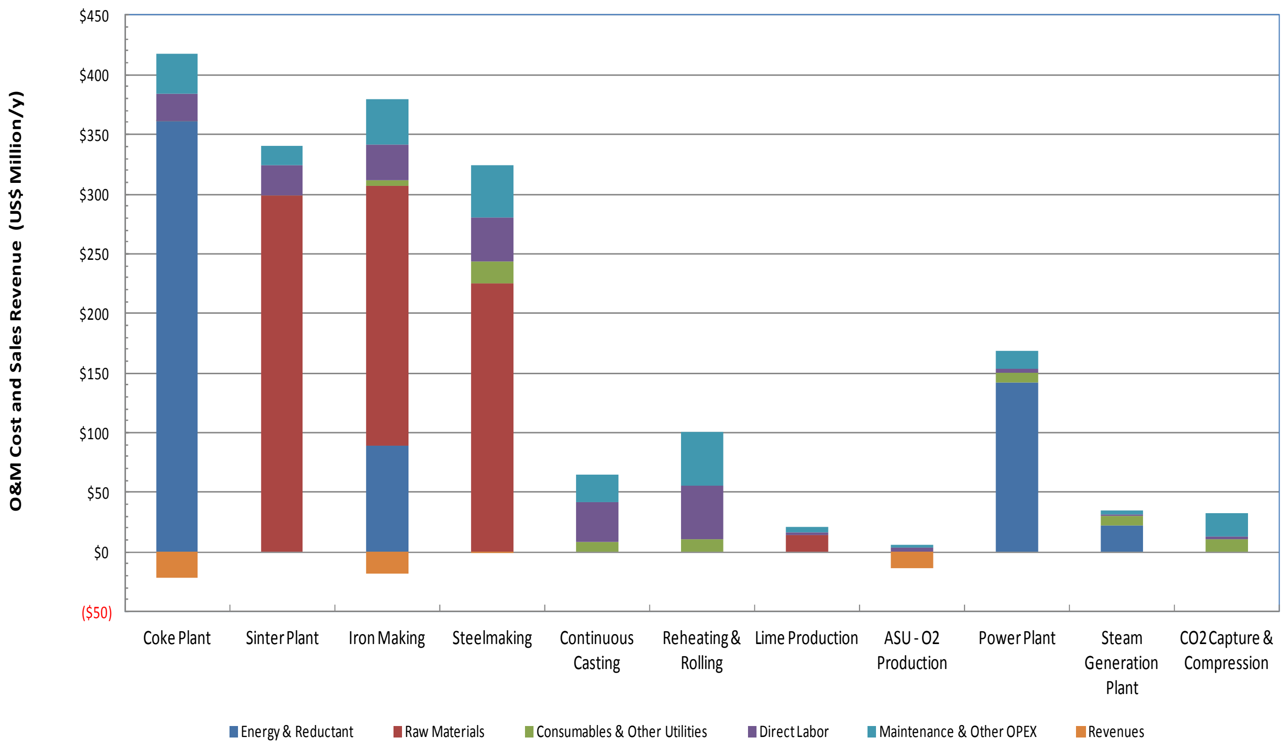

Figure D-3(a): Cost Base of the Major Processes of the Integrated Steel Mill with Post-Combustion CO2 Capture (EOP-L1 Case)
(excl. Indirect Labour Cost)

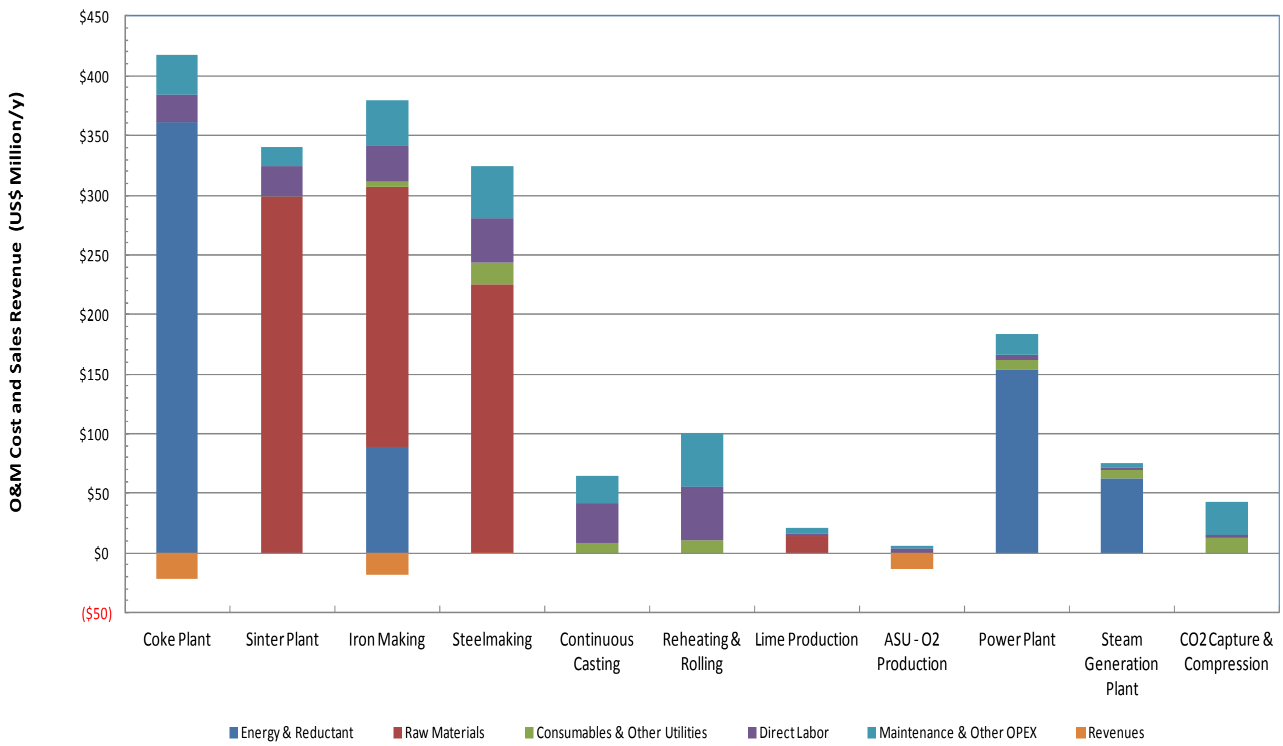

Figure D-3(b): Cost Base of the Major Processes of the Integrated Steel Mill with Post-Combustion CO2 Capture (EOP-L2 Case)
(excl. Indirect Labour Cost)

9. BREAK EVEN PRICE

The breakeven price (or levelised cost) of the hot rolled coil (ex-works) for the steel mill with CO_2 capture is calculated based on the discounted cash flow presented in Annex 4 and 5 for EOP-L1 and EOP-L2 Cases respectively.

The breakeven price of the hot rolled coil produced from the Integrated Steel Mill with CO_2 capture producing 4 million tonnes per year was estimated at US$ 652.44 per tonne HRC and US$ 677.70 per tonne HRC for EOP-L1 and EOP-L2 Cases respectively. The breakdown of this price is presented in Figures D-4(a) and D-4(b). This is an increase of ~US$ 77.20 and ~US$ 102.50 per tonne HRC for EOP-L1 and EOP-L2 Cases as compared to the breakeven price of the HRC produced from REFERENCE Steel Mill without CO_2 Capture (at US$ 575.23 per tonne HRC).

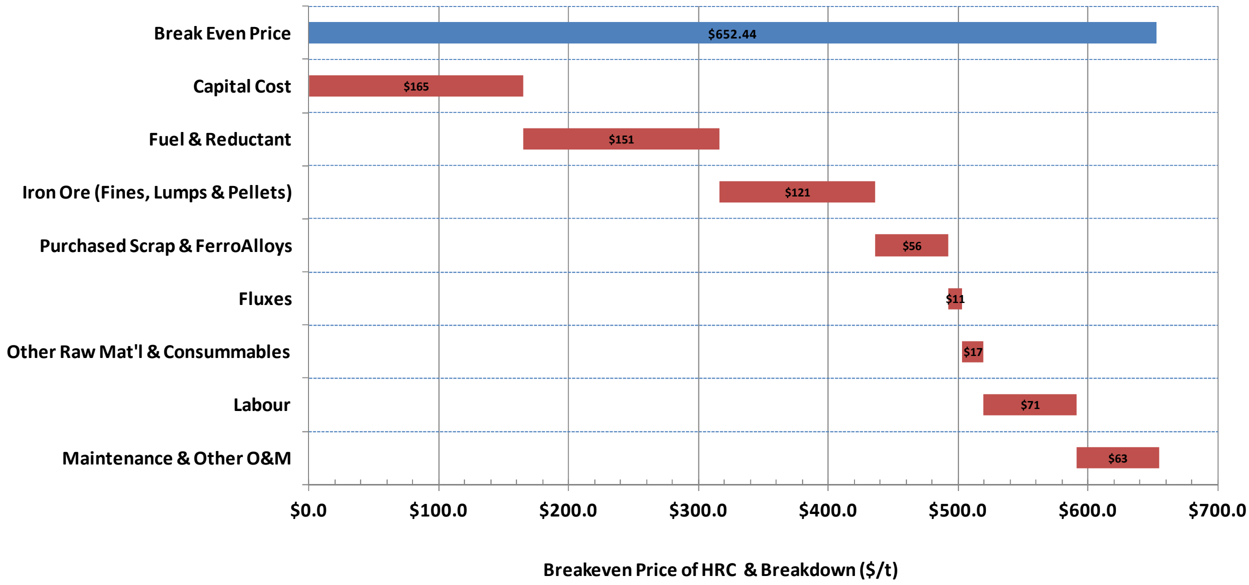

Figure D-4(a): Breakeven Price of Hot Rolled Coil -
Integrated Steel Mill with Post-Combustion CO_2 Capture – EOP-L1 Case ($/t HRC) ex-Works

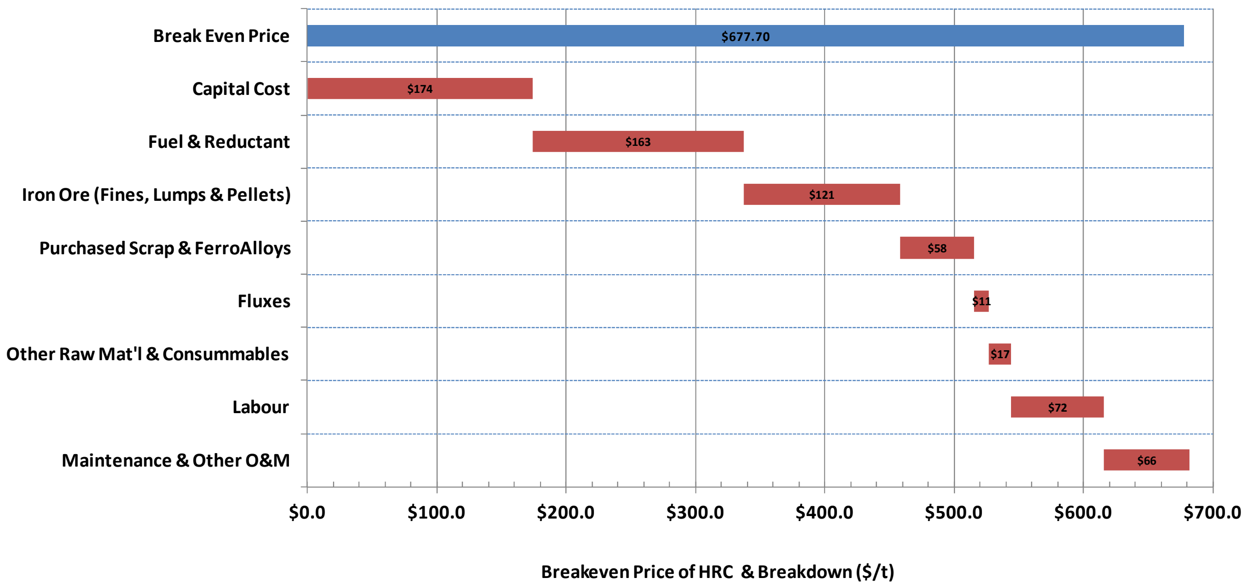

Figure D-4(b): Breakeven Price of Hot Rolled Coil -
Integrated Steel Mill with Post-Combustion CO_2 Capture – EOP-L2 Case ($/t HRC) ex-Works

9.1. Simplified Profit and Loss Account

The simplified profit and loss account of the Integrated Steel Mill without and with CO_2 capture at the respective breakeven prices of the hot rolled coil (ex-works) is presented in Table D-15. These numbers indicate the minimum annual profit (EBITDA) required to achieve break even of the operation of the integrated steel mill without and with CO_2 capture to cover capital repayment over the 25 years economic life.

Table D-15: Simplified Profit and Loss Account (Operating Years: 4 - 25)

Earnings (EBITDA) of the Steel Mill without & with CO_2 Capture at their Respective Breakeven Price (Ex-Works) Level

Hot Rolled Coil Production	**4,000,000 Tonnes HRC per year**		
	REFERENCE - Base Case ($'000)	Post-Combustion CO_2 Capture - EOP-L1 Case ($'000)	Post-Combustion CO_2 Capture - EOP-L2 Case ($'000)
Breakeven Price ($/t HRC)	$ 575.23	$ 652.44	$ 677.70
Sales Revenues			
Hot Rolled Coil	$ 2,300,934.15	$ 2,609,765.03	$ 2,710,810.73
Coke By-Products	21,422.91	21,422.91	21,422.91
Granulated Slag	17,780.03	17,780.03	17,780.03
LD Slag	449.81	449.81	449.81
Argon	14,017.68	14,017.68	14,017.68
	$ 2,354,604.57	$ 2,663,435.45	$ 2,764,481.15
Fixed Production Cost			
Annual Maintenance Cost	$ (141,996.10)	$ (169,902.80)	$ (179,996.35)
Direct Labour	(204,580.78)	(208,246.78)	(208,622.78)
Indirect Labour	(76,140.00)	(76,140.00)	(76,140.00)
	$ (422,716.88)	$ (454,289.58)	$ (464,759.13)
Variable Production Cost			
Energy and Reductant	$ (483,937.74)	$ (615,480.92)	$ (666,361.92)
Iron Ore Products	(492,053.74)	(492,053.74)	(492,053.74)
Purchased Scrap & Ferroalloys	(218,228.11)	(218,228.11)	(218,228.11)
Fluxes	(44,649.89)	(44,649.89)	(44,649.89)
Consumable & Other Utilities	(49,780.77)	(67,942.82)	(71,326.10)
Miscellaneous Cost	(62,246.77)	(62,246.77)	(62,246.77)
Other OPEX	(8,181.34)	(11,333.92)	(12,068.56)
	$ (1,359,078.36)	$ (1,511,936.17)	$ (1,566,935.10)
NET PROFIT/(LOSS) - EBITDA	$ 572,809.34	$ 697,209.70	$ 732,786.92

10. CO_2 AVOIDANCE COST

Table D-16 summarized the calculation of the CO_2 avoidance cost for both EOP-L1 and EOP-L2 cases as compared to the REFERENCE Base Case.

Table D-15: CO_2 Avoidance Cost

	HRC Breakeven Price	Direct CO2 Emission	% CO2 Avoided	CO2 Avoidance Cost
REFERENCE Case	575.23	2090.14 kg/t HRC	-	-
EOP-L1 Case	652.44	1041.73 kg/t HRC	50.2%	\$73.64/t CO_2 Avoided
EOP-L2 Case	677.70	827.42 kg/t HRC	60.4%	\$81.15/t CO_2 Avoided

10.1. Sensitivity of the CO_2 Avoidance Cost to the Technology Choice of the Steam Production

The technology choice of producing steam could impact the CO_2 avoidance and its cost. It was roughly estimated that by replacing the steam generation plant with a combine heat and power plant could reduced the CO_2 avoidance cost by 12-14% as compared to the CO_2 avoidance cost reported in study cases (i.e. EOP-L1 and EOP-L2)

Figure D-5 presents an indicative reduction of the CO_2 avoidance costs if a CHP plant were to replace the current Low Pressure Steam Boiler assumed in this study. The increase in CO_2 capture rate is due to the fact that some natural gas is used in the CHP plant and CO_2 is captured. The use of supplementary NG is to maximized the supply of electricity from the CHP in order to supplement the electricity supply of the smaller NGCC plant assumed in the step-off cases.

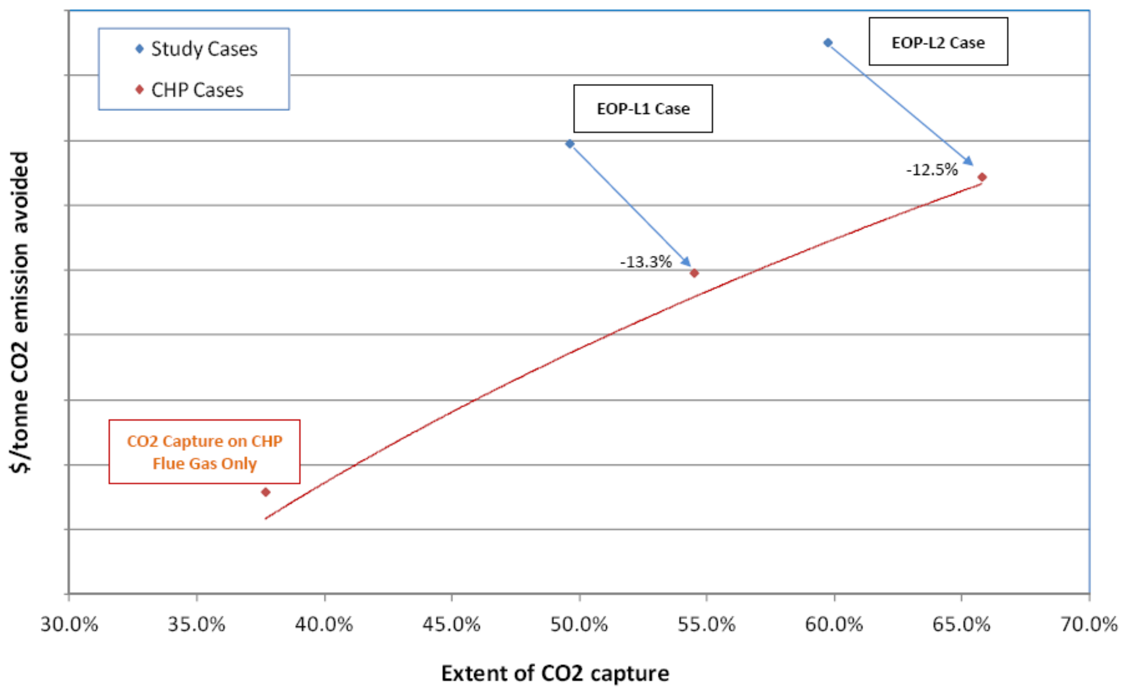

Figure D-5: Potential Reduction in the CO_2 Avoidance Cost by introduction of simple CHP option

Synthesis Report:

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

REPORT ANNEX

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Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

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Annex I

General Assumptions and Design Basis

I N D E X

1. INTRODUCTION

This section of the report provides the general information and assumptions used in establishing the operating parameters of the Steel Mills with Post-Combustion CO_2 Capture. These include the information regarding:

- General Assumptions
- Design Basis for the Site Specific Conditions

2. GENERAL ASSUMPTIONS

2.1. Extra-Ordinary Assumptions

Some assumptions which are classified as extra-ordinary were used to simplify the accounting of the CO_2 emissions, the energy demand, and the cost of steel produced. It should be noted that these assumptions are only used to provide a clear illustration and to establish a comparable cost basis between steel mills with and without CO_2 capture.

It should be emphasized that these assumptions are very idealized and not intended to represent any actual integrated steel mills in operation. These are only used to simplify the accounting of energy imports and exports and the CO_2 emissions associated with these.

The steering committee agreed to the following extra-ordinary assumptions to be used in the study:

a) Only one type of steel product produced and sold.

   It was assumed in the study that a standard grade hot rolled coil will be the only main product to be sold outside the set boundary limit.

   It should be noted that typical integrated steel mills would produce several grades and forms of steel in a single site; and also have the possibility to sell semi-finished products like slab, beam or billet.

   Annual production of 4 million tonnes of hot rolled coil per year was assumed. This is agreed to represent typical capacity of European Integrated Steel Mills.

b) Plant ownership structure

   The study assumed captive ownership of the lime plant (UNIT 1000), oxygen plant (UNIT 1100), power plant (UNIT 1200) and steam generation plant (UNIT 2000)

   In general, European integrated steel mills, do not own these plants. Electricity, industrial gases (O_2, Ar & N_2) and lime required by the steel mill are generally bought based on long term over the fence contracts and guarantees. CO_2 emissions from these facilities are typically not accounted for in the direct emissions of the integrated steel mill.

   However, directly or indirectly, these plants use the off-gases of the steel mill as their primary energy source. In order to simplify the accounting of the direct CO_2 emissions and cost evaluation without the consideration of the "CO_2 Emission Export", these plants were assumed to be included in the boundary limit and owned by the steel mill.

c) Balanced coke production

The study assumed that coke plant (UNIT 100) will produce lump coke and coke breeze that are sufficient for the demands of the steel mill – i.e. there will be no export or import of coke.

In general – coke is a tradable commodity and any surplus coke produced by an integrated steel mill is sold in the market. Typically, there is no integrated steel mill that will have coke production in balance with the steel mill's requirements.

d) Captive power plant – with balanced electricity production

The captive power plant is assumed to produce electricity that is only enough to supply the requirements of the whole steel mill. There will be no import or export of electricity into or out of the boundary limit. For steel mills with post-combustion CO_2 capture, the study assumed that natural gas is imported into the boundary limit to serve as its primary fuel.

In reality the majority of Western European integrated steel mills do not own their power plant. Any excess off-gases produced from these steel mills are sold as fuel to a power plant or other users outside the steel mill complex. Delivery is via a pipeline based on an off take supply contract. The electricity required by the steel mill is generally bought from a power plant outside their steel mill complex based on a long term over the fence contract or is bought directly from the grid.

e) Other operating considerations

- CO_2 emissions resulting from manufacture of purchased pellets, burnt dolomites and merchant scrap will not be accounted as direct CO_2 emissions of the steel mill.

- Granulated BF Slag will not be given CO_2 emission credit – even if this could be considered as substitute clinker for the cement industry.

2.2. Key Assumptions

Key technical assumptions used to define the boundary conditions in determining the heat and mass balance are summarized below.

a) The steel mill is assumed to have access to natural gas delivered via pipeline.

b) Iron Ore Burden

The iron ore burden composition for the blast furnace was fixed in the study and this consisted of: (1.) Sinter ~70%w; (2.) Pellets ~22%w; and (3.) Lump ore ~8%w. This distribution is maintained constant over the economic life of the integrated steel mill.

The iron ore fines used to produce the sinter are assumed to be imported from Brazil (Hematite), Australia (Hematite & Goethite) and Sweden (Magnetite). The lump ore is from Australia; and the pellets are from Brazil.

In general, there are very wide variations in iron ore burden composition among the operating blast furnaces in Western Europe ranging from 100% pellet to 100% sinter. The burden chosen has been agreed among the members of the Steering Committee and accepted as representative ferrous burden of a typical European Steel Mill equipped with a sinter plant.

c) Coking Coal and Coke By-Products

The study assumed a By-Product Recovery Coking Plant with Coke Oven Gas, Crude Tar, Benzole and Sulphur as the only coking by-products produced by the "Reference" Steel Mill.

Based on industry norms the coke and coke by-products were specified according to the following yields (as %w of the input coking coal):

- Lump Coke 67.2%w
- Coke Breeze 10.6%w
- Coke Oven Gas (wet) 14.2%w
- Crude Tar 3.2%w
- Benzole 0.9%w
- Sulphur 0.2%w

However, it should be noted that the study did not provide a detailed mass balance for the coke by-product plant. Coke demand/coke rate was calculated from the Blast Furnace Model as briefly described in Section B6.3. Coking coal required is defined by the coke demand of the steel mill and typical coke yield reported by the industry.

It should be noted that it is very typical for steel mills to buy their coking coal from various sources and blend both high and low quality coking coal to the coke ovens (type of coking coal used is normally of several varieties unless it is being sourced from a single coal mine).

To represent the typical blends of high and low quality coking coal used in any steel mill, a proportion of 60%w hard coking coal and 40%w semi-soft coking coal was assumed. Both types of coking coal are imported from Australia. This distribution is maintained constant over the economic life of the integrated steel mill.

d) Key Ironmaking Operating Parameters

The following parameters were fixed to determine the overall iron ore requirements, sinter rate and coke rate of the blast furnace.

- PCI Coal Injection rate ~150 kg/thm
- Oxygen enrichment of the blast air 24%
- Slag rate ~280 kg/thm.
- Hot metal temperature set to 1470°C with hot metal Si and C content fixed at 0.5% and 4.7% respectively.

Hot Metal loss was fixed at ~1.9%Fe for the HM Desulphurisation Plant (UNIT 400).

e) Key Steelmaking Operating Parameters

The study assumed liquid steel production based on 2x 220 tonnes BOS Furnaces operating at 45 minutes per cycle, each equipped with waste heat boiler.

The following parameters were fixed to determine the amount of fluxes and additives needed for the steelmaking process.

- Total scrap rate ~190 kg/tls (with purchased scrap at ~116 kg/tls)
- Pellets for cooling ~5 kg/tls
- Burnt dolomite ~11 kg/tls
- Oxygen charged ~52 Nm^3/tls
- Slag rate ~113 kg/tls (with composition of the slag fixed)
- BOF gas recovery set at 75% of carbon recovery using a fixed gas composition.

Other operating considerations

- Continuous casting was assumed to have a slab yield of ~97%.
- Reheating and rolling mills was assumed to have steel recovery of ~95%.

f) Off-Gas Distribution and Utilisation

The composition of off gases obtained from the coke ovens, blast furnaces and basic oxygen furnaces were specified according to industry norms.

The study assumed that all off-gas produced from the coke ovens (UNIT 100), blast furnaces (UNIT 300) and basic oxygen steel furnaces (UNIT 500) are recovered based on industry norms and are used within the steel mill. For steel mills with post-combustion CO_2 capture (i.e. Cases 2A and 2B), any excess off-gases are delivered to the captive steam generation plant (UNIT 2000) as fuel.

In case that any surplus off gases is produced – it will be assumed to be flared. In addition to flared off-gases which are normal in any operating steel mills, all off-gases that are considered lost or not recovered will also be accounted for as "flared".

For Cases EOP-L1 and EOP-L2, the study assumed the following with regard to the utilisation of the off-gases from the steel mill:

- COG would supply fuel to the following:
  - coke plant (UNIT 100)
  - sinter plant (UNIT 200)
  - hot stoves (UNIT 300)
  - reheating furnace (UNIT 800) and
  - lime plant (UNIT 1000)

- BFG would supply fuel to the following:
  - hot stoves (UNIT 300) and
  - steam generation plant (UNIT 2000)

- BOFG would supply fuel to the steam generation plant (UNIT 2000).

The off-gas distribution will be maintained constant over the economic life of the Steel Mills with Post-Combustion CO_2 Capture.

3. DESIGN BASIS - SITE SPECIFIC CONDITIONS

3.1. Ambient Conditions

The average ambient conditions of the site were assumed as follows:

- Ambient Air Temperature 12°C
- Atmospheric Pressure 1.013 Bar
- Relative Humidity 80%

3.2. Raw Water

Raw water is obtained from the grid. This is normally treated and demineralised to the required standard for process water use and machinery cooling.

For machinery cooling, a maximum of 10°C rise was used during normal operation. It was assumed that a closed loop system was employed with sea water as the medium for cooling the machinery cooling water.

Raw Water

- Source: from grid
- Type : potable water
- Operating pressure at grade: 0.8 barg (min)
- Operating temperature : Ambient

Demineralised Water

- Type: treated water (mixed bed demineralization)
- Operating pressure at grade: 5.0 barg
- Operating temperature: Ambient
- Characteristics:
  - pH 6.5 to 7.0
  - Total dissolved solids (mg/kg) 0.1 max
  - Conductance at 25°C (µS) 0.15 max
  - Iron (mg/kg as Fe) 0.01 max
  - Free CO_2 (mg/kg as CO_2) 0.01 max
  - Silica (mg/kg as SiO_2) 0.015 max

3.3. Sea Water

Seawater used by the steel mill is normally for cooling duty using a once through cooling system. It is generally filtered and chlorinated to remove suspended solids and organic matter.

Sea Water

- Supply temperature:
  - average supply temperature: 12 °C
  - max allowed sea water temperature increase: 7 °C

- Other Data
  - Operating pressure at Users inlet: 0.9 barg
  - Max allowable ΔP for Users: 0.5 barg
  - Design pressure for Users: 4.0 barg
  - Design pressure for sea water line: 4.0 barg

- Design temperature: 55 °C
- Cleanliness Factor (for steam condenser): 0.9
- Fouling Factor: 0.0002 h °C m^2/kcal

3.4. Steam

Steam is available for plant used at 8 Barg and 175^{o}C (saturated).

For the REFERENCE Steel Mill Base Case, it is verified that the steam produced from the basic oxygen steelmaking plant (UNIT 500) should deliver enough steam for the demand of the entire steel mill. Back up steam, if required, could be obtained by extracting low pressure steam from the captive power plant's steam turbine.

It should be noted that the Combined NH_3 cracker and Claus Plant should also produced a small amount of low to medium pressure steam which is not modelled in the study. However, it could be assumed that this will be used by the coke plant and will not be distributed to the works' steam network.

3.5. Electricity

The electricity required for the steel mill is produced from the captive power plant. It was assumed that the steel mill has access to the main grid to provide backup electricity.

Specification of the electricity grid of the steel mill is presented below.

- Voltage: 110kV
- Frequency: 50 Hz
- Fault Duty: 50 kA

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Annex II

Specification: Raw Materials, Intermediate, By-Products and Finished Products

INDEX

1. INTRODUCTION

This section of the report provides the general information and assumptions used in establishing the operating parameters of the REFERENCE Steel Mill. These include the information regarding:

- Raw materials
- Energy and Reductants
- Products, Intermediate Products and By-Products
- Waste Materials for Disposal or Recycling

It should be noted that specifications reported in this section for all the energy, reductants, raw materials, products, by-products and waste are not the full assay normally required by the steel mill. However, the numbers provided should allow enough details for modelling of the mass and energy balance differences required for techno-economic evaluation.

2. ENERGY AND REDUCTANTS (EXTERNALLY SOURCED)

2.1. Coking Coal

Table A1-1: Specification of the Coking Coal

Dry Basis (%wt.)	Typical Range	Average (used in the study)
C	75 - 85	78.85
H	4 - 6	4.51
Fe	15 - 35	0.33
CaO	-	0.05
MgO	-	0.05
SiO_2	3 - 5	4.68
$Al2O_3$	1 - 3	2.10
Moisture	-	8.00
LHV (MJ/kg) - dry	-	31.10

2.2. PCI Coal

Table A1-2: Specification of the PCI Coal (after drying)

Dry Basis (%wt.)	Average (used in the study)
C	87.00
H	4.03
Fe	0.52
CaO	0.19
MgO	0.04
SiO_2	2.41
Al_2O_3	1.62
Moisture	1.00
LHV (MJ/kg) - dry	33.37

2.3. Natural Gas

Table A1-3: Specification of the Natural Gas

Dry Basis (%vol.)	Average (used in the study)
CH_4	83.90
C_2H_6	9.20
C_3H_8	3.30
C_4H_{10}	1.20
C_5H_{12}	0.20
CO_2	1.80
N_2	0.40
LHV (MJ/Nm^3) - dry	40.64

3. RAW MATERIALS

3.1. Iron Ore – Fines, Lumps and Pellets

Table A1-4: Specification of the Iron Ore Burden

Dry Basis (%wt.)	Iron Ore Fines			Lump Ore (Australia)	Pellets (Brazil)
	Hematite (Australia)	Hematite/Geothite (Brazil)	Magnetite (Sweden)		
Fe (Total)	66.2	57.95	69.77	61.00	65.50
CaO	0.05	0.28	0.42	0.30	1.80
MgO	0.06	0.18	0.45	0.20	1.20
Al_2O_3	0.87	1.91	0.17	2.76	0.60
SiO_2	2.58	5.02	1.15	8.38	2.80
Others[1]	Difference	Difference	Difference	Difference	Difference
Moisture	5.00	5.00	5.00	5.00	2.00

It should be noted that full assay of the iron ore also includes the specification for FeO, Fe_xO_y, Mn, P, S, and other trace elements (i.e. zinc, vanadium, titanium, lead, et. al.). These elements and compounds are all accounted for in the model of the mass balance developed by Swerea MEFOS.

3.2. Purchased Scrap and Ferroalloys

Purchased Scrap

Table A1-5: Specification of the Scrap Steel (External)

Dry Basis (%wt.)	Average (used in the study)
Fe[2]	98.89
C	0.11
Si	0.01
Others[3]	Difference

[1] Others include trace elements such Ti, V, Mn, etc... that comes together with the iron ore.
[2] External scrap comes in various forms and shape. Typically, Fe content should be in the range of 92 to 99%.
[3] Others include P, S, Cr, Nb, Ti, B, Ni, Cu, Pb, Zn, Mg, others trace elements.

Ferroalloys and Aluminium

Table A1-6: Specification of the Ferroalloys

Dry Basis (%wt.)	FeMnC	FeSi-75	Aluminium
Fe	14.58	22.56	0.67
C	6.87	0.03	-
Si	0.11	76.61	1.34
Mn	78.27	0.01	0.23
Al	0.00	0.71	96.30
Others[3]	Difference	Difference	Difference

3.3. Fluxes

Fluxes used in the iron and steelmaking process include:

- Limestone (Lime Production, Sinter Production and Blast Furnace)
- Quartzite (Sinter Production, Blast Furnace)
- Olivine (Sinter Production)
- Burnt Dolomite (Basic Oxygen Steelmaking Furnace)
- Calcium Carbine (Hot Metal Desulphurisation)

Table A1-7: Specification of Different Fluxes Used in Iron and Steelmaking Processes

Dry Basis (%wt.)	Limestone	Quartzite	Olivine	Burnt Dolomite
$CaCO_3$	94.20	-	-	-
CaO	1.20	-	0.20	40.00
$MgCO_3$	2.30	-	-	-
MgO	-	-	47.90	55.00
Al_2O_3	0.50	1.90	0.48	1.00
SiO_2	1.20	98.00	41.60	1.00
Fe (Total)	0.30	-	5.70	0.15
Others[4]	Difference	Difference	Difference	Difference
CO_2 (Total)	42.60	-	-	-
Moisture	1.0	1.0	1.0	1.0

Table A1-8: Specification of Calcium Carbide

Dry Basis (%wt.)	Average (used in the study)
CaC_2	79.00
CaO	15.80
CaS	1.20
Al_2O_3	1.20
SiO_2	1.50
Fe (Total)	0.20
C (Residual)	1.00
Others[4]	Difference
Moisture	0.00

[4] Others include TiO_2, V_2O_5, P_2O_5, MnO, Na_2O, K_2O

4. PRODUCTS, INTERMEDIATE PRODUCTS AND BY-PRODUCTS

4.1. Hot Rolled Coil

Table A1-9: Specification of the Hot Rolled Coil

Dry Basis (%wt.)	Average (used in the study)
Fe	98.73
C	0.12
Others[5]	Difference

The HRC produced from the finishing mill is directly transferred to the product stockyards ready for sale and delivery. Transport of finished goods is generally by rail. Hot Rolled Coil produced could be delivered in several sizes (thickness, width and length) dependent on the setting of the finishing mills. Thickness of the hot rolled coil could be in the range of 1 to 20mm; and width of 0.5 to 1.5m. Table A1-10 presents the typical dimension of the hot rolled coil delivered by the integrated steel mill with CO_2 capture presented in this study.

Table A1-10: Dimension of the Hot Rolled Coil

Hot Rolled Coil	Dimension
Thickness	1.47 mm
Width	700 mm
Hot Rolled Coil (Inside Diameter)	762 mm
Hot Rolled Coil (Outside Diameter)	1000 mm
Tolerance (Inside Diameter)	+0 / -50 mm

4.2. Slab

Typically, slabs are usually rectangular (though sometimes trapezoidal, i.e. a tapered slab), with a dimension in the order of 250 mm thick, 5000 to 12000 mm long, and 300 to 1500 mm wide. The slab should have a similar chemical composition to the hot rolled coil as shown in Table A1-9.

4.3. Liquid Steel

Table A1-11: Specification of the Liquid Steel

Dry Basis (%wt.)	Liquid Steel (after BOF)	Liquid Steel (after Ladle Metallurgy)
Fe	99.91	98.73
C	0.04	0.12
Others[5]	Difference	Difference

[5] Others are alloying materials added and other residual element.

4.4. Hot Metal

Table A1-12: Specification of the Hot Metal

Dry Basis (%wt.)	Hot Metal (Before Desulphurisation)	Hot Metal (After Desulphurisation)
Fe	94.15	94.24
C	4.70	4.65
Si	0.50	0.49
Mn	0.27	0.27
Others	Difference	Difference

For this study, the sulphur content of the hot metal prior to desulphurisation is estimated at 0.032%. After desulphurisation, the sulphur content of the hot metal is reduced to less than 0.01%.

4.5. Sinter

Table A1-13: Specification of Sinter

Dry Basis (%wt.)	Average (used in the study)
Fe (Total)	57.88
CaO	9.40
MgO	1.50
Al_2O_3	1.04
SiO_2	5.23
Others[6]	Difference
Moisture	0.00

4.6. Coke and Coke Breeze

Table A1-14: Chemical Composition of Coke (Lump & Breeze)

Dry Basis (%wt.)	Average (used in the study)
C	88.05
H	0.10
N	1.10
S	0.60
Fe	0.42
CaO	0.06
MgO	0.07
SiO_2	6.27
Al_2O_3	2.82
Alkalis (Na_2O & K_2O)	< 0.30
P	< 0.03
Moisture	4.00
Volatiles Matter	< 2.00
Ash	10.00
LHV (MJ/kg) - dry	29.01

[6] Others include other trace elements that are derived from the iron ore and fluxes.

4.7. Lime

Table A1-15: Specification of Lime

Dry Basis (%wt.)	Average (used in the study)
$CaCO_3$	6.80
CaO	87.40
MgO	1.86
Al_2O_3	0.85
SiO_2	2.03
Fe (Total)	0.51
Others[7]	Difference
CO_2 (Total)	3.00
Moisture	0.00

4.8. Coal Tar, BTX and Sulphur

Coal Tar

For this study, it was assumed that the crude tar sold as by-product has an LHV of 42 MJ/kg (dry) and moisture of 2.0%.

Benzene, Toluene and Xylene (BTX)

The chemical composition (%wt.) of Crude Benzole typically contains the following:

- Benzene 55 - 65%
- Toluene 10 - 20%
- Xylene 5 - 10%
- Others Difference

For this study, Crude Benzole is sold as by-product with an assumed LHV of 38 MJ/kg.

Sulphur

The solid sulphur produced from the Claus unit is estimated to have an LHV of 9.3 MJ/kg. Typically, the sulphur sold as by-product has the following properties:

Table A1-16: Sulphur Qualities

Sulphur	Quality
Status	Solid
Colour	Bright yellow
Purity	99.9% S (min.)
H_2S	< 10 ppm (max.)
Ash Content	< 0.05% (max.)
Carbonaceous Materials	< 0.05% (max)

[7] Others include TiO_2, V_2O_5, P_2O_5, MnO, Na_2O, K_2O

4.9. Steel Mill Slag

The steel mill produce a variety of slag sold as by-products, recycled or discharge as waste. For this study, the following slags were accounted for in the Techno-Economic Evaluation of the Steel Mill with Post-Combustion (End of Pipe) CO_2 capture.

- Granulated BF Slag (GBF Slag)
- Hot Metal Desulphurisation Slag (De-S Slag)
- Basic Oxygen Furnace Slag (BOF Slag also known as LD Slag or BOS Slag)
- Ladle Metallurgy Slag (LM Slag also known as SM Slag)

Table A1-17: Composition of the Steel Mill's Slag

Dry Basis (%wt.)	Granulated BF Slag	De-S Slag	BOF Slag	Ladle Slag (SM Slag)
Fe (Total)	0.30	79.49	20.00	1.08
C (Total)	-	4.16	-	-
CaO	42.21	11.40	50.74	62.46
MgO	7.63	n.r.	5.47	n.r.
Al_2O_3	10.33	n.r.	0.56	28.32
SiO_2	36.71	1.93	9.45	8.03
Others	Difference	Difference	Difference	Difference
Moisture	12.00	1.00	1.00	1.00

4.10. Off-Gases

Coke Oven Gas

For this study, the coke oven gas or COG is a medium CV fuel gases produced from the three coke oven batteries (UNIT 100). The gas from the coke oven is primarily processed to remove the tar, naphthalene, benzene/toluene/xylene (BTX), H_2S, ammonia and particulates as described in Section D. The fuel gas composition is summarized in Table A1-18.

Table A1-18: Specification of the Coke Oven Gas

Wet Basis (%vol.)	COG
CH_4	23.04
H_2	59.53
CO	3.84
CO_2	0.96
N_2	5.76
O_2	0.19
H_2O	3.98
Other HC	2.69
LHV (MJ/Nm^3) - wet	17.33

Blast Furnace Gas

Blast Furnace Gas or BFG is a low CV by-product gas produced by the blast furnaces (UNIT 300). This gas is primarily cleaned to remove the particulates. The specification of the BF gas used in this study is presented below.

Table A1-19: Specification of the Blast Furnace Gas

Wet Basis (%vol.)	BFG to Hot Stove	BFG to Other Users
H_2	3.59	3.63
CO	22.10	22.34
CO_2	21.86	22.10
N_2	48.24	48.77
H_2O	4.21	3.15
LHV (MJ/Nm^3) - wet	3.18	3.21

Basic Oxygen Furnace Gas

Basic Oxygen Furnace Gas or BOFG (also known as BOS Gas, LD Gas or Converter Gas) is a medium CV by-product gas produced by the basic oxygen furnace (UNIT 600). This gas is primarily cleaned to remove the particulates. The specification of the BOF gas used in this study is presented below.

Table A1-20: Specification of the Basic Oxygen Furnace Gas

Wet Basis (%vol.)	BOFG
H_2	2.64
CO	56.92
CO_2	14.44
N_2	13.83
H_2O	12.16
LHV (MJ/Nm^3) - wet	7.47

4.11. Oxygen, Nitrogen and Argon

Oxygen, nitrogen and argon are all produced from the Air Separation Unit (UNIT 1100). All gases will be available in both liquid and gaseous products at required delivery pressure. Table A1-21 summarized the product specification of the oxygen, nitrogen and argon from the ASU.

Table A1-21: Specification of the Oxygen, Nitrogen and Argon

	Oxygen	Nitrogen	Argon
Main Product	Gaseous Oxygen (GOX)	Gaseous Nitrogen (GAN)	Gaseous Argon (GAR) Liquid Argon (LAR)
Purity	99.9%	99.98%	99.99%
Delivery Pressure	7 Bar and 31 Bar	7 Bar and 21 Bar	7 Bar and 31 Bar
Product Sale	-	-	Liquid Argon (LAR)

4.12. Steam

The whole steel mill has an access to steam line at 9 bar_a and 175°C. The steam required by the CO_2 Capture and Compression Plant (Unit 4000) is mainly supplied from the Steam Generation Plant. Whilst the steam required by the whole steel mill is supplied by the steam produced from the waste heat boilers installed at the Basic Oxygen Furnace (UNIT 600).

4.13. Electricity

The electricity required for the steel mill is produced from the captive power plant (UNIT 1200). As backup, it was assumed that electricity could be bought from the grid. For simplicity in CO_2 emissions audit, it is assumed in this study that electricity produced from the captive power plant is balanced.

Specification of the Electricity produced by the captive power plant is presented below.

- Nominal Power Output: 292 MWe
- Voltage: 110 kV
- Frequency: 50 hz
- Fault Duty: 50 Ka

4.14. CARBON DIOXIDE

The Carbon Dioxide characteristics at plant B.L., are the following:

- Status: Supercritical/Dense Phase
- Pressure: 110 bar g
- Temperature: 25°C
- Purity:
  - CO_2: > 99% mol
  - Moisture: < 100 ppmv
  - Oxygen: < 10 ppmv

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

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Annex III

Process Overview and Mass Balances

I N D E X

1. NOMENCLATURE

With reference to the different PFD presented in this section, the list below gives the arrangements and nomenclatures used for each processes.

- Unit 100: Coke Production
  - 105: Coal Handling and Blending Facility
  - 110: Coke Oven Batteries
  - 120: Coke Quenching
  - 125: Coke Screening
  - 130: COG Cooling and Tar Separation
  - 131: Primary Gas Cooler
  - 132: Tar ESP
  - 133: Tar Recovery Unit and Tar Dehydrator
  - 140: Naphthalene Scrubber
  - 150: H_2S and NH_3 Scrubber
  - 155: H_2S and NH_3 Stripper
  - 160: Combine Claus Plant and NH_3 Cracker
  - 170: BTX Scrubber
  - 175: BTX Distillation
  - 180: Gas Exhauster and Gas Holder

- Unit 200: Sinter Production
  - 210: Raw Materials Handling and Blending Station
  - 220: Sinter Plant
  - 230: Gas Cleaning (from Sinter Strand) – Fabric Filter and ESP
  - 240: Sinter Crusher, Cooler and Screening
  - 250: Gas Cleaning (from Sinter Cooler) - ESP

- Unit 300: Hot Metal Production
  - 310: Raw Materials Handling, Blending and Feeding
  - 320: Blast Furnace
  - 330: BF Slag Granulation Plant
  - 340: Hot Stoves
  - 350: Recuperators
  - 360: Main Air Compression Plant
  - 370: BF Gas Cleaning - Cyclone and Scrubber
  - 380: Gas Holder
  - 1310: PCI Coal Preparation (Coal Mill) and Drying – part of ancillary unit

- Unit 400: Hot Metal Desulphurisation
  - 410: Hot Metal Desulphurisation Station
  - 420: Slag & HM Spillage Processing Unit

- Unit 500: Primary Steelmaking
  - 510: Basic Oxygen Furnace
  - 520: Slag Processing Unit
  - 530: Gas Recovery Hood and Waste Heat Boiler
  - 540: BOF Gas Cleaning – Cyclone and Scrubber
  - 550: Gas Holder

- Unit 600: Secondary Steelmaking (Ladle Metallurgy)
    - 610: Ladle Station
- Unit 700: Continuous Casting
    - 710: Continuous Slab Caster
- Unit 800 & 900: Reheating and Rolling Mills
    - 810: Reheating Furnaces
    - 820: Recuperators
    - 910: Hot Rolling Mill
- Unit 1000: Lime Production
    - 1010: Lime Kiln
    - 1020: Gas Cleaning – ESP
    - 1030: Screening
- Unit 1100: Air Separation Unit – Oxygen Production
    - 1110: Main Air Compressor
    - 1120: Air Pre-Cooling and Treatment
    - 1130: Main Heat Exchanger and Cryogenic Separation Plant
    - 1140: Liquid Product Storage
    - 1150: Product Evaporation and Compression Plant
- Unit 1200: Captive Power Plant
    - 1210: Gas Turbine Island
    - 1220: Electricity Generators
    - 1230: Heat Recovery Steam Generator
    - 1240: Steam Turbine Island
- Unit 2000: Steam Generation Plant
    - 1110: Boiler Island
    - 1120: Steam Delivery Manifolds
- Unit 4000: CO_2 Capture and Compression Plant
    - 3010: Flue Gas FD Fans
    - 3020: Direct Contact Coolers
    - 3030: Gas Holder
    - 3110: Absorber Column
    - 3120: Heat Integration and Exchange Networks
    - 3130: Flash Columns
    - 3140: Stripper Columns
    - 3200: CO_2 Compression Train

2. UNIT 100: COKE PRODUCTION

2.1. Study Specification

For EOP-L1 (Case 2A) and EOP-L2 (Cases 2B), the steel mill's coke production is based on 3 batteries of by-product recovery coke ovens equipped with 48 ovens per batteries (144 ovens in total). The total charge volume is ~45m^3.

Table A3-1 summarises the specification of the coke production of the Integrated Steel Mills with Post-Combustion CO_2 Capture.

2.2. PFD and Mass Balance

Figure A3-1 and Table A3-2 present the process flow diagram and a summary of the mass balance of the coke production for the Integrated Steel Mills with Post-Combustion CO_2 capture (Cases 2A and 2B).

Furthermore, below is the list of other users of coke oven gas within the Steel Mills with Post-Combustion CO_2 Capture not specified in any PFDs presented in this section of the report.

	Attached Unit	Nm^3 COG/t HRC
Torpedo heating	300: Hot Metal Production	1.10
Ignition, BF flare	300: Hot Metal Production	1.10
Ladle heating	500: BOF Steelmaking	10.86
Ignition, BOF flare	500: BOF Steelmaking	1.10

Table A3-1: General Information – Study Specification (Unit 100: Coke Production)

Description	Summary - Relevant Specifications	
No. of Coke Oven Batteries Total No. of Ovens Total Charge Volume	3 (each battery consists of 48 ovens) 144 45 m^3	
Coking Coal (dry) • Hard Coking Coal • Semi-Soft Coking Coal COG Consumption (wet) BFG Consumption (wet) Steam Consumption (9 bar_a, sat.) Electricity Consumption COG Export (wet)	1285.2 kg/t coke (2.10 Mt/y) 771.1 kg/t coke 514.1 kg/t coke 112.6 Nm^3/t coke 450.4 Nm^3/t coke 150.0 kg/t coke 35.0 kWh/t coke 327.0 Nm^3/t coke	523.8 kg/t HRC 314.3 kg/t HRC 209.5 kg/t HRC 45.9 Nm^3/t HRC 183.6 Nm^3/t HRC 61.1 kg/t HRC 14.3 kWh/t HRC 133.3 Nm^3/t HRC
Total Coke Production (dry) • BF Coke • Coke Breeze Crude Tar / Naphthalene (dry) Benzene, Toluene, Xylene (dry) Sulphur (dry)	1000.0 kg/t coke (1.63 Mt/y) 863.7 kg/t coke (1.41 Mt/y) 136.3 kg/t coke (0.22 Mt/y) 41.1 kg/t coke 12.1 kg/t coke 3.0 kg/t coke	407.6 kg/t HRC 352.0 kg/t HRC 55.6 kg/t HRC 16.8 kg/t HRC 4.9 kg/t HRC 1.2 kg/t HRC

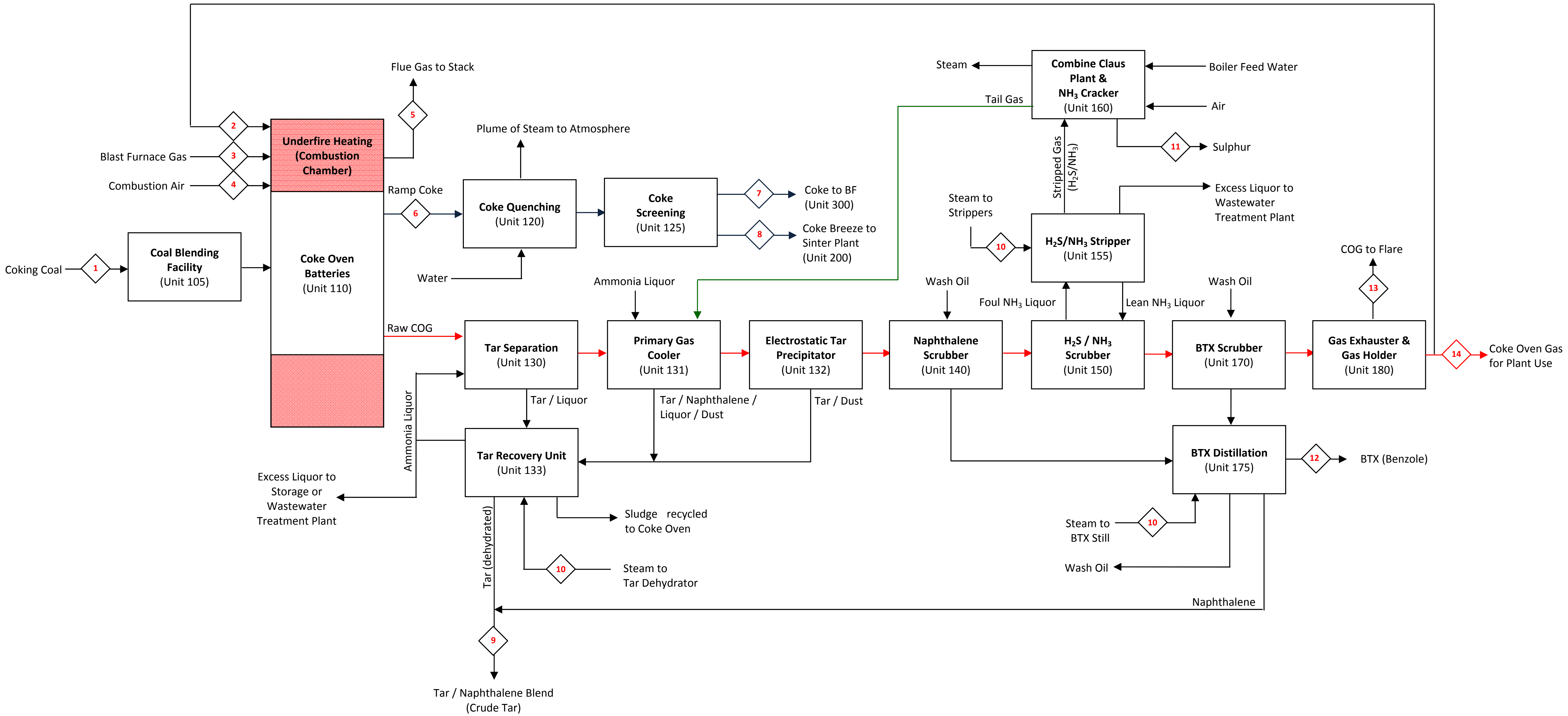

Figure A3-1: PFD of the coke production (Unit 100)

Table A3-2: Mass Balance (Unit 100: Coke Production)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Stream		**Coking Coal**	**COG to Underfire Heating**	**BFG**	**Combustion Air**	**Flue Gas**	**Ramp Coke**	**Coke to BF**	**Coke to Sinter**	**Crude Tar & Napthalene**	**Steam to Various Users**	**Sulphur**	**BTX (Benzole)**	**COG to flare**	**COG to Users**
Total Mass Flow (wet)	**t/y**	**2,277,702**	**79,713**	**992,429**	**2,402,783**	**3,474,968**	**1,698,457**	**1,466,917**	**231,540**	**68,449**	**244,578**	**4,937**	**19,729**	**7,321**	**231,457**
Total Mass Flow (dry)	**t/y**	**2,095,486**	**73,838**	**973,827**	**2,386,050**	**3,246,484**	**1,630,519**	**1,408,241**	**222,278**	**67,080**	**244,578**	**4,937**	**19,729**	**6,782**	**214,400**
Specific Mass Flow (wet)	kg/t coke	1396.9	48.9	608.7	1473.6	2131.2	1041.7	899.7	142.0	42.0	150.0	3.0	12.1	4.5	142.0
Specific Mass Flow (dry)	kg/t coke	1285.2	45.3	597.2	1463.4	1991.1	1000.0	863.7	136.3	41.1	150.0	3.0	12.1	4.2	131.5
Pressure	Bara	amb.	1.11	1.11	amb.	1.03	amb.	amb.	amb.	amb.	9.01	amb.	amb.	1.11	1.11
Temperature	oC	12	29	25	12	250	25	25	25	12	175	12	12	29	29
Phase		solid	gas	gas	gas	gas	solid	solid	solid	liquid	gas	solid	liquid	gas	gas
Solid Composition (dry basis)															
Fe	%wt.	0.33	-	-	-	-	0.42	0.42	0.42	-	-	-	-	-	-
C	%wt.	78.85	-	-	-	-	88.05	88.05	88.05	-	-	-	-	-	-
H	%wt.	4.51	-	-	-	-	0.10	0.10	0.10	-	-	-	-	-	-
CaO	%wt.	0.05	-	-	-	-	0.06	0.06	0.06	-	-	-	-	-	-
MgO	%wt.	0.05	-	-	-	-	0.07	0.07	0.07	-	-	-	-	-	-
SiO2	%wt.	4.68	-	-	-	-	6.27	6.27	6.27	-	-	-	-	-	-
Al2O3	%wt.	2.10	-	-	-	-	2.82	2.82	2.82	-	-	-	-	-	-
Moisture (wet basis)	%wt.	8.0	-	-	-	-	4.0	4.0	4.0	2.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/t coke	-	112.60	450.4	1149.74	1619.34	-	-	-	-	-	-	-	10.34	326.96
Average MW			9.7	30.3	28.7	29.5					18.0			9.7	9.7
Gas Composition (wet basis)															
CH4	%v.	-	23.04	-	-	-	-	-	-	-	-	-	-	23.04	23.04
Other HC (Average MW = C2.5H5)	%v.	-	2.69	-	-	-	-	-	-	-	-	-	-	2.69	2.69
H2	%v.	-	59.53	3.63	-	-	-	-	-	-	-	-	-	59.53	59.53
CO2	%v.	-	0.96	22.10	-	14.77	-	-	-	-	-	-	-	0.96	0.96
CO	%v.	-	3.84	22.34	-	-	-	-	-	-	-	-	-	3.84	3.84
O2	%v.	-	0.19	-	20.72	5.00	-	-	-	-	-	-	-	0.19	0.19
N2	%v.	-	5.76	48.77	78.17	69.47	-	-	-	-	-	-	-	5.76	5.76
H2O	%v.	-	3.98	3.15	1.11	10.76	-	-	-	-	100.00	-	-	3.98	3.98

3. UNIT 200: SINTER PRODUCTION

3.1. Study Specification

The model for the steel mills described in Cases 2A and 2B has assumed that the sinter production is equipped with a single train sintering machine with an annual production of 4.45 million tonnes sinter. This is equipped with raw materials handling (comprising different feed hoppers) and blending station (mixing drum), sinter strand, flue gas cleaning based on ESP and fabric filter, sinter crusher and rotary cooler, hot and cold screens, and off-gas cleaning consisting of ESP.

The sinter strand is a standard travelling grate equipped with an ignition furnace consisting of roof burners fired with coke oven gas as primary fuel and natural gas as back-up fuel. The sinter strand is assumed to have a grate area estimated at 410 m^2 with 90% utilization at 35 t/(m^2-24h).

Table A3-3 summarises the specification of the sinter production of the Integrated Steel Mills with Post-Combustion CO_2 Capture.

3.2. PFD and Mass Balance

Figure A3-2 and Table A3-4 present the process flow diagram and a summary of the mass balance of the sinter production for the Integrated Steel Mills with Post-Combustion CO_2 capture (Cases 2A and 2B).

Table A3-3: General Information – Study Specification (Unit 200: Sinter Production)

Description	Summary - Relevant Specifications	
No. of Sinter Plant Grate Area Type of Sinter Cooler Flue Gas Clean Up Sinter Basicity (Ratio of CaO/SiO_2)	1 (Standard Travelling Grate) 410 m^2 with 90% utilization at 35 t/(m^2-24h). Rotary Cooler ESP and fabric filter 1.80	
Coke Breeze (dry) COG Consumption (wet) Electricity Consumption	50.0 kg/t sinter 4.2 Nm^3/t sinter 32.0 kWh/t sinter	55.6 kg/t HRC 4.6 Nm^3/t HRC 35.6 kWh/t HRC
Sinter(dry) Iron Ore Fines (dry) • Hematite (Brazil) • Hematite/Goethite (Australia) • Magnetite (Sweden)	1000.0 kg/t sinter (4.45 Mt/y) 792.3 kg/t sinter (3.52 Mt/y) 657.6 kg/t sinter 79.3 kg/t sinter 55.5 kg/t sinter	1111.4 kg/t HRC 880.5 kg/t HRC 730.8 kg/t HRC 88.1 kg/t HRC 61.6 kg/t HRC

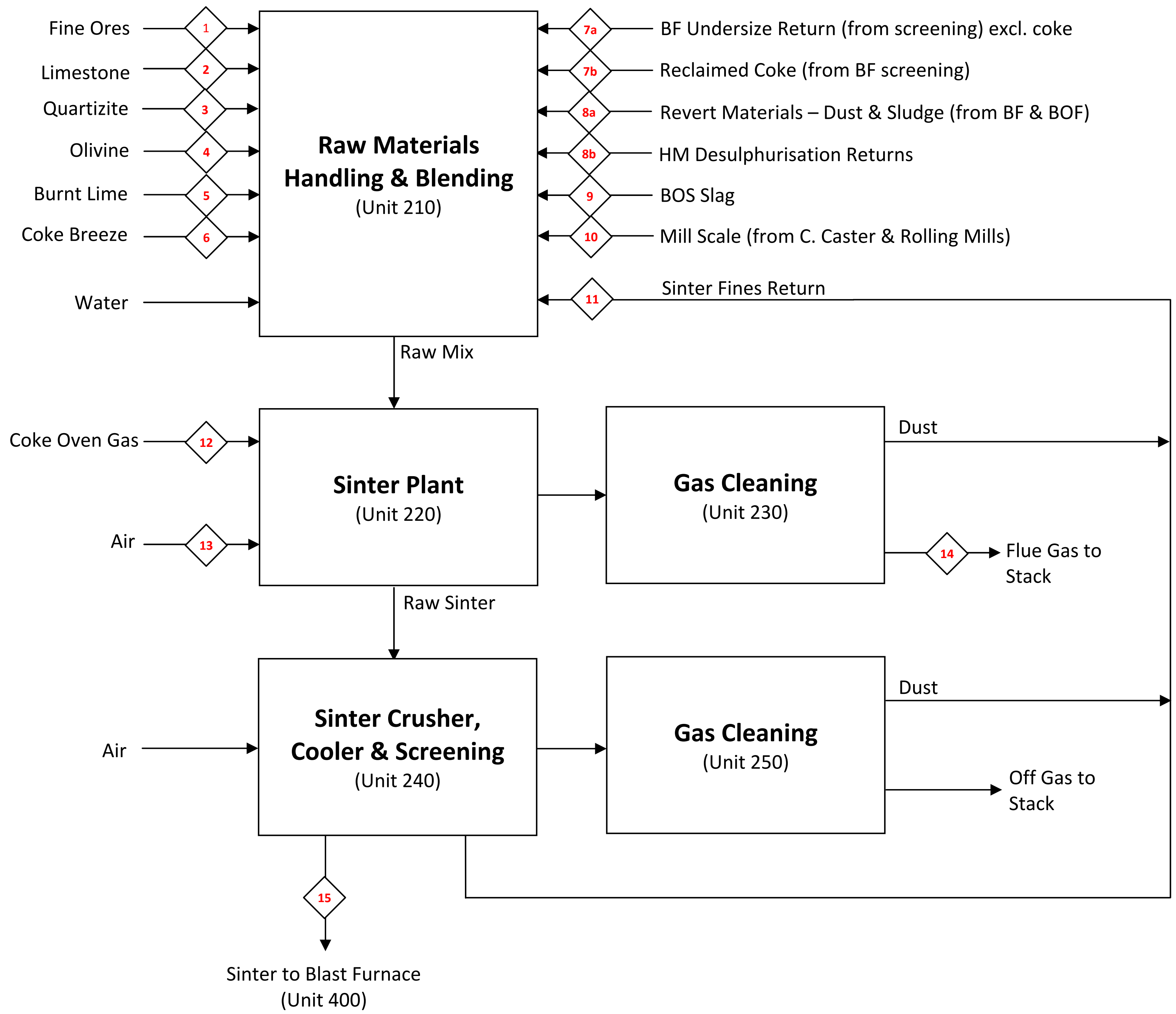

Figure A3-2: PFD of the sinter production (Unit 200)

Table A3-4: Mass Balance (Unit 200: Sinter Production)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stream		**Iron Ore Fines**	**Limestone**	**Quartzite**	**Olivine**	**Lime**	**Coke Breeze**	**BF Undersize**	**Revert Materials**	**BOS Slag**	**Mill Scale**	**Sinter Fines Return**	**COG**	**Combustion Air**	**Flue Gas**	**Sinter to BF**
Total Mass Flow (wet)	**t/y**	**3,707,389**	**523,103**	**53,886**	**91,261**	**44,456**	**231,540**	**93,796**	**255,479**	**138,275**	**97,131**	**1,111,390**	**8,000**	**12,645,530**	**1,818,115**	**4,445,559**
Total Mass Flow (dry)	**t/y**	**3,522,020**	**517,872**	**53,347**	**90,349**	**44,456**	**222,278**	**90,795**	**220,398**	**136,893**	**96,159**	**1,111,390**	**7,530**	**12,557,468**	**1,737,452**	**4,445,559**
Specific Mass Flow (wet)	kg/t sinter	834.0	117.7	12.1	20.5	10.0	52.1	21.1	57.5	31.1	21.8	250.0	1.8	2844.5	409.0	1000.0
Specific Mass Flow (dry)	kg/t sinter	792.3	116.5	12.0	20.3	10.0	50.0	20.4	49.6	30.8	21.6	250.0	1.7	2824.7	390.8	1000.0
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	1.11	amb.	1.03	amb.
Temperature	oC	12	12	12	12	12	12	12	12	12	12	80	25	12	120	45
Phase		solid	solid	solid	solid	solid	solid	solid	solid	solid	solid	solid	gas	gas	gas	solid
Solid Composition (dry basis)																
Fe	%wt.	65.62	0.30	-	5.70	0.51	0.42	42.01	54.80	20.00	70.00	57.84	-	-	-	57.84
C	%wt.	-	-	-	-	-	88.05	27.51	14.18	-	-	-	-	-	-	-
H	%wt.	-	-	-	-	-	0.10	-	-	-	-	-	-	-	-	-
CO2 (resiudual)	%wt.	-	42.60	-	-	3.00	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	0.10	54.00	-	0.20	91.26	0.06	1.73	10.22	50.72	0.72	9.45	-	-	-	9.45
MgO	%wt.	0.10	1.10	-	47.90	1.86	0.07	0.56	2.34	5.47	0.07	1.50	-	-	-	1.50
SiO2	%wt.	2.72	1.20	98.00	41.60	2.03	6.27	6.76	2.22	9.45	0.84	5.25	-	-	-	5.25
Al2O3	%wt.	0.93	0.50	1.90	0.48	0.85	2.82	1.87	0.60	0.56	0.16	1.04	-	-	-	1.04
Moisture (wet basis)	%wt.	5.0	1.0	1.0	1.0	-	4.0	3.2	13.7	1.0	1.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/t sinter	-	-	-	-	-	-	-	-	-	-	-	4.18	2219.33	2388.41	-
Average MW													9.7	28.7	28.0	
Gas Composition (wet basis)																
CH4	%v.	-	-	-	-	-	-	-	-	-	-	-	23.24	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	-	-	-	-	-	-	-	-	2.71	-	-	-
H2	%v.	-	-	-	-	-	-	-	-	-	-	-	60.05	-	-	-
CO2	%v.	-	-	-	-	-	-	-	-	-	-	-	0.97	-	4.81	-
CO	%v.	-	-	-	-	-	-	-	-	-	-	-	3.87	-	0.74	-
O2	%v.	-	-	-	-	-	-	-	-	-	-	-	0.19	20.72	14.90	-
N2	%v.	-	-	-	-	-	-	-	-	-	-	-	5.81	78.17	72.65	-
H2O	%v.	-	-	-	-	-	-	-	-	-	-	-	3.15	1.11	6.90	-

4. UNIT 300: HOT METAL PRODUCTION

4.1. Study Specification

The hot metal production of the integrated steel mill is designed based on 2 trains of blast furnace each producing around 1.98 Mt/y of hot metal (providing a total of 3.97 Mt/y). Each blast furnace is equipped with 3 hot stoves operating in staggered configuration. The main air compression that provides the blast air to the hot stove is electrically driven. Hot metal produced by the blast furnace is transferred to the Hot Metal Desulphurisation stations via pre-heated torpedo cars. The slag produced by the blast furnace is processed in a conventional wet slag granulation plant.

The blast furnace has a hearth diameter of 11 meter and a working volume of ~2750 m^3. The charging of the raw materials to the blast furnace is based on a bell less top technology. The blast furnace is equipped with PCI injection delivering coal at a rate of ~152 kg dry coal/thm. Blast furnace gas and coke oven gas are used as fuel to heat up the hot stoves. Hot blast air used by the blast furnace has oxygen added to enrich it to 24% O_2. Blast furnace gas collected is cleaned using a cyclone and wet scrubber system before being distributed to the different users (hot stove heating, coke oven under-fire heating, and power plant) within the steel mill.

Table A3-5 summarises the specification of the hot metal production of the Integrated Steel Mills with Post-Combustion CO_2 capture.

4.2. PFD and Mass Balance

Figure A3-3 and A3-6 present the process flow diagram and a summary of the mass balance of the hot metal production for the Integrated Steel Mills with Post-Combustion CO_2 capture (Cases 2A and 2B).

Table A3-5: General Information – Study Specification (Unit 300: Hot Metal Production)

Description	Summary - Relevant Specifications	
No. of Blast Furnace	2 (Each having a hearth diameter of 11 m & working volume of 2750 m^3)	
No. of Hot Stoves	6 (Each BF is equipped with 3 hot stoves with a central recuperator)	
No. of Main Air Compressors	2 (Each BF has 1 Axial Air Compressor ~250,000 Nm^3/h @ 3.8 Bara)	
Main Air Compressors Drive	Electrically Driven	
PCI Coal Injection Facility	Yes – with 1x PCI Coal Drying/Milling & 2x Injection Facilities	
Off-Gas Clean Up	2 trains of cyclone and wet scrubber (1 per BF)	
No. of Casthouses	2 (1 per BF with 2 operating tapholes for hot metal and slag withdrawal)	
No. of Slag Granulation Plant	2 (1 per BF – equipped with slag dewatering facility)	
Hot Metal Transfer Mode	Via Torpedo Cars to HM Desulphurisation Stations (Unit 400)	
BF Iron Burden Distribution (dry)	Sinter (70%w.), Pellets (22%w.), Lump (8%w.)	
Sinter Basicity (CaO/SiO_2 Ratio)	1.80	
Reducing Agent Rate – RAR (dry)	507 kg/thm	
Blast Volume (wet)	1053 Nm^3/thm	
Blast Pressure	3.8 Bara	
Blast Temperature	1118°C	
Blast O_2 Enrichment	24%v.	
Blast Moisture	16 g/Nm^3(dry)	
Hot Metal Temperature	1470°C	
Hot Metal Carbon Content (dry)	4.7%w.	
Hot Metal Silicon Content (dry)	0.5%w.	
Slag Rate (dry)	280 kg/thm	
Slag Basicity (CaO/SiO_2 Ratio)	1.15	
Top Pressure	2.4 Bara	
Top Gas Temperature	140°C	
PCI Coal (dry)	152.0 kg/thm	150.8 kg/t HRC
Lump Coke (dry)	354.8 kg/thm	352.1 kg/t HRC
COG Consumption – hot stoves (wet)	7.2 Nm^3/thm	7.2 Nm^3/t HRC
COG Consumption – PC drying (wet)	1.4 Nm^3/thm	1.4 Nm^3/t HRC
BFG Consumption – hot stoves (wet)	479.2 Nm^3/thm	475.4 Nm^3/t HRC
Steam Consumption (9 bar_a, sat.)	8.0 kg/thm	7.9 kg/t HRC
Electricity Consumption - HM Prod.	98.8 kWh/thm	98.1 kWh/t HRC
Electricity Consumption - Ancillary	4.9 kWh/thm	4.8 kWh/t HRC
BFG Export (wet)	1119.3 Nm^3/thm	1110.6 Nm^3/t HRC
Hot Metal (dry)	1000.0 kg/thm (3.97 Mt/y)	992.2 kg/t HRC
Sinter(dry)	1120.1 kg/thm	1111.4 kg/t HRC
Lump Ore (dry)	125.3 kg/thm	124.3 kg/t HRC
Pellets (dry)	351.8 kg/thm	349.0 kg/t HRC
Granulated Slag (dry)	280.0 kg/thm	277.8 kg/t HRC

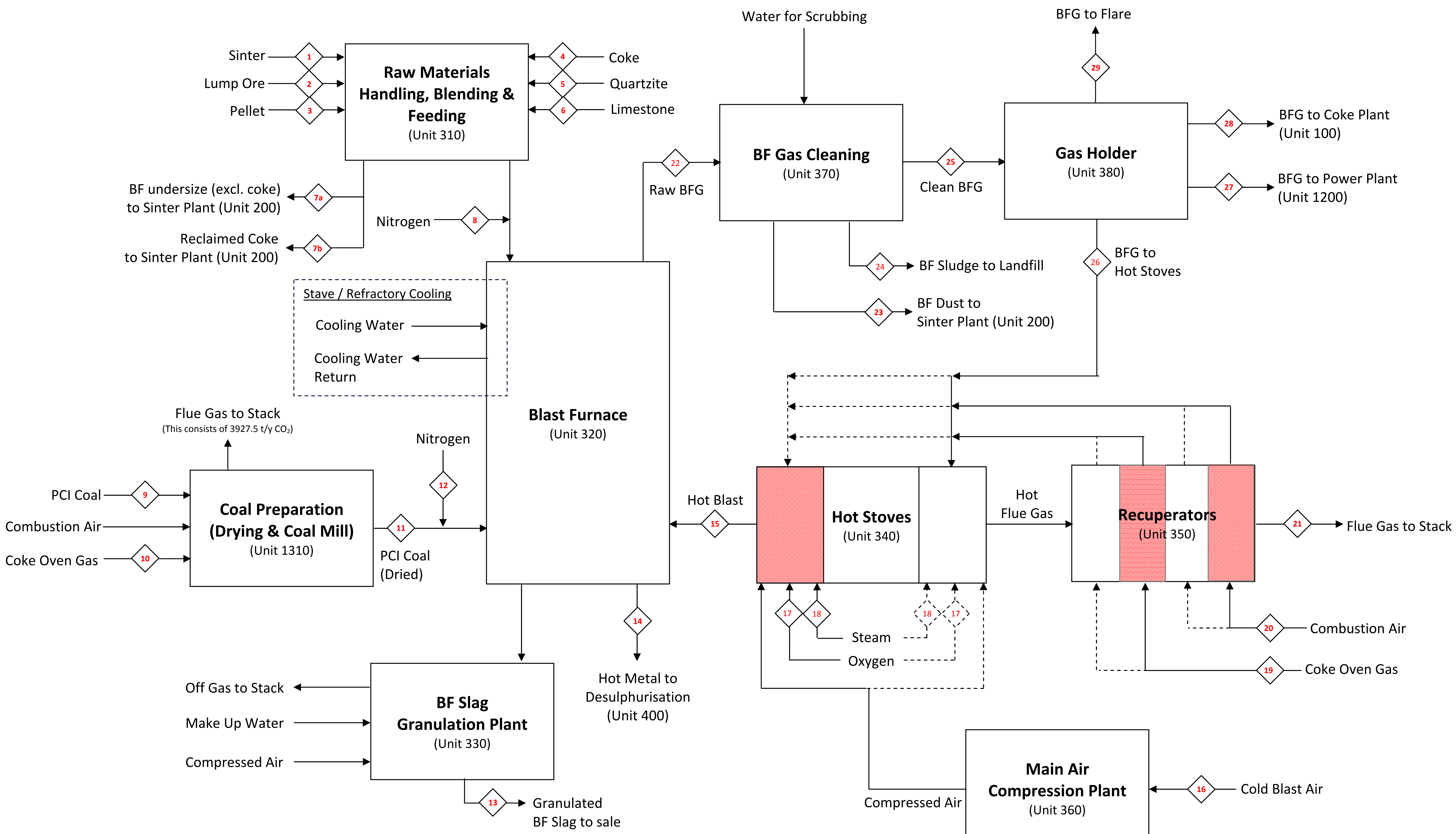

Figure A3-3: PFD of the hot metal production (Unit 300)

Table A3-6: Mass Balance (Unit 300: Hot Metal Production)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stream		**Sinter**	**Lump Ore**	**Iron Ore Pellets**	**Coke**	**Limestone**	**Quartzite**	**BF Undersize**	**N2 to RM Feeder (Top)**	**PCI Coal to Dryer**	**COG to Dryer**	**PCI Coal (dried)**	**N2 to PCI**	**BF Granulated Slag**	**Hot Metal**	**Hot Blast**
Total Mass Flow (wet)	**t/y**	**4,445,559**	**523,304**	**1,424,671**	**1,466,917**	**53,027**	**43,564**	**93,814**	**9,923**	**655,708**	**2,394**	**609,344**	**14,884**	**1,262,786**	**3,968,756**	**5,363,687**
Total Mass Flow (dry)	**t/y**	**4,445,559**	**497,139**	**1,396,178**	**1,408,241**	**52,497**	**43,129**	**90,795**	**9,923**	**603,251**	**2,254**	**603,251**	**14,884**	**1,111,252**	**3,968,756**	**5,296,779**
Specific Mass Flow (wet)	kg/thm	1120.1	131.9	359.0	369.6	13.4	11.0	23.6	2.5	165.2	0.6	153.5	3.8	318.2	1000.0	1351.5
Specific Mass Flow (dry)	kg/thm	1120.1	125.3	351.8	354.8	13.2	10.9	22.9	2.5	152.0	0.6	152.0	3.8	280.0	1000.0	1334.6
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	amb.	6.01	amb.	amb.	amb.	21.01	amb.	amb.	3.81
Temperature	oC	45	12	12	25	12	12	12	60	12	25	120	60	12	1470	1118
Phase		solid	solid	solid	solid	solid	solid	solid	gas	solid	gas	solid	Gas	solid	liquid	gas
Solid & Liquid Composition (dry basis)																
Fe	%wt.	57.88	61.00	65.50	0.42	0.30	-	42.01	-	0.52	-	0.52	-	0.30	94.15	-
C	%wt.	-	-	-	88.05	-	-	27.51	-	87.00	-	87.00	-	-	4.70	-
H	%wt.	-	-	-	0.10	-	-	-	-	4.03	-	4.03	-	-	-	-
Si	%wt.	-	-	-	-	-	-	-	-	-	-	-	-	-	0.50	-
CO2 (residual)	%wt.	-	-	-	-	42.60	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	9.40	0.30	1.80	0.06	54.00	-	1.73	-	0.19	-	0.19	-	42.21	-	-
MgO	%wt.	1.50	0.20	1.20	0.07	1.10	-	0.56	-	0.04	-	0.04	-	7.63	-	-
SiO2	%wt.	5.23	8.38	2.80	6.27	1.20	98.00	6.76	-	2.41	-	2.41	-	36.71	-	-
Al2O3	%wt.	1.04	2.76	0.60	2.82	0.50	1.90	1.87	-	1.62	-	1.62	-	10.33	-	-
Moisture (wet basis)	%wt.	-	5.0	2.0	4.0	1.0	1.0	3.2	-	8.0	-	1.0	-	12.0	-	-
Specific Vol. Flow (wet)	Nm3/thm	-	-	-	-	-	-	-	2.00	-	1.40	-	3.00	-	-	1052.68
Average MW									28.0		9.66		28.0			28.8
Gas Composition (wet basis)																
CH4	%v.	-	-	-	-	-	-	-	-		23.24	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	-	-	-	-	-		2.71	-	-	-	-	-
H2	%v.	-	-	-	-	-	-	-	-		60.05	-	-	-	-	-
CO2	%v.	-	-	-	-	-	-	-	-		0.97	-	-	-	-	-
CO	%v.	-	-	-	-	-	-	-	-		3.87	-	-	-	-	-
O2	%v.	-	-	-	-	-	-	-	0.02		0.19	-	0.02	-	-	24.13
N2	%v.	-	-	-	-	-	-	-	99.98		5.81	-	99.98	-	-	73.88
Ar	%v.	-	-	-	-	-	-	-	-		-	-	-	-	-	-
H2O	%v.	-	-	-	-	-	-	-	-		3.15	-	-	-	-	1.99

Table A3-6: Mass Balance (Unit 300: Hot Metal Production) – cont'd.

		16	17	18	19	20	21	22	23	24	25	26	27	28	29
Stream		**Cold Blast (Air)**	**O2**	**Steam**	**COG to Hot Stove**	**Combustion Air to Hot Stove**	**Flue Gas from Hot Stove**	**Raw BFG (Top Gas)**	**BF Dust to Sinter Plant**	**BF Sludge to Landfill**	**Clean BFG (Total)**	**BFG to Hot Stove**	**BFG to Power Plant**	**BFG to Coke Plant**	**Flared BFG**
Total Mass Flow (wet)	**t/y**	**5,060,744**	**271,438**	**31,568**	**12,336**	**1,820,735**	**4,390,757**	**8,724,518**	**59,531**	**17,639**	**8,668,140**	**2,557,673**	**5,012,625**	**992,397**	**122,228**
Total Mass Flow (dry)	**t/y**	**5,025,502**	**271,438**	**31,568**	**11,611**	**1,808,056**	**4,231,961**	**8,505,664**	**59,531**	**15,875**	**8,505,664**	**2,493,264**	**4,918,668**	**973,795**	**119,937**
Specific Mass Flow (wet)	kg/thm	1275.1	68.4	8.0	3.1	458.8	1106.4	2198.4	15.0	4.4	2184.2	644.5	1263.1	250.1	30.8
Specific Mass Flow (dry)	kg/thm	1266.3	68.4	8.0	2.9	455.6	1066.4	2143.2	15.0	4.0	2143.2	628.2	1239.4	245.4	30.2
Pressure	Bara	amb.	11.01	9.01	1.11	1.11	1.11	2.41	amb.	amb.	1.11	1.11	1.11	1.11	1.11
Temperature	oC	12	60	175	25	41	140	140	12	12	25	30	25	25	25
Phase		gas	gas	gas	gas	gas	gas	gas	solid	solid	gas	gas	gas	gas	gas
Solid & Liquid Composition (dry basis)															
Fe	%wt.	-	-	-	-	-	-	-	26.10	37.70	-	-	-	-	-
C	%wt.	-	-	-	-	-	-	-	47.03	23.69	-	-	-	-	-
H	%wt.	-	-	-	-	-	-	-	0.43	-	-	-	-	-	-
Si	%wt.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2 (residual)	%wt.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	-	-	-	-	-	-	-	6.00	6.18	-	-	-	-	-
MgO	%wt.	-	-	-	-	-	-	-	1.23	1.71	-	-	-	-	-
SiO2	%wt.	-	-	-	-	-	-	-	4.93	4.61	-	-	-	-	-
Al2O3	%wt.	-	-	-	-	-	-	-	1.98	1.90	-	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	-	-	-	-	0.0	10.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/thm	994.88	47.90	-	7.21	357.95	780.41	1633.97	-	-	1616.30	479.05	934.68	185.05	22.79
Average MW		28.7	32.0	18.0	9.7	28.7	31.8	30.2			30.3	30.2	30.3	30.3	30.3
Gas Composition (wet basis)															
CH4	%v.	-	-	-	23.24	-	-	-	-	-	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	2.71	-	-	-	-	-	-	-	-	-	-
H2	%v.	-	-	-	60.05	-	-	3.59	-	-	3.63	3.59	3.63	3.63	3.63
CO2	%v.	-	-	-	0.97	-	27.30	21.86	-	-	22.10	21.86	22.10	22.10	22.10
CO	%v.	-	-	-	3.87	-	-	22.10	-	-	22.34	22.10	22.34	22.34	22.34
O2	%v.	20.72	99.90	-	0.19	20.72	0.80	-	-	-	-	-	-	-	-
N2	%v.	78.17	0.01	-	5.81	78.17	65.52	48.25	-	-	48.77	48.24	48.77	48.77	48.77
Ar	%v.	-	0.09	-	-	-	-	-	-	-	-	-	-	-	-
H2O	%v.	1.11	-	100.00	3.15	1.11	6.38	4.20	-	-	3.15	4.21	3.15	3.15	3.15

5. UNIT 400: HOT METAL DESULPHURISATION

5.1. Study Specification

The study assumed the hot metal desulphurisation station reducing hot metal sulphur content from ~0.032%w. to less than 0.01%w. based on mono-reagent injection using CaC_2. The process is not expected to be energy intensive; nonetheless, best practice in place is aimed to achieve energy efficiency by reducing hot metal spillage to minimum during slag skimming, and reducing hot metal temperature drop during hot metal transfer.

The study assumed 1.9% hot metal loss and a temperature drop of 110^{o}C (from BF tapping to BOF charging). Metal spillage and slag are combined in the slag processing unit of which 37% is returned to the sinter plant and 63% sent to landfill.

Table A3-7 summarises the specification of the hot metal desulphurisation of the steel mill.

5.2. PFD and Mass Balance

Figure A3-4 and Table A3-8 present the process flow diagram and a summary of the mass balance of the hot metal desulphurisation of the Integrated Steel Mills with Post-Combustion CO_2 capture (Cases 2A and 2B).

Table A3-7: General Information – Study Specification (Unit 400: HM Desulphurisation)

Description	Summary - Relevant Specifications	
No. of HM Desulphurisation Station	2 stations (including slag and spillage processing unit)	
Desulphurisation Reagent	Mono-injection system using CaC_2	
Reagent Injection Carrier Gas	Nitrogen	
Off-Gas Clean Up	De-dusting Equipment (i.e. Cyclone)	
Hot Metal Loss	1.9%	
Hot Metal Temperature Drop	110^{o}C	
Sulphur Content	< 0.01%w.	
Electricity Consumption	Accounted for in Unit 300	-
De-S Hot Metal (dry)	1000.0 kg/t de-S HM (3.89 Mt/y)	973.6 kg/t HRC
Hot Metal from BF (dry)	1019.1 kg/t de-S HM (3.97 Mt/y)	992.2 kg/t HRC

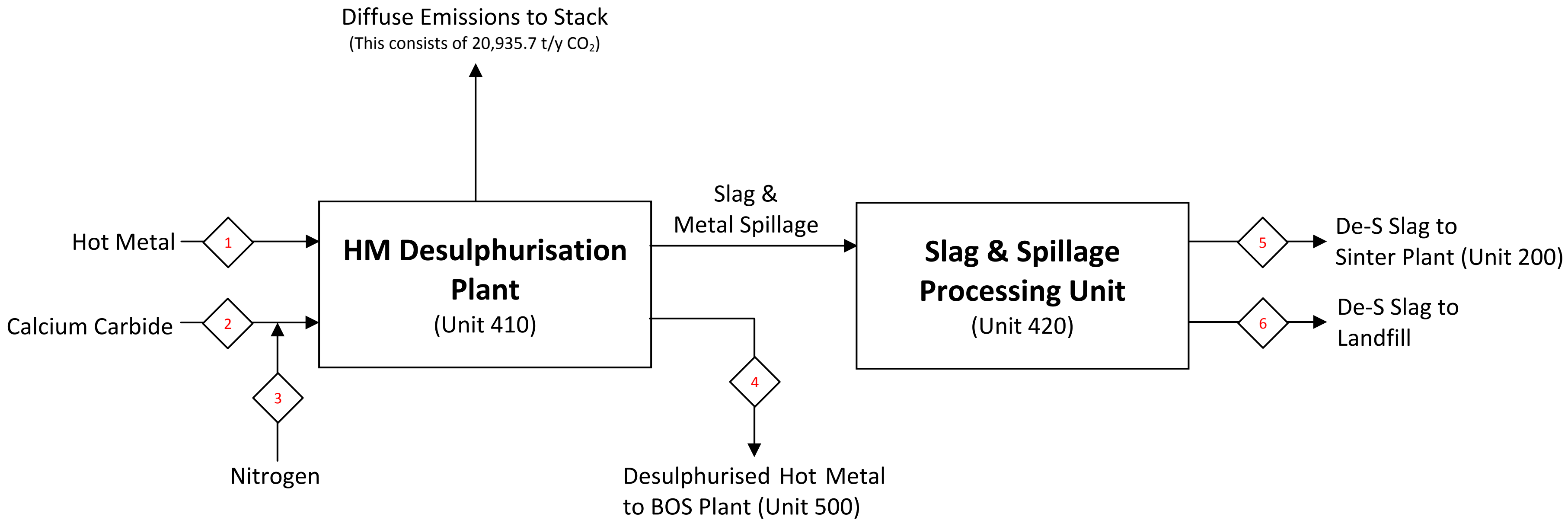

Figure A3-4: PFD of the hot metal desulphurisation (Unit 400)

Table A3-8: Mass Balance (Unit 400: Hot Metal Desulphurisation)

		1	2	3	4	5	6
Stream		**Hot Metal from BF**	**Calcium Carbide**	**N2 to CaC2 Feed**	**De-S Hot Metal**	**De-S Slag to Landfill**	**De-S Slag to Sinter**
Total Mass Flow (wet)	**t/y**	**3,968,756**	**12,710**	**715**	**3,894,263**	**53,604**	**31,482**
Total Mass Flow (dry)	**t/y**	**3,968,756**	**12,710**	**715**	**3,894,263**	**53,068**	**31,167**
Specific Mass Flow (wet)	kg/thm (de-S)	1019.1	3.3	0.2	1000.0	13.8	8.1
Specific Mass Flow (dry)	kg/thm (de-S)	1019.1	3.3	0.2	1000.0	13.6	8.0
Pressure	Bara	amb.	amb.	21.01	amb.	amb.	amb.
Temperature	oC	1470	12	60	1360	12	12
Phase		liquid	solid	gas	liquid	solid	solid
Solid & Liquid Composition (dry basis)							
Fe	%wt.	94.15	0.20	-	94.24	79.49	79.49
C	%wt.	4.70	1.00	-	4.65	4.16	4.16
Si	%wt.	0.50	-	-	0.49	-	-
CaC2	%wt.	-	79.00	-	-	-	-
CaS	%wt.	-	1.20	-	-	n.r.	n.r.
CaO (incl. carbonates)	%wt.	-	15.80	-	-	11.40	11.40
MgO	%wt.	-	-	-	-	-	-
SiO2	%wt.	-	1.50	-	-	1.93	1.93
Al2O3	%wt.	-	1.20	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	-	1.0	1.0
Specific Vol. Flow (wet)	Nm3/thm (de-S)	-	-	0.15	-	-	-
Average MW				28.0			
Gas Composition (wet basis)							
O2	%v.	-	-	0.02	-	-	-
N2	%v.	-	-	99.98	-	-	-
H2O	%v.	-	-	-	-	-	-

6. UNIT 500: BASIC OXYGEN STEELMAKING PLANT

6.1. Study Specification

The primary steelmaking of the integrated steel mill is based on 2 trains of Basic Oxygen Furnace having a capacity of 220 tonnes per vessel. Each of the converter furnaces is equipped with a suppressed combustion off-gas recovery hood and waste heat boilers to recover the BOF gas and produce the steam required by the steel mill.

The BOF operation is assumed to have a scrap rate of ~190 kg/tls, which comprises 73 kg/tls supplied from internal scrap; and 117 kg/tls from external source. Oxygen injection rate of about 52 Nm^3/tls is required to reduce the carbon content of the hot metal. A small amount of pellets are used coolant. Lime and burnt dolomite are used as fluxes. The total processing time per charge is about 45 minutes.

It was assumed that 75% of the carbon is recovered in the off-gas whilst the unrecovered off-gases are flared. The off-gas is cleaned via a cyclone, wet scrubber and wet ESP. Dust and sludge collected are recycled to the sinter plant (Unit 200).

28% of the slag produced from the BOF operation is recycled to the Sinter Plant (Unit 200); 46% of slag is sold as liming materials (i.e. agricultural application) and the remaining 26% of the slag produce is sent to landfill.

Table A3-9 summarises the specification of the basic oxygen steelmaking operation of the Integrated Steel Mills with Post-Combustion CO_2 Capture.

6.2. PFD and Mass Balance

Figure A3-5 and Table A3-10 present the process flow diagram and a summary of the mass balance of the primary steelmaking for the Integrated Steel Mills with Post-Combustion CO_2 capture (Cases 2A and 2B).

Table A3-9: General Information – Study Specification (Unit 500: BOF Steelmaking)

Description	Summary - Relevant Specifications	
No. of Basic Oxygen Furnace	2 converter furnaces – top blowing with inert gas bottom stirring	
Off-gas recovery	Each furnace are equipped w/ suppressed combustion BOFG recovery	
Waste Heat Boiler	Yes (1 per BOF – providing 9 Bara saturated steam)	
Off-Gas Clean Up	2 trains of cyclone, wet scrubber and wet ESP (1 per BOF)	
Scrap Rate (dry)	190.0 kg/tls	
Oxygen Consumption	52.0 Nm^3/tls	
Flux Consumption	75.7 kg/tls (lime and burnt dolomite – including lime splashing)	
Slag Rate (dry)	113.1 kg/tls (28% to Sinter Plant, 46% to Sale, and 26% to Landfill)	
Dust and Sludge (dry)	30.0 kg/tls	
Electricity Consumption	20.0 kWh/tls	21.6 kWh/t HRC
Steam Export (9 bara, sat.)	70.6 kg/tls	76.3 kg/t HRC
BOFG Export (wet)	81.8 Nm^3/tls	88.4 Nm^3/t HRC
Liquid Steel (dry)	1000.0 kg/tls (4.32 Mt/y)	1080.8 kg/t HRC
Hot Metal (dry)	900.8 kg/tls (3.97 Mt/y)	992.2 kg/t HRC
Merchant Scrap (dry)	116.9 kg/tls	126.4 kg/t HRC
Internal Scrap (dry)	73.1 kg/tls	79.0 kg/t HRC
Pellets (dry)	5.0 kg/tls	5.4 kg/t HRC

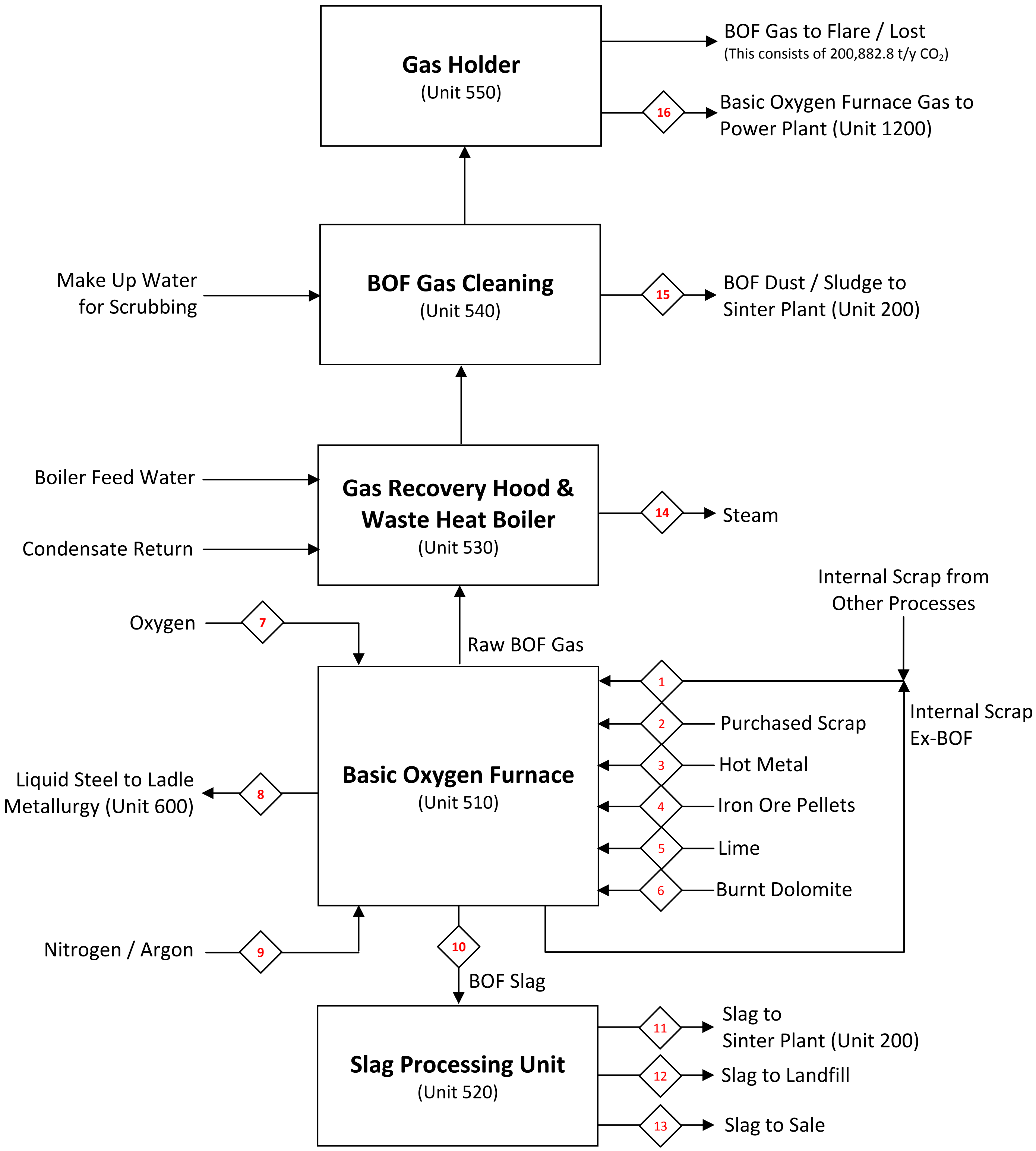

Figure A3-5: PFD of the basic oxygen steelmaking plant (Unit 500)

Table A3-10: Mass Balance (Unit 500: BOS Plant)

		1	2	3	4	5	6	7	8	9a	9b	10	11	12	13	14	15	16
Stream		**Internal Scrap to BOF**	**Purchased Scrap**	**De-S Hot Metal**	**Iron Ore Pellets (Cooling)**	**Lime**	**Burnt Dolomite**	**O2**	**Liquid Steel**	**N2**	**Ar**	**BOF Slag**	**Slag to Sinter Plant**	**Slag to Landfill**	**Slag to Sale**	**Steam**	**BOF Dust & Sludge to Sinter Plant**	**BOF Gas to Power Plant**
Total Mass Flow (wet)	**t/y**	**315,940**	**505,492**	**3,894,263**	**21,983**	**280,230**	**47,640**	**318,514**	**4,323,327**	**1,638**	**3,348**	**493,859**	**138,275**	**128,408**	**227,175**	**305,283**	**169,174**	**448,173**
Total Mass Flow (dry)	**t/y**	**315,940**	**505,492**	**3,894,263**	**21,544**	**280,230**	**47,164**	**318,514**	**4,323,327**	**1,638**	**3,348**	**488,920**	**136,893**	**127,124**	**224,903**	**305,283**	**129,700**	**413,619**
Specific Mass Flow (wet)	kg/tls	73.1	116.9	900.8	5.1	64.8	11.0	73.7	1000.0	0.4	0.8	114.2	32.0	29.7	52.5	70.6	39.1	103.7
Specific Mass Flow (dry)	kg/tls	73.1	116.9	900.8	5.0	64.8	10.9	73.7	1000.0	0.4	0.8	113.1	31.7	29.4	52.0	70.6	30.0	95.7
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	31.01	amb.	21.01	21.01	amb.	amb.	amb.	amb.	9.01	amb.	1.11
Temperature	oC	12	12	1360	12	40	12	60	1672	60	60	12	12	12	12	175	12	50
Phase		solid	solid	solid	solid	solid	solid	gas	Gas	gas	gas	solid	solid	solid	solid	gas	solid	gas
Solid & Liquid Composition (dry basis)																		
Fe	%wt.	98.89	98.89	94.24	65.50	0.51	0.15	-	99.91	-	-	20.00	20.00	20.00	20.00	-	62.04	-
C	%wt.	0.11	0.11	4.65	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-
Si	%wt.	0.01	0.01	0.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2 (residual)	%wt.	-	-	-	-	3.00	2.00	-	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	-	-	-	1.80	91.26	40.00	-	-	-	-	50.72	50.72	50.72	50.72	-	11.87	-
MgO	%wt.	-	-	-	1.20	1.86	55.00	-	-	-	-	5.47	5.47	5.47	5.47	-	3.42	-
SiO2	%wt.	-	-	-	2.80	2.03	-	-	-	-	-	-	-	-	-	-	-	-
Al2O3	%wt.	-	-	-	0.60	0.85	-	-	-	-	-	-	-	-	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	2.0	-	1.0	-	-	-	-	1.0	1.0	1.0	1.0	-	23.3	-
Specific Vol. Flow (wet)	Nm3/tls	-	-	-	-	-	-	51.59	-	0.30	0.43	-	-	-	-	-	-	81.75
Average MW								32.0		28.0	39.9					18.0		28.4
Gas Composition (wet basis)																		
H2	%v.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.64
CO2	%v.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.44
CO	%v.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	56.92
O2	%v.	-	-	-	-	-	-	99.90	-	0.02	0.01	-	-	-	-	-	-	-
N2	%v.	-	-	-	-	-	-	0.01	-	99.98	-	-	-	-	-	-	-	13.83
Ar	%v.	-	-	-	-	-	-	0.09	-	-	99.99	-	-	-	-	-	-	-
H2O	%v.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	12.16

7. UNIT 600: LADLE METALLURGY (SECONDARY STEELMAKING)

7.1. Study Specification

The secondary steelmaking of the REFERENCE integrated steel mill is based on 2 stations of ladle metallurgy (with heat size up to ~250 ton per ladle). The final chemistry of the liquid steel is adjusted by addition of ferroalloys (FeMnC and FeSi-75), and aluminium is used to remove the oxygen content of the liquid steel. The secondary steelmaking of the REFERENCE integrated steel mill is not equipped with vacuum degassers or other additional steel refinement steps. The temperature of the liquid steel is controlled and maintained by electric arc heating. Furthermore, ladle pre-heating using COG and oxygen is employed to minimise the heating duty of the electrode therefore reducing electricity consumption. Argon is used for purging, oxidation shielding and inert stirring. A small amount of scrap is used for cooling (temperature moderation duty).

Table A3-11 summarises the specification of the ladle metallurgy operation of the Integrated Steel Mills with Post-Combustion CO_2 Capture.

7.2. PFD and Mass Balance

Figure A3-6 and Table A3-12 present the process flow diagram and a summary of the mass balance of the secondary steelmaking process for the Integrated Steel Mills with Post-Combustion CO_2 capture (Cases 2A and 2B).

Table A3-11: General Information – Study Specification (Unit 600: Ladle Metallurgy)

Description	Summary - Relevant Specifications	
No. of Ladle Metallurgy Station	2 stations – based on ladle transfer cars configuration.	
Fe loss to internal scrap	9.9 kg/tls – refined (1%).	
Oxygen Consumption	2.1 Nm^3/tls – refined	
Flux Consumption	5.0 kg/tls – refined (lime – including lime splashing)	
Slag Rate (dry)	7.9 kg/tls – refined (100% to Landfill)	
COG Consumption (pre-heating)	0.9 Nm^3/tls - refined	0.9 Nm^3/t HRC
Electricity Consumption	25.0 kWh/tls – refined	27.2 kWh/t HRC
Liquid Steel from Ladle (dry)	1000.0 kg/tls - refined (4.35 Mt/y)	1086.3 kg/t HRC
Liquid Steel from BOF (dry)	995.0 kg/tls – refined (4.32 Mt/y)	1080.8 kg/t HRC
Cooling Scrap (dry)	1.0 kg/tls – refined	1.1 kg/t HRC
Internal Scrap to BOF (dry)	9.9 kg/tls - refined	10.8 kg/t HRC
Ferroalloys (dry)		
• FeMnC (dry)	11.0 kg/tls – refined	11.9 kg/t HRC
• FeSi-75 (dry)	3.0 kg/tls – refined	3.3 kg/t HRC
• Aluminium (dry)	1.5 kg/tls – refined	1.6 kg/t HRC

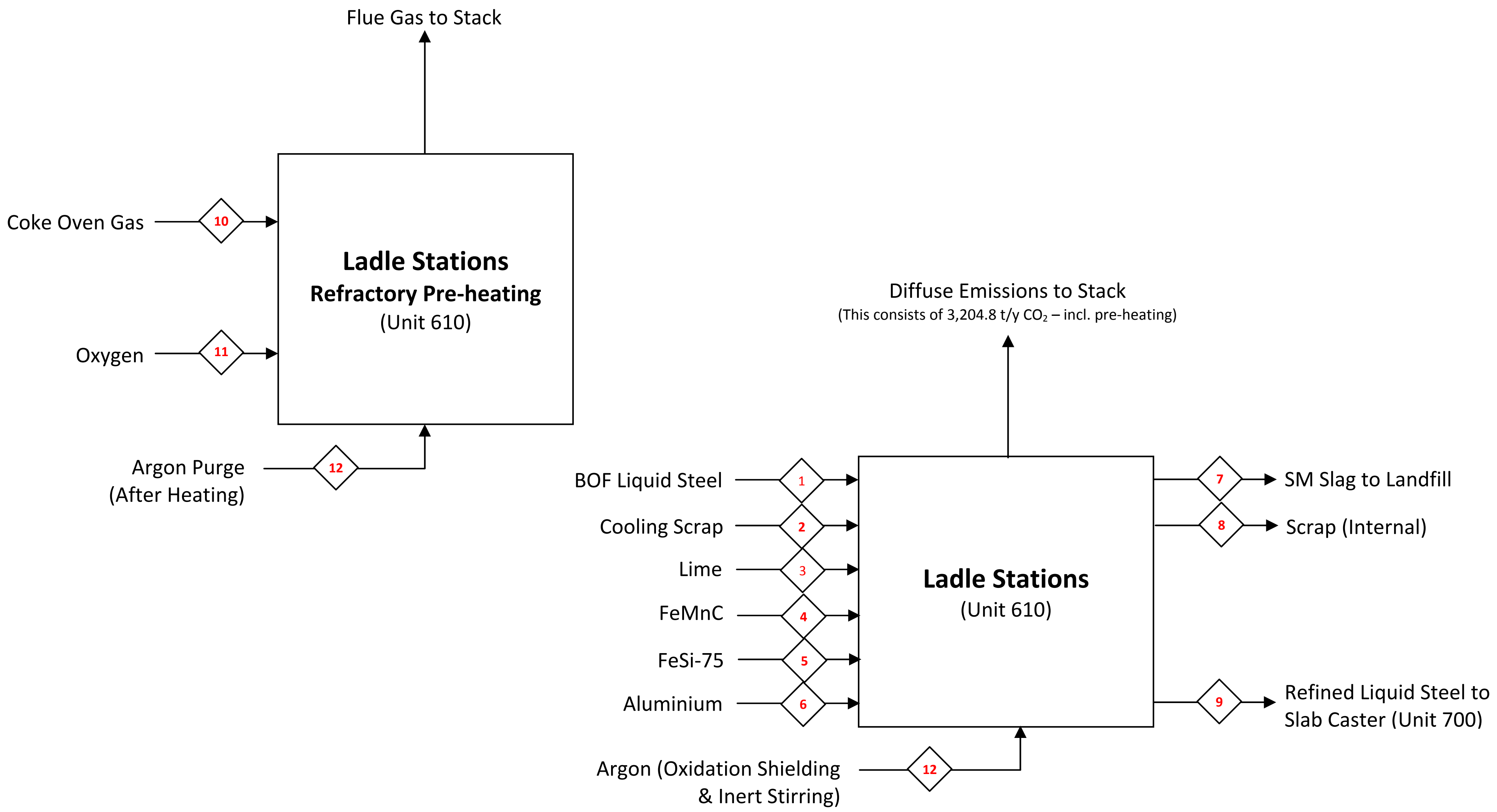

Figure A3-6: PFD of the ladle metallurgy (Unit 600)

Table A3-12: Mass Balance (Unit 600: Ladle Metallurgy)

		1	2	3	4	5	6	7	8	9	10	11	12
Stream		**Liquid Steel from BOF**	**Scrap (Cooling)**	**Lime**	**FeMnC**	**FeSi-75**	**DeOx. Aluminium**	**LM Slag to Landfill**	**Scrap to BOF**	**Liquid Steel from LM**	**COG**	**O2**	**Ar**
Total Mass Flow (wet)	**t/y**	**4,323,327**	**4,345**	**21,726**	**47,798**	**13,036**	**6,518**	**34,760**	**43,233**	**4,345,228**	**1,607**	**13,030**	**2,232**
Total Mass Flow (dry)	**t/y**	**4,323,327**	**4,345**	**21,726**	**47,798**	**13,036**	**6,518**	**34,412**	**43,233**	**4,345,228**	**1,512**	**13,030**	**2,232**
Specific Mass Flow (wet)	kg/tls (ladle)	995.0	1.0	5.0	11.0	3.0	1.5	8.0	9.9	1000.0	0.4	3.0	0.5
Specific Mass Flow (dry)	kg/tls (ladle)	995.0	1.0	5.0	11.0	3.0	1.5	7.9	9.9	1000.0	0.3	3.0	0.5
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	1.11	31.01	21.01
Temperature	oC	1672	12	40	12	12	12	12	12	1531	25	60	60
Phase		liquid	solid	Solid	solid	Solid	solid	solid	solid	liquid	gas	gas	gas
Solid & Liquid Composition (dry basis)													
Fe	%wt.	99.91	98.89	0.51	14.58	22.56	0.67	1.08	98.89	98.73	-	-	-
C	%wt.	0.04	0.11	-	6.87	0.03	-	-	0.11	0.12	-	-	-
Si	%wt.	-	0.01	-	0.11	76.61	1.34	-	0.01	-	-	-	-
Mn	%wt.	-	0.10	-	78.27	0.01	0.23	-	0.10	-	-	-	-
Al	%wt.	-	-	-	-	0.71	96.30	-	-	-	-	-	-
CO2 (residual)	%wt.	-	-	3.00	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	-	-	91.26	-	-	-	62.46	-	-	-	-	-
MgO	%wt.	-	-	1.86	-	-	-	-	-	-	-	-	-
SiO2	%wt.	-	-	2.03	-	-	-	8.03	-	-	-	-	-
Al2O3	%wt.	-	-	0.85	-	-	-	28.32	-	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	-	-	-	1.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/tls (ladle)	-	-	-	-	-	-	-	-	-	0.86	2.10	0.29
Average MW											9.7	32.0	39.9
Gas Composition (wet basis)													
CH4	%v.	-	-	-	-	-	-	-	-	-	23.24	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	-	-	-	-	-	-	2.71	-	-
H2	%v.	-	-	-	-	-	-	-	-	-	60.05	-	-
CO2	%v.	-	-	-	-	-	-	-	-	-	0.97	-	-
CO	%v.	-	-	-	-	-	-	-	-	-	3.87	-	-
O2	%v.	-	-	-	-	-	-	-	-	-	0.19	99.90	0.01
N2	%v.	-	-	-	-	-	-	-	-	-	5.81	0.01	-
Ar	%v.	-	-	-	-	-	-	-	-	-	-	0.09	99.99
H2O	%v.	-	-	-	-	-	-	-	-	-	3.15	-	-

8. UNIT 700: CONTINUOUS CASTING

8.1. Study Specification

The study assumed that the continuous casting of the REFERENCE integrated steel mill is based on the operation of 2 trains of slab casting machine, each equipped with a tundish feeding liquid steel into two moulds (twin strand). The moulds are cooled with water and air where liquid steel solidifies and forms the slab. The resulting slabs are cut using oxygen torches. To maintain the temperature of the liquid steel in the tundish, COG is used as fuel for heating.

The study also assumed that 25.8 kg/t slab (~2.6%) is lost as scrap, and 8.7 kg/t slab (~0.9%) is lost as mill scale. The scrap is recycled back to the BOF (Unit 500); whilst the mill scales are recycled back to the sinter plant (Unit 200).

Table A3-13 summarises the specification of the continuous casting operation of the Integrated Steel Mills with Post-Combustion CO_2 Capture.

8.2. PFD and Mass Balance

Figure A3-7 and Table A3-14 present the process flow diagram and a summary of the mass balance of the continuous slab casting of the Integrated Steel Mills with Post-Combustion CO_2 capture (Cases 2A and 2B).

Table A3-13: General Information – Study Specification (Unit 700: Continuous Casting)

Description	Summary - Relevant Specifications	
No. of Continuous Casting Fe loss to internal scrap Fe loss to mill scales Oxygen Consumption	2 trains of twin strand slab casting machines (Vertical Bending Type) 25.8 kg/t slab (2.6%). 8.7 kg/t slab (0.9%). 2.1 Nm^3/t slab	
COG Consumption (pre-heating) Electricity Consumption	1.1 Nm^3/t slab 10.3 kWh/t slab	1.1 Nm^3/t HRC 10.9 kWh/t HRC
Slab (dry) Liquid Steel from Ladle (dry)	1000.0 kg/t slab (4.21 Mt/y) 1032.0 kg/t slab (4.35 Mt/y)	1052.6 kg/t HRC 1086.3 kg/t HRC

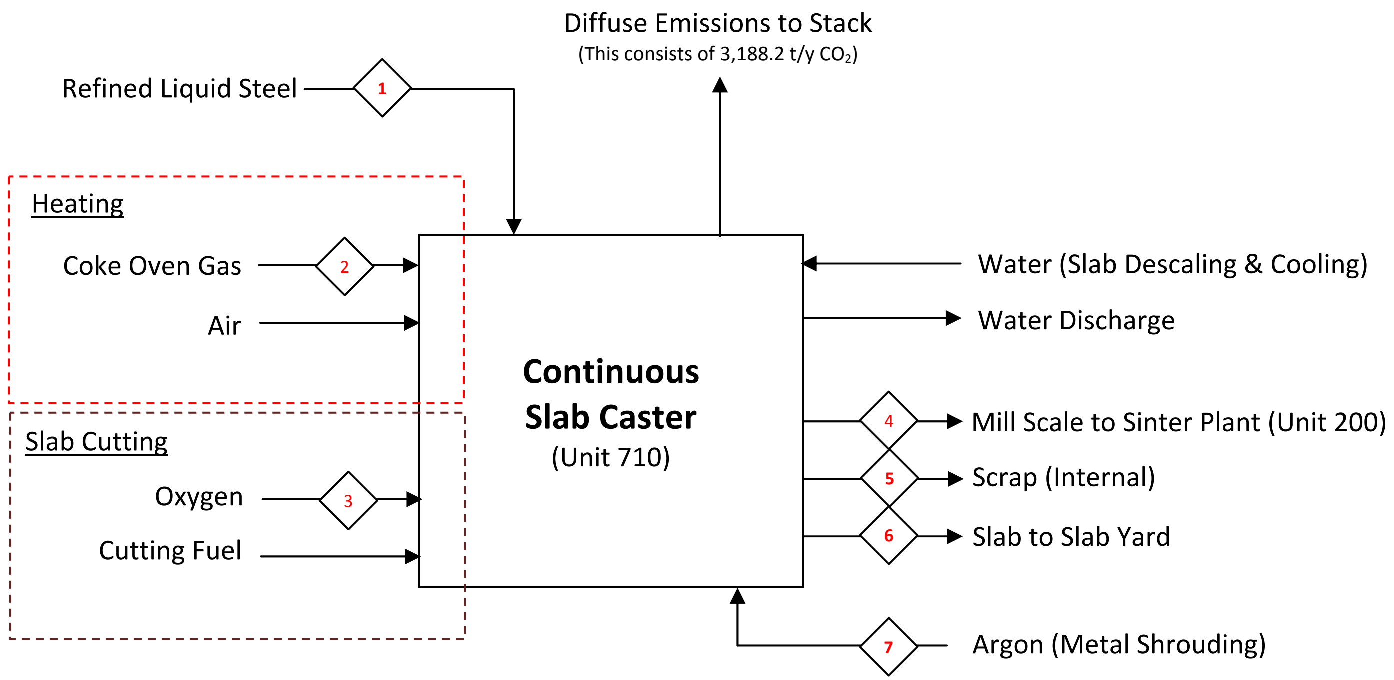

Figure A3-7: PFD of the Continuous Casting (Unit 700)

Table A3-14: Mass Balance (Unit 700: Continuous Casting)

		1	2	3	4	5	6	7
Stream		**Liquid Steel from LM**	**COG**	**O2**	**Mill Scales to Sinter**	**Scrap to BOF**	**Slab to Reheating Furnace**	**Ar**
Total Mass Flow (wet)	**t/y**	**4,345,228**	**1,934**	**12,409**	**37,144**	**108,631**	**4,210,526**	**774**
Total Mass Flow (dry)	**t/y**	**4,345,228**	**1,820**	**12,409**	**36,772**	**108,631**	**4,210,526**	**774**
Specific Mass Flow (wet)	kg/t slab	1032.0	0.5	2.9	8.8	25.8	1000.0	0.2
Specific Mass Flow (dry)	kg/t slab	1032.0	0.4	2.9	8.7	25.8	1000.0	0.2
Pressure	Bara	amb.	1.11	31.01	amb.	amb.	amb.	21.01
Temperature	oC	1531	25	60	12	12	25	60
Phase		liquid	Gas	gas	solid	solid	solid	gas
Solid & Liquid Composition (dry basis)								
Fe	%wt.	98.73	-	-	70.00	98.73	98.73	-
C	%wt.	0.12	-	-	-	0.12	0.12	-
Moisture (wet basis)	%wt.	-	-	-	1.0	-	-	-
Specific Vol. Flow (wet)	Nm3/t slab	-	1.07	2.06	-	-	-	0.10
Average MW			9.7	32.0				39.9
Gas Composition (wet basis)								
CH4	%v.	-	23.24	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	2.71	-	-	-	-	-
H2	%v.	-	60.05	-	-	-	-	-
CO2	%v.	-	0.97	-	-	-	-	-
CO	%v.	-	3.87	-	-	-	-	-
O2	%v.	-	0.19	99.90	-	-	-	0.01
N2	%v.	-	5.81	0.01	-	-	-	-
Ar	%v.	-	-	0.09	-	-	-	99.99
H2O	%v.	-	3.15	-	-	-	-	-

9. UNIT 800 & 900: REHEATING AND HOT ROLLING MILL

9.1. Study Specification

Integrated Steel Mills with Post-Combustion CO2 Capture is evaluated based on 2 lines of Reheating and Rolling Mills producing 4 million tonnes of hot rolled coils per year. Each line of Hot Rolling Mills comprises: walking beam furnaces (total of 4 furnaces); roughing mills (total of 2 roughing mills); finishing mills (total of 6 finishing mills); coilers (total of 3 coilers).

Coke Oven Gas is used to heat the reheating furnace with natural gas as back up fuel. The reheating furnace is equipped with recuperators to preheat the combustion air.

The rolling mills employ the use of oxyfuel firing to oxidise slab surface irregularities to form mill scales. After this, the slab undergoes descaling to remove the scales. The study assumes that 14.8 kg/t HRC (~1.5%) is lost as mill scales. Roughing and finishing mills involve the width reduction, slitting, trimming and cutting of the coil. The study assumes 42.1 kg/t HRC (~4.2%) is lost as scrap during the rolling process. The mill scales are recycled back to the sinter plant (Unit 200); whilst scrap is recycled back to the BOF (Unit 500).

Table A3-15 summarises the specification of the continuous casting operation of the Integrated Steel Mills with Post-Combustion CO_2 Capture.

9.2. PFD and Mass Balance

Figure A3-8 and Table A3-16 present the process flow diagram and a summary of the mass balance of the slab reheating and hot rolling mills for the Integrated Steel Mills with Post-Combustion CO_2 capture (Cases 2A and 2B).

Table A3-15: General Information – Study Specification (Unit 800 & 900: Reheating & Hot Rolling Mills)

Description	Summary - Relevant Specifications	
No. of Reheating Furnaces Heat Recovery System Fuel Energy Requirements Rolling Mills Fe loss to internal scrap Fe loss to mill scales Oxygen Consumption	4 (2 walking beam furnaces per line of rolling mill) 2 recuperators (1 per line to preheat combustion air) 1438 MJ/t slab reheated (1514 MJ/t HRC) 2 lines (2x Roughing Mills, 6x Finishing Mills and 3x Coilers) 42.1 kg/t HRC (4.2%). 14.8 kg/t HRC (1.5%). 2.6 Nm^3/t HRC	
COG Consumption (Reheating) Electricity Consumption	84.3 Nm^3/t HRC 105.3 kWh/t HRC	- -
Hot Rolled Coil (dry) Slab (dry)	1000.0 kg/t HRC (4.00 Mt/y) 1052.6 kg/t HRC (4.21 Mt/y)	- -

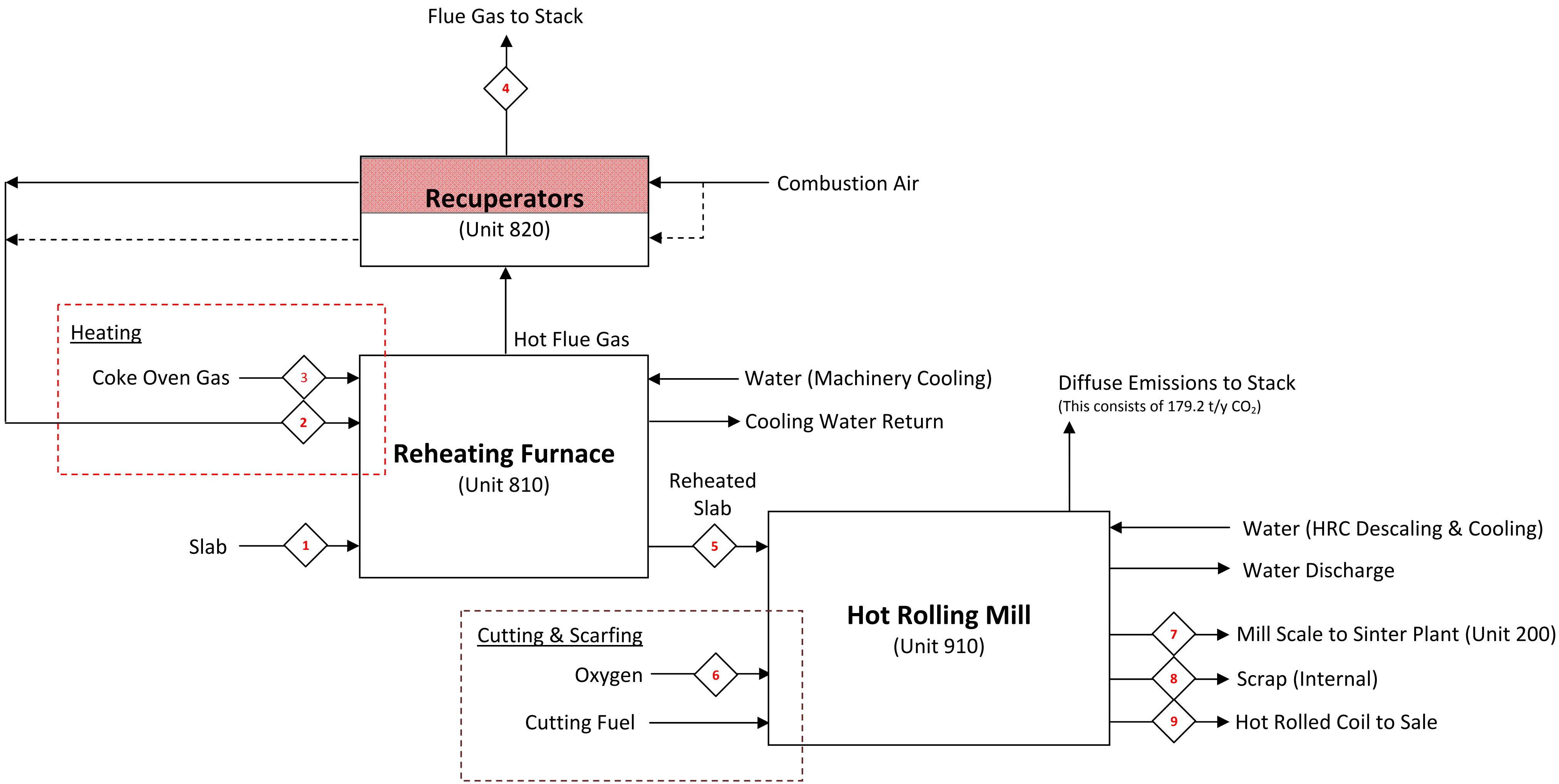

Figure A3-8: PFD of the hot strip mill (Unit 800 & 900)

Table A3-16: Mass Balance (Unit 800 & 900: Reheating and Rolling Mill)

		1	2	3	4	5	6	7	8	9
Stream		**Slab to Reheating Furnace**	**Combustion Air**	**COG (Reheating Furnace)**	**Flue Gas (Reheating Furnace)**	**Reheated Slab**	**O2 to HRM**	**Mill Scale to Sinter**	**Internal Scrap to BOF**	**HRC to Sale**
Total Mass Flow (wet)	**t/y**	**4,210,526**	**2,985,364**	**145,313**	**3,130,752**	**4,210,526**	**15,031**	**59,987**	**168,421**	**4,000,000**
Total Mass Flow (dry)	**t/y**	**4,210,526**	**2,964,574**	**136,772**	**2,794,253**	**4,210,526**	**15,031**	**59,387**	**168,421**	**4,000,000**
Specific Mass Flow (wet)	kg/t HRC	1052.6	746.3	36.3	782.7	1052.6	3.8	15.0	42.1	1000.0
Specific Mass Flow (dry)	kg/t HRC	1052.6	741.1	34.2	698.6	1052.6	3.8	14.8	42.1	1000.0
Pressure	Bara	amb.	1.11	1.11	1.03	amb.	21.01	amb.	amb.	amb.
Temperature	oC	25	400	25	500	1200	60	12	12	12
Phase		solid	gas	gas	gas	solid	gas	solid	solid	solid
Solid & Liquid Composition (dry basis)										
Fe	%wt.	98.73	-	-	-	98.73	-	70.00	98.73	98.73
C	%wt.	0.12	-	-	-	0.12	-	-	0.12	0.12
Moisture (wet basis)	%wt.	-	-	-	-	-	-	1.0	-	-
Specific Vol. Flow (wet)	Nm3/t HRC	-	582.30	84.29	640.23	-	2.63	-	-	-
Average MW			28.7	9.7	27.4		32.0			
Gas Composition (wet basis)										
CH4	%v.	-	-	23.24	-	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	2.71	-	-	-	-	-	-
H2	%v.	-	-	60.05	-	-	-	-	-	-
CO2	%v.	-	-	0.97	4.59	-	-	-	-	-
CO	%v.	-	-	3.87	-	-	-	-	-	-
O2	%v.	-	20.72	0.19	7.20	-	99.90	-	-	-
N2	%v.	-	78.17	5.81	71.86	-	0.01	-	-	-
Ar	%v.	-	-	-	-	-	0.09	-	-	-
H2O	%v.	-	1.11	3.15	16.34	-	-	-	-	-

10. UNIT 1000: LIME PRODUCTION

10.1. Study Specification

The lime production of the REFERENCE Integrated Steel Mill is based on 2 trains of PFR lime kilns producing 346.4 kt/y of burnt lime (of which 87% is consumed by the steelmaking process – BOF and LM and 13% consumed by the sinter plant). The study assumed that the lime produced has a residual CO_2 of ~3%. COG is used as fuel for the lime kiln with natural gas as back up fuel.

Table A3-17 summarises the specification of the lime kiln operation of the Integrated Steel Mills with Post-Combustion CO_2 Capture.

Table A3-17: General Information – Study Specification (Unit 1000: Lime Production)

Description	Summary - Relevant Specifications	
No. of lime kilns Residual CO_2 (dry)	2 trains of Parallel Flow Regenerative (PFR) Kilns 3%	
COG Consumption (pre-heating) Electricity Consumption	200.2 Nm^3/t lime 30.0 kWh/t lime	17.3 Nm^3/t HRC 2.6 kWh/t HRC
Lime(dry) • Lime to BOF/LM (dry) • Lime to Sinter Plant (dry) Limestone (dry)	1000.0 kg/t lime (0.34 Mt/y) 871.7 kg/t lime 128.3 kg/t lime 1690.0 kg/t lime (0.59 Mt/y)	86.6 kg/t HRC 75.5 kg/t HRC 11.1 kg/t HRC 146.4 kg/t HRC

10.2. PFD and Mass Balance

Figure A3-9 and Table A3-18 present the process flow diagram and a summary of the mass balance of the lime production for the Integrated Steel Mills for Cases 2A and 2B.

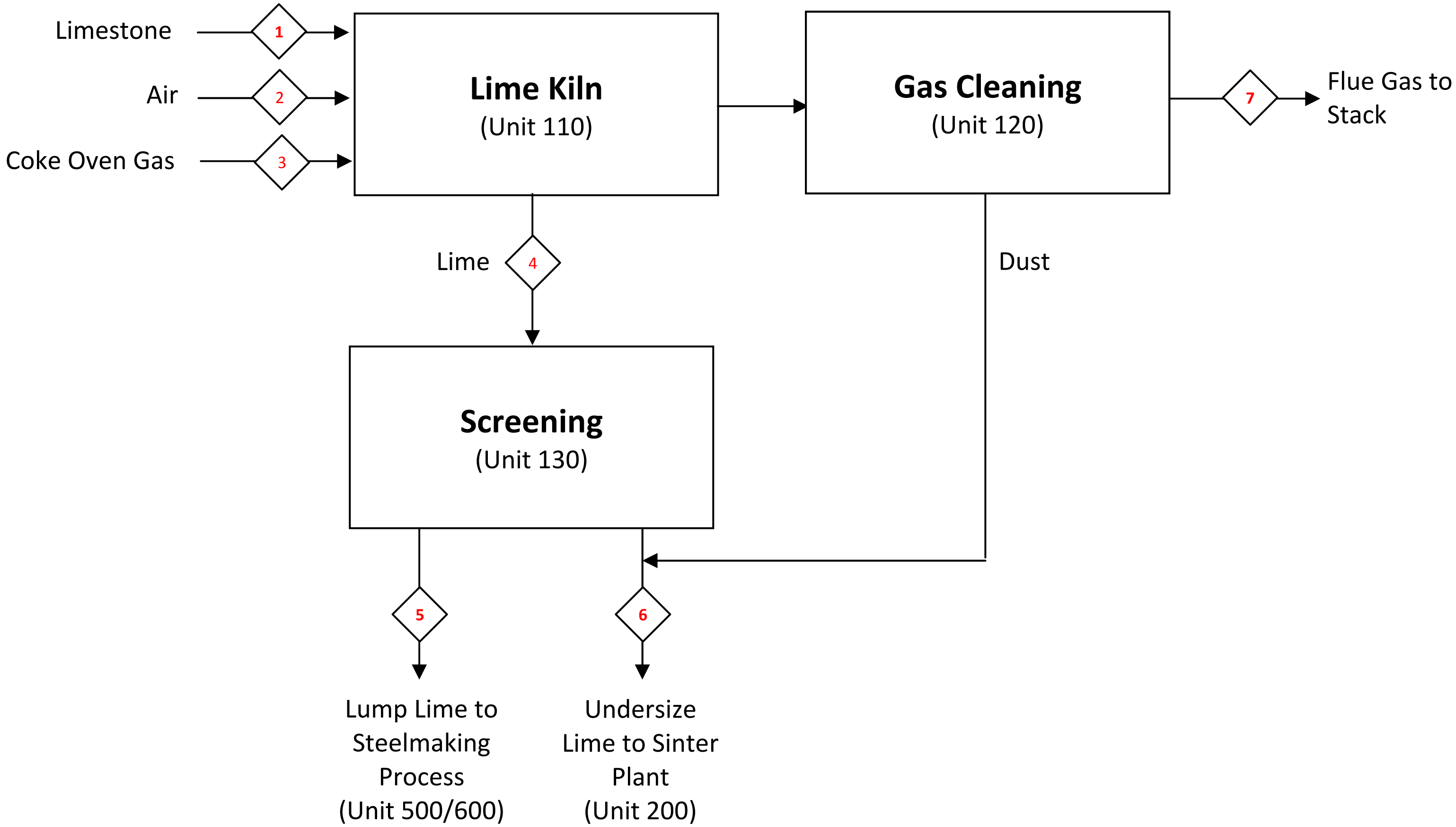

Figure A3-9: PFD of the Lime Production (Unit 1000)

Table A3-9: Mass Balance (Unit 1000: Lime Production)

		1	2	3	4	5	6	7
Stream		**Limestone**	**Air**	**COG**	**Lime (Total)**	**Lime to BOF & LM**	**Lime to Sinter**	**Flue Gas**
Total Mass Flow (wet)	**t/y**	**591,361**	**736,814**	**29,889**	**346,410**	**301,956**	**44,454**	**1,011,785**
Total Mass Flow (dry)	**t/y**	**585,447**	**731,683**	**28,132**	**346,410**	**301,956**	**44,454**	**935,796**
Specific Mass Flow (wet)	kg/t lime	1707.1	2127.0	86.3	1000.0	871.7	128.3	2920.8
Specific Mass Flow (dry)	kg/t lime	1690.0	2112.2	81.2	1000.0	871.7	128.3	2701.4
Pressure	Bara	amb.	1.03	1.11	amb.	amb.	amb.	1.03
Temperature	oC	12	12	25	40	40	40	130
Phase		solid	gas	gas	solid	solid	solid	gas
Solid & Liquid Composition (dry basis)								
Fe	%wt.	0.30	-	-	0.51	0.51	0.51	-
CO2 (residual)	%wt.	42.60	-	-	3.00	3.00	3.00	-
CaO (incl. carbonates)	%wt.	54.00	-	-	91.26	91.26	91.26	-
MgO	%wt.	1.10	-	-	1.86	1.86	1.86	-
SiO2	%wt.	1.20	-	-	2.03	2.03	2.03	-
Al2O3	%wt.	0.50	-	-	0.85	0.85	0.85	-
Moisture (wet basis)	%wt.	1.0	-	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/t lime	-	1659.51	200.20	-	-	-	2169.76
Average MW			28.7	9.7				30.2
Gas Composition (wet basis)								
CH4	%v.	-	-	23.24	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	2.71	-	-	-	-
H2	%v.	-	-	60.05	-	-	-	-
CO2	%v.	-	-	0.97	-	-	-	19.41
CO	%v.	-	-	3.87	-	-	-	-
O2	%v.	-	20.72	0.19	-	-	-	7.77
N2	%v.	-	78.17	5.81	-	-	-	60.24
H2O	%v.	-	1.11	3.15	-	-	-	12.58

11. UNIT 1100: AIR SEPARATION UNIT (OXYGEN PLANT)

11.1. Study Specification

The oxygen plant (or Air Separation Unit - ASU) of the REFERENCE integrated steel mill is evaluated based on a captive single ASU train with a design capacity of 1900 tpd O_2 delivering around 693,464 t/y gaseous O_2 and 6,355 t/y gaseous Ar to the steel mill; and selling 26,865 t/y liquid Ar to the market.

The oxygen delivered to the steel mill will have 99.9% purity and be available at pressure of 13 bara and 37 bara. Argon and nitrogen supplied to the steel mill will have 99.99% and 99.98% purity respectively and are available at 7 bara and 25 bara. Liquid argon will also have a purity of 99.99%.

Steam at 0.16 MJ/Nm^3 total O_2 is required for product re-gasification and TSA regeneration. Hydrogen is used for purification of the crude argon, however this is not accounted for in this study. System losses and buffer requirements for oxygen supply to cover for disruption and uneven demand were also accounted for in this study (9%wt. of total O_2 production).

Table A3-19 summarises the specification of the captive air separation unit of the Integrated Steel Mills with Post-Combustion CO_2 Capture.

11.2. PFD and Mass Balance

Figure A3-10 and Table A3-20 present the process flow diagram and a summary of the mass balance of the oxygen production for the Integrated Steel Mills for Cases 2A and 2B.

Table A3-19: General Information – Study Specification (Unit 1100: Oxygen Production)

Description	Summary - Relevant Specifications	
No. of ASU	1 train of ASU @ 1900 tpd O_2 (GOX, GAN, GAR, LAR)	
Main Products	Gaseous O_2, N_2, Ar and Liquid Ar (with Liquid O_2 as buffer)	
Argon Purification Unit	via H_2 catalytic combustion (De Oxo Process)	
Annual Oxygen Production (Total)	485,643,965 Nm^3/y (693,464 t/y)	
Annual Liquid Argon to Sale	15,073,913 Nm^3/y (28,886 t/y)	
Steam Requirements	0.06 kg/Nm^3 O_2	
Purity (Delivery Pressure)		
• Gaseous O_2	99.90% (13 bar_a & 37 bar_a)	
• Gaseous N_2	99.98% (7 bar_a & 25 bar_a)	
• Gaseous Ar	99.99% (25 bar_a)	
Product Recovery Rate		
• O_2	96%	
• Ar	83%	
Steam Consumption (9 bar_a, sat.)	0.06 kg/Nm^3 O_2	7.3 kg/t HRC
Electricity Consumption	0.55 kWh/Nm^3 O_2	66.8 kWh/t HRC
Oxygen (Total Produced)	1.000 Nm^3 O_2/Nm^3 O_2 (Total)	121.4 Nm^3 O_2/t HRC
• O_2 to BF Hot Stoves	0.391 Nm^3 O_2/Nm^3 O_2 (Total)	47.5 Nm^3 O_2/t HRC
• O_2 to BOF	0.459 Nm^3 O_2/Nm^3 O_2 (Total)	55.8 Nm^3 O_2/t HRC
• O_2 to Ladle Metallurgy	0.019 Nm^3 O_2/Nm^3 O_2 (Total)	2.3 Nm^3 O_2/t HRC
• O_2 to Continuous Casting	0.018 Nm^3 O_2/Nm^3 O_2 (Total)	2.2 Nm^3 O_2/t HRC
• O_2 to Hot Rolling Mills	0.022 Nm^3 O_2/Nm^3 O_2 (Total)	2.6 Nm^3 O_2/t HRC
Liquid Argon to Sale	0.031 Nm^3 Ar/Nm^3 O_2 (Total)	3.8 Nm^3 Ar/t HRC

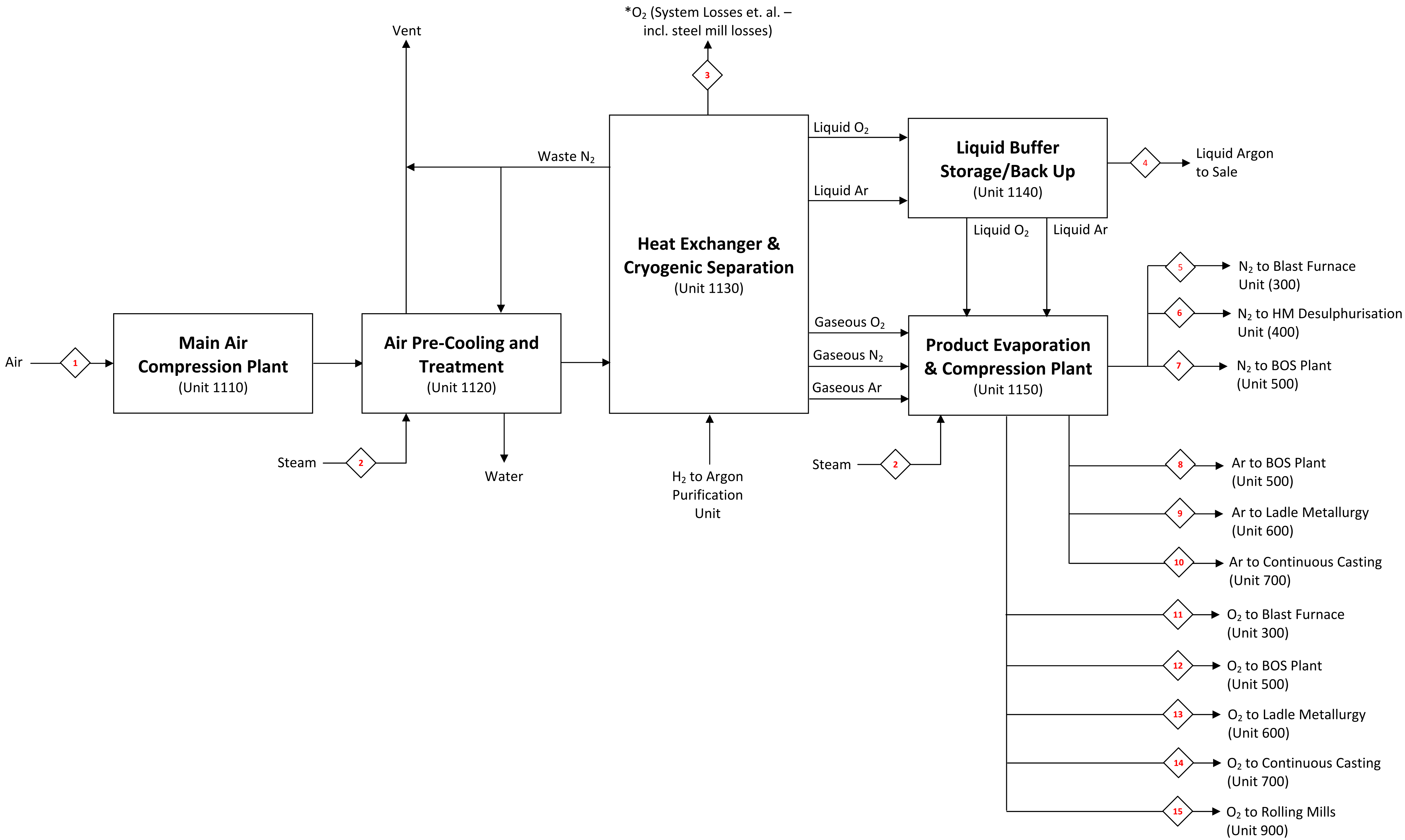

Figure A3-10: PFD of the air separation unit (Unit 1100)

Table A3-20: Mass Balance (Unit 1100: Air Separation Unit)

		1	2	3	4	5a	5b	6	7
Stream		**Air**	**Steam**	**O2 (Lost or Flared)**	**Ar to Sale**	**N2 to BF (RM Feeder)**	**N2 to BF (PCI Coal Feeder)**	**N2 to HM Desulph.**	**N2 to BOF**
Total Mass Flow (wet)	**t/y**	**3,142,730**	**29,139**	**63,042**	**26,865**	**9,923**	**14,884**	**715**	**1,638**
Total Mass Flow (dry)	**t/y**	**3,120,932**	**29,139**	**63,042**	**26,865**	**9,923**	**14,884**	**715**	**1,638**
Specific Mass Flow (wet)	kg/Nm3 O2	6.471	0.060	0.130	0.055	0.020	0.031	0.001	0.003
Specific Mass Flow (dry)	kg/Nm3 O2	6.426	0.060	0.130	0.055	0.020	0.031	0.001	0.003
Pressure	Bara	1.03	9.01	1.03	1.01	7.01	25.01	25.01	25.01
Temperature	oC	12	175	60	-	60	60	60	60
Phase		gas	gas	gas	Liquid	gas	gas	gas	Gas
Specific Vol. Flow (wet)	Nm3/Nm3 O2	5.0298	-	0.0909	0.0310	0.0163	0.0245	0.0012	0.0027
Average MW		28.8	18.0	32.0	39.9	28.0	28.0	28.0	28.0
Gas Composition (wet basis)									
O2	%v.	20.71	-	99.90	0.01	0.02	0.02	0.02	0.02
N2	%v.	77.26	-	0.01	-	99.98	99.98	99.98	99.98
Ar	%v.	0.92	-	0.09	99.99	-	-	-	-
H2O	%v.	1.11	100.00	-	-	-	-	-	-

		8	9	10	11	12	13	14	15
Stream		**Ar to BOF**	**Ar to Ladle Metallurgy**	**Ar to Slab Casting**	**O2 to BF (Hot Stoves)**	**O2 to BOF**	**O2 to Ladle Metallurgy**	**O2 to Slab Casting**	**O2 to HRM**
Total Mass Flow (wet)	**t/y**	**3,348**	**2,232**	**774**	**271,454**	**318,495**	**13,030**	**12,409**	**15,031**
Total Mass Flow (dry)	**t/y**	**3,348**	**2,232**	**774**	**271,454**	**318,495**	**13,030**	**12,409**	**15,031**
Specific Mass Flow (wet)	kg/Nm3 O2	0.007	0.005	0.002	0.559	0.656	0.027	0.026	0.031
Specific Mass Flow (dry)	kg/Nm3 O2	0.007	0.005	0.002	0.559	0.656	0.027	0.026	0.031
Pressure	Bara	25.01	25.01	25.01	13.01	37.01	37.01	37.01	25.01
Temperature	oC	60	60	60	60	60	60	60	60
Phase		gas	gas	gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/Nm3 O2	0.0039	0.0026	0.0009	0.3914	0.4593	0.0188	0.0179	0.0217
Average MW		39.9	39.9	39.9	32.0	32.0	32.0	32.0	32.0
Gas Composition (wet basis)									
O2	%v.	0.01	0.01	0.01	99.90	99.90	99.90	99.90	99.90
N2	%v.	-	-	-	0.01	0.01	0.01	0.01	0.01
Ar	%v.	99.99	99.99	99.99	0.09	0.09	0.09	0.09	0.09
H2O	%v.	-	-	-	-	-	-	-	-

12. UNIT 1200: CAPTIVE POWER PLANT

12.1. Study Specification

The captive power plant of the Integrated Steel Mill with Post-Combustion CO_2 capture is evaluated based on the performance of NGCC that are capable to provide the electricity demand of the steel mill.

The NGCC power plant used for this study providing electricity to the Steel Mill with Post-Combustion CO_2 capture are based on the following features:

- E-Class Gas turbine fired with NG in a single shaft arrangement delivering between ~192MWe (EOP-L1 Case) and ~208 MWe (EOP-L2 Case).
- Heat from the flue gas of the gas turbine will be recovered by the heat recovery steam generation (HRSG) unit. This will deliver steam to the steam turbine at 3 different pressure levels and IP reheated steam.
- Steam turbine is based on triple pressure and single reheat arrangement delivering about ~100MWe.

12.2. PFD and Mass Balance

Figure A3-11 presents the process flow diagram of the captive power plant of the integrated steel mill with post-combustion CO_2 capture. Tables A3-21 and A3-22 present a summary of the mass balance for the captive power plant of the integrated steel mill for Cases 2A and 2B respectively.

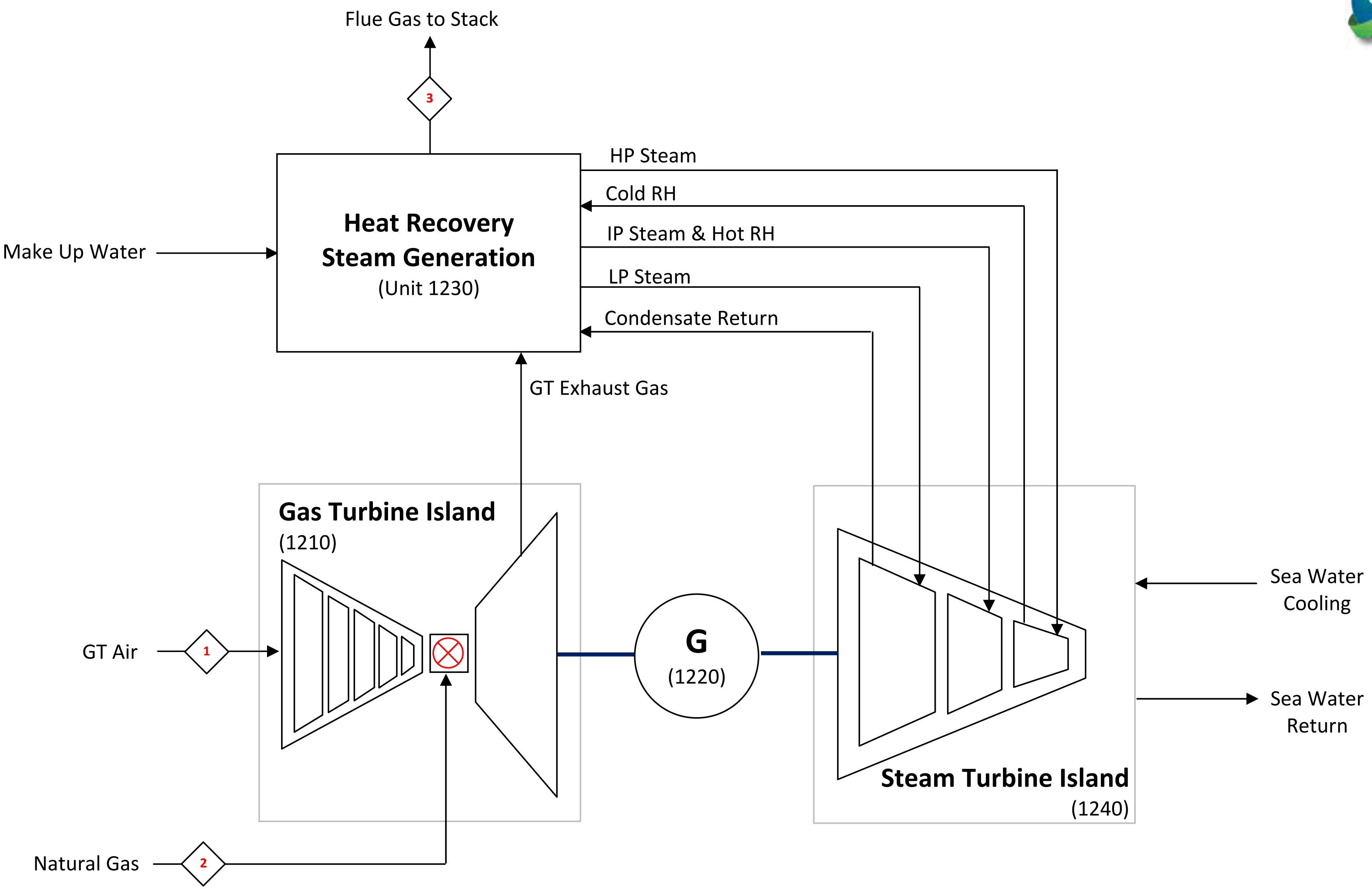

Figure A3-11: PFD of the captive power plant (Unit 1200)

Table A3-21: Mass Balance (Unit 1200: Power Plant for Case 2A)

		1	2	3
Stream		**air**	**NG**	**Flue gas**
Total Mass Flow (wet)	**t/y**	**15,046,404**	**310,717**	**15,357,272**
Total Mass Flow (dry)	**t/y**	**14,941,622**	**310,717**	**14,630,572**
Specific Mass Flow (wet)	kg/kWh	6.57	0.14	6.71
Specific Mass Flow (dry)	kg/kWh	6.52	0.14	6.39
Pressure	Bara	1.03	1.01	1.01
Temperature	oC	12	12	150
Phase		gas	gas	gas
Specific Vol. Flow (wet)	Nm3/kWh	5.1253	0.1565	5.2976
Average MW		28.7	19.4	28.4
Gas Composition (wet basis)				
CH4	%v.	-	83.90	-
C2H6	%v.	-	9.20	-
C3H8	%v.	-	3.30	-
C4H10	%v.	-	1.20	-
C5H12	%v.	-	0.20	-
H2	%v.	-	-	-
CO2	%v.	-	1.80	3.54
CO	%v.	-	-	-
O2	%v.	20.72	-	13.37
N2	%v.	78.17	0.40	75.64
H2O	%v.	1.11	-	7.45

Table A3-22: Mass Balance (Unit 1200: Power Plant for Case 2B)

		1	2	3
Stream		**air**	**NG**	**Flue gas**
Total Mass Flow (wet)	**t/y**	**16,337,026**	**337,369**	**16,674,560**
Total Mass Flow (dry)	**t/y**	**16,223,257**	**337,369**	**15,885,526**
Specific Mass Flow (wet)	kg/kWh	6.57	0.14	6.71
Specific Mass Flow (dry)	kg/kWh	6.52	0.14	6.39
Pressure	Bara	1.03	1.01	1.01
Temperature	oC	12	12	150
Phase		gas	gas	gas
Specific Vol. Flow (wet)	Nm3/kWh	4.9133	0.1554	5.0844
Average MW		28.7	19.4	28.4
Gas Composition (wet basis)				
CH4	%v.	-	83.90	-
C2H6	%v.	-	9.20	-
C3H8	%v.	-	3.30	-
C4H10	%v.	-	1.20	-
C5H12	%v.	-	0.20	-
H2	%v.	-	-	-
CO2	%v.	-	1.80	3.66
CO	%v.	-	-	-
O2	%v.	20.72	-	13.12
N2	%v.	78.17	0.40	75.55
H2O	%v.	1.11	-	7.67

13. UNIT 2000: STEAM GENERATION PLANT

13.1. Study Specification

The captive steam generation plant assumed for this study is based on multiple trains of packaged water tube boilers each with a capacity of 60 tph delivering 9 Bar_a saturated steam. These boilers will be fuelled by the BFG and BOFG; and supplemented by the natural gas.

13.2. PFD and Mass Balance

Figure A3-12 presents the process flow diagram of the captive steam generation plant of the integrated steel mill with post-combustion CO_2 capture. Tables A3-23 and A3-24 present a summary of the mass balance for the captive steam generation plant of the integrated steel mill for Cases 2A and 2B respectively.

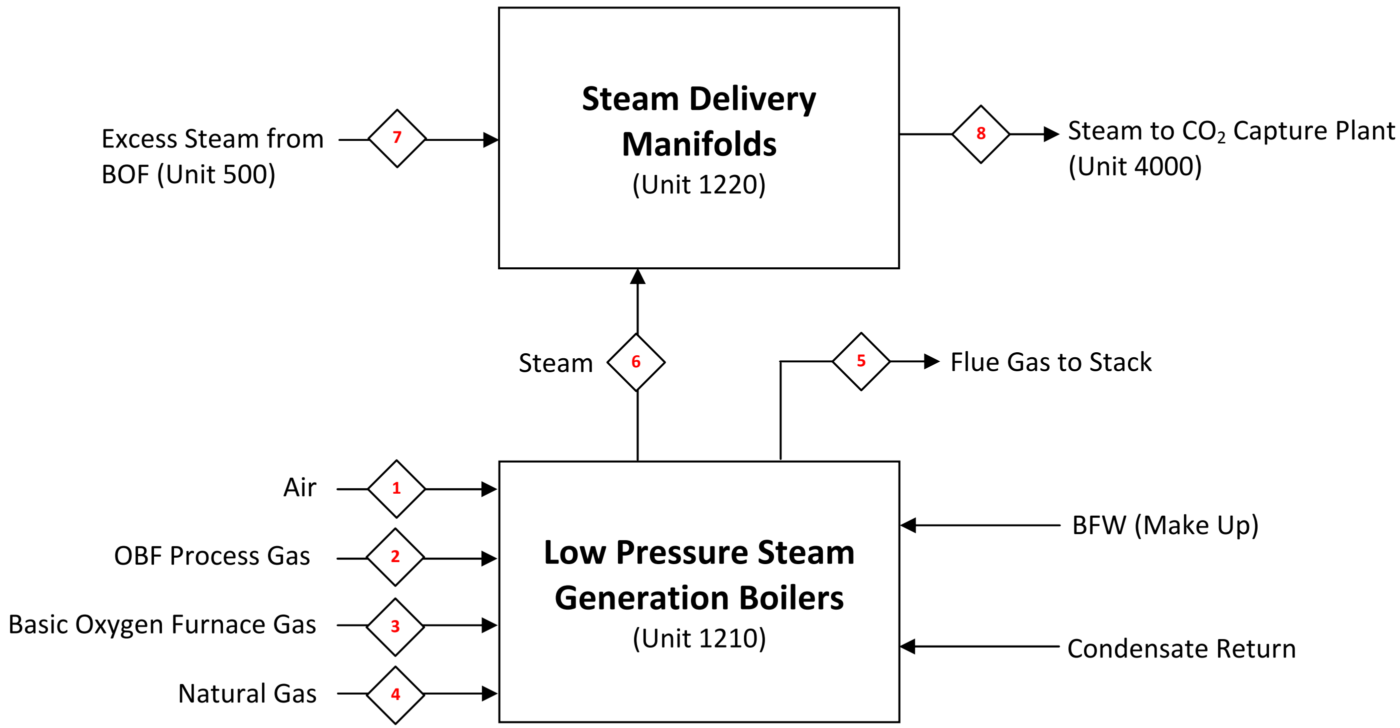

Figure A3-12: PFD of the steam generation plant (Unit 2000)

Table A3-23: Mass Balance (Unit 2000: Steam Generation Plant for Case 2A)

		1	2	3	4	5	6	7	8
Stream		**Combustion Air**	**BFG**	**BOFG**	**NG**	**Flue Gas**	**Steam from Boilers**	**Steam from BOF**	**Steam to CO2 Capture Plant**
Total Mass Flow (wet)	**t/y**	**4,830,186**	**742,502**	**864,177**	**107,397**	**6,544,321**	**6,820,655**	**23,907**	**6,844,563**
Total Mass Flow (dry)	**t/y**	**4,796,549**	**725,588**	**797,526**	**107,397**	**6,130,624**	**6,820,655**	**23,907**	**6,844,563**
Specific Mass Flow (wet)	kg/MJ	0.3217	0.0495	0.0576	0.0072	0.4359	0.4543	0.0016	0.4559
Specific Mass Flow (dry)	kg/MJ	0.3195	0.0483	0.0531	0.0072	0.4083	0.4543	0.0016	0.4559
Pressure	Bara	1.03	1.11	1.11	1.11	1.03	9.01	9.01	9.01
Temperature	oC	12	25	50	12	150	175	175	175
Phase		gas	gas	gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/MJ	0.2459	0.2470	0.0235	0.0038	0.4815	-	-	-
Average MW		28.7	24.9	28.4	19.4	30.6	18.0	18.0	18.0
Gas Composition (wet basis)									
CH4	%v.	-	-	-	83.90	-	-	-	-
C2H6	%v.	-	-	-	9.20	-	-	-	-
C3H8	%v.	-	-	-	3.30	-	-	-	-
C4H10	%v.	-	-	-	1.20	-	-	-	-
C5H12	%v.	-	-	-	0.20	-	-	-	-
H2	%v.	-	3.63	2.64	-	-	-	-	-
CO2	%v.	-	22.10	14.44	1.80	27.22	-	-	-
CO	%v.	-	22.34	56.92	-	-	-	-	-
O2	%v.	20.72	-	-	-	0.70	-	-	-
N2	%v.	78.17	48.77	13.83	0.40	65.62	-	-	-
H2O	%v.	1.11	3.15	12.16	-	6.45	100.00	100.00	100.00

Table A3-24: Mass Balance (Unit 2000: Steam Generation Plant for Case 2B)

		1	2	3	4	5	6	7	8
Stream		**Combustion Air**	**BFG**	**BOFG**	**NG**	**Flue Gas**	**Steam from Boilers**	**Steam from BOF**	**Steam to CO2 Capture Plant**
Total Mass Flow (wet)	**t/y**	**6,185,164**	**5,011,731**	**448,151**	**135,647**	**11,780,798**	**8,479,735**	**23,897**	**8,503,631**
Total Mass Flow (dry)	**t/y**	**6,142,092**	**4,917,790**	**413,587**	**135,647**	**11,221,924**	**8,479,735**	**23,897**	**8,503,631**
Specific Mass Flow (wet)	kg/MJ	0.3314	0.2685	0.0240	0.0073	0.6311	0.4543	0.0013	0.4556
Specific Mass Flow (dry)	kg/MJ	0.3291	0.2635	0.0222	0.0073	0.6012	0.4543	0.0013	0.4556
Pressure	Bara	1.03	1.11	1.11	1.11	1.03	9.01	9.01	9.01
Temperature	oC	12	25	50	12	150	175	175	175
Phase		gas	gas	gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/MJ	0.2585	0.1987	0.0189	0.0084	0.4539	-	-	-
Average MW		28.7	30.3	28.4	19.4	31.2	18.0	18.0	18.0
Gas Composition (wet basis)									
CH4	%v.	-	-	-	83.90	-	-	-	-
C2H6	%v.	-	-	-	9.20	-	-	-	-
C3H8	%v.	-	-	-	3.30	-	-	-	-
C4H10	%v.	-	-	-	1.20	-	-	-	-
C5H12	%v.	-	-	-	0.20	-	-	-	-
H2	%v.	-	3.63	2.64	-	-	-	-	-
CO2	%v.	-	22.10	14.44	1.80	24.64	-	-	-
CO	%v.	-	22.34	56.92	-	-	-	-	-
O2	%v.	20.72	-	-	-	0.70	-	-	-
N2	%v.	78.17	48.77	13.83	0.40	66.45	-	-	-
H2O	%v.	1.11	3.15	12.16	-	8.20	100.00	100.00	100.00

14. UNIT 4000: CO_2 CAPTURE AND COMPRESSION PLANT

14.1. Study Specification

For EOP-L1 Case, two absorber columns were used to capture CO_2 from the flue gases of the hot stoves and steam generation plant; and a single stripper column was used to regenerate the rich amine solvent.

For the EOP-L2 Case, in addition to the absorbers and stripper columns used for EOP-L1 Case, two more absorber columns were added to capture CO_2 from the flue gases of the underfire heaters of the coke oven batteries and the lime kilns, and an additional stripper column was also added to the central stripper unit to regenerate the rich amine solution.

This study assumed 90% capture rate for all the CO_2 absorbers regardless of varying CO_2 concentration.

It should be noted that energy requirements of the CO_2 capture plant using MEA as solvent has been optimised by using a Split Flow Configuration as described in Section C, Vol. 2 of this report.

14.2. PFD and Mass Balance

Figures A3-13 and A3-14 present the process flow diagram of the CO_2 capture and compression plant of the integrated steel mill with post-combustion CO_2 capture for Cases 2A and 2B.

Tables A3-25 and A3-26 present a summary of the mass balance for the CO_2 capture and compression plant of the integrated steel mill – for Case 2A and 2B respectively.

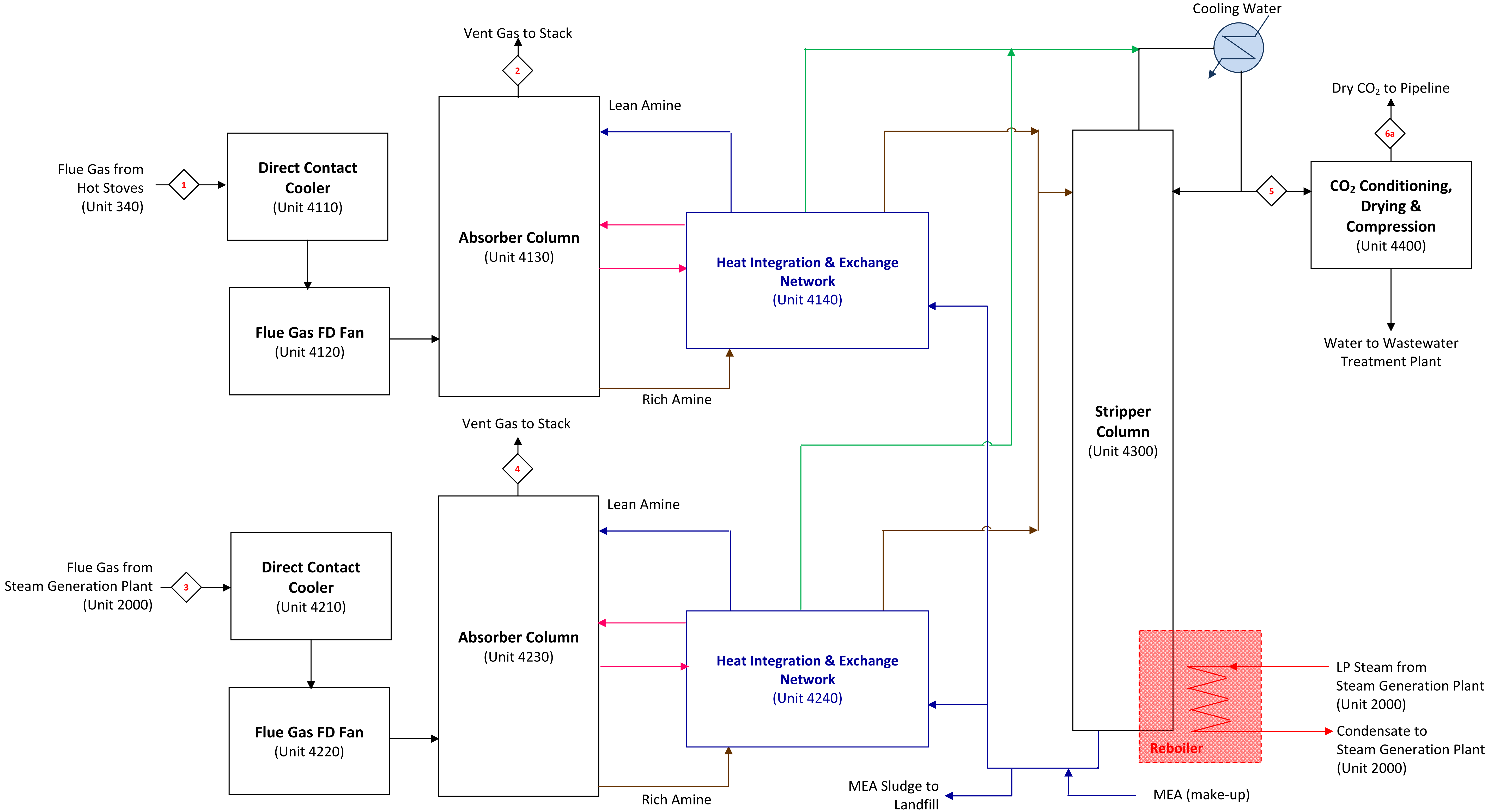

Figure A3-13: Process Flow Diagram – CO_2 Capture and Compression Plant – Steam Generation Plant and Hot Stoves (EOP-L1 and EOP-L2 Case)

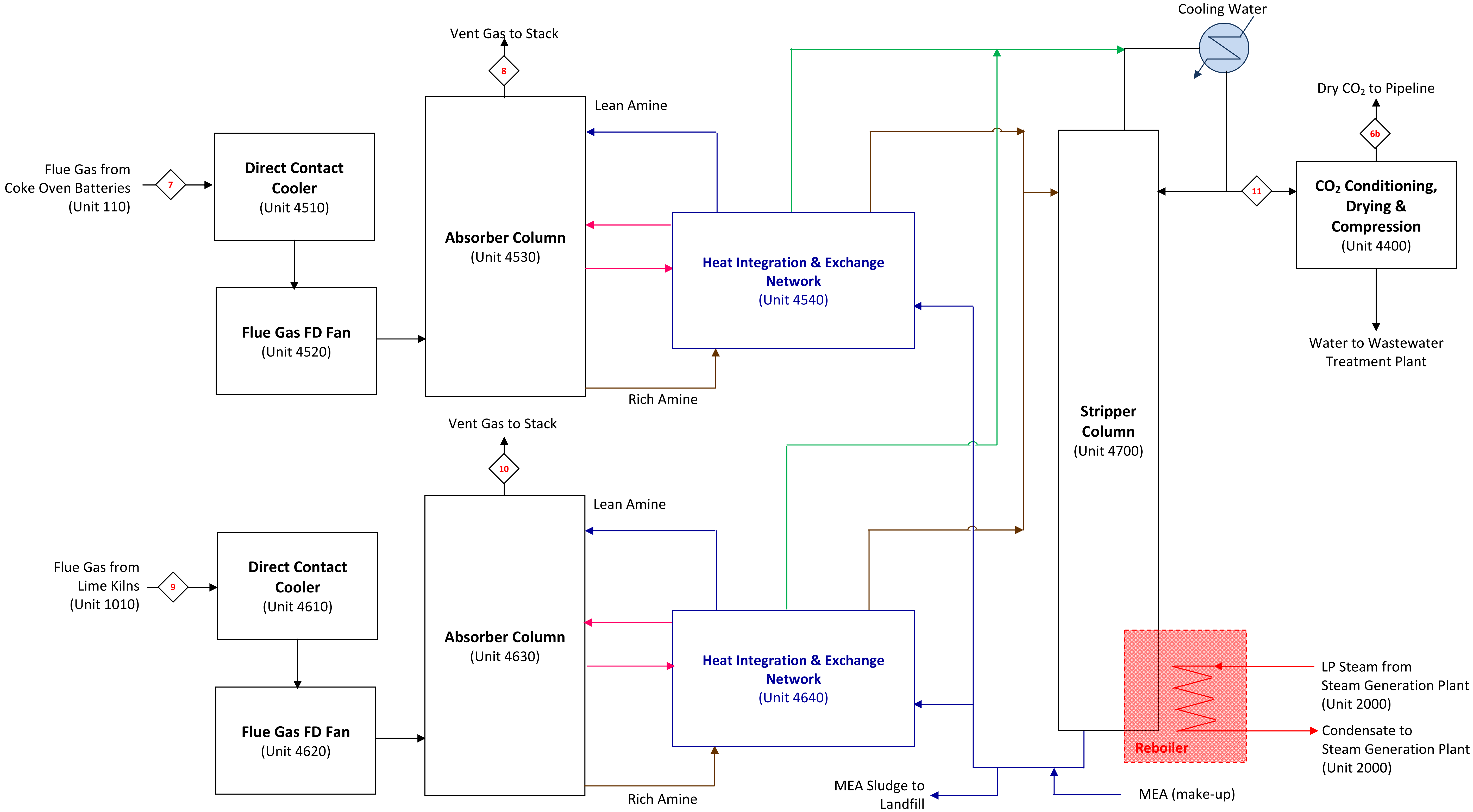

Figure A3-14: Process Flow Diagram – CO_2 Capture and Compression Plant – Coke Oven Batteries and Lime Plant (EOP-L2 Case)

Table A3-25: Mass Balance (Unit 4000: CO_2 Capture and Compression Plant for Case 2A)

		1	2	3	4	5	6
Stream		**Flue Gas from Hot Stoves**	**Vent Gas from Absorber (Unit 4130)**	**Flue Gas from SGP**	**Vent Gas from Absorber (Unit 4230)**	**Wet CO2 from Stripper Column (Unit 4300)**	**CO2 to Pipeline**
Total Mass Flow (wet)	**t/y**	**4,390,584**	**2,806,294**	**10,241,478**	**6,572,694**	**5,009,212**	**4,972,575**
Total Mass Flow (dry)	**t/y**	**4,231,794**	**2,731,277**	**9,866,392**	**6,396,951**	**4,972,525**	**4,972,540**
Specific Mass Flow (wet)	kg/t CO2 captured[1]	882.9	564.3	2059.6	1321.8	1007.4	1000.0
Specific Mass Flow (dry)	kg/t CO2 captured	851.0	549.3	1984.1	1286.4	1000.0	1000.0
Pressure	Bara	1.02	1.09	1.02	1.09	1.81	110.01
Temperature	oC	148	30	150	30	148	148
Phase		gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/t CO2 Captured	622.82	447.84	1453.90	1049.16	518.46	509.29
Average MW		31.8	28.2	31.8	28.2	43.5	44.0
Gas Composition (wet basis)							
CO2	%v.	27.30	3.79	27.22	3.78	98.23	100.00
O2	%v.	0.80	1.11	0.70	0.97	-	-
N2	%v.	65.52	90.91	65.62	91.06	-	-
H2O	%v.	6.38	4.19	6.45	4.19	1.77	0.002

[1] This is based on the total CO_2 captured.

Table A3-26: Mass Balance (Unit 4000: CO_2 Capture and Compression Plant for Case 2B)

		1	2	3	4	5	6
Stream		**Flue Gas from Hot Stoves**	**Vent Gas from Absorber (Unit 4130)**	**Flue Gas from SGP**	**Vent Gas from Absorber (Unit 4230)**	**Wet CO2 from Stripper Column (Unit 4300)**	**CO2 to Pipeline (Total)**
Total Mass Flow (wet)	**t/y**	**4,390,584**	**3,219,336**	**11,781,328**	**8,858,289**	**5,222,423**	**6,131,310**
Total Mass Flow (dry)	**t/y**	**4,231,794**	**3,133,244**	**11,222,429**	**8,620,817**	**5,184,604**	**6,131,267**
Specific Mass Flow (wet)	kg/t CO2 captured	716.1	525.1	1921.6	1444.8	851.8	1000.0
Specific Mass Flow (dry)	kg/t CO2 captured	690.2	511.0	1830.4	1406.1	845.6	1000.0
Pressure	Bara	1.02	1.09	1.02	1.09	1.81	110.01
Temperature	oC	148	30	150	30	25	25
Phase		gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/t CO2 Captured	505.13	416.68	1382.07	1149.37	438.34	509.31
Average MW		31.8	28.2	31.2	28.2	43.6	44.0
Gas Composition (wet basis)							
CO2	%v.	27.30	3.79	24.64	3.39	98.25	100.00
O2	%v.	0.80	1.11	0.70	0.96	-	-
N2	%v.	65.52	90.91	66.45	91.45	-	-
H2O	%v.	6.38	4.19	8.20	4.19	1.75	0.002

		7	8	9	10	11
Stream		**Flue Gas from Coke Oven Batteries**	**Vent Gas from Absorber (Unit 4530)**	**Flue Gas from Lime Kiln**	**Vent Gas from Absorber (Unit 4630)**	**Wet CO2 from Stripper Column (Unit 4700)**
Total Mass Flow (wet)	**t/y**	**3,474,713**	**2,627,278**	**1,006,794**	**684,944**	**953,635**
Total Mass Flow (dry)	**t/y**	**3,246,246**	**2,556,767**	**931,180**	**666,561**	**946,662**
Specific Mass Flow (wet)	kg/t CO2 captured	566.7	428.5	164.2	111.7	155.5
Specific Mass Flow (dry)	kg/t CO2 captured	529.5	417.0	151.9	108.7	154.4
Pressure	Bara	1.02	1.09	1.02	1.09	1.81
Temperature	oC	250	30	150	30	25
Phase		gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/t CO2 Captured	430.62	341.27	121.99	88.97	80.05
Average MW		29.5	28.1	30.2	28.1	43.6
Gas Composition (wet basis)						
CO2	%v.	14.77	1.86	19.41	1.86	98.23
O2	%v.	5.00	6.31	7.77	6.31	-
N2	%v.	69.47	87.64	60.24	87.64	-
H2O	%v.	10.76	4.19	12.58	4.19	1.77

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

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Annex IV

FINANCIAL ASSUMPTIONS

Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

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1 Plant Location

The Integrated Steel Mill with Post-Combustion CO_2 Capture is located along the Coastal Region of Western Europe. The plant location has been described in Volume 2 (Section B) of the report.

- Site should have no special civil works required to add onto the construction cost.
- The study assumed that the site is accessible to the Port of Rotterdam with no extra additional cost needed to deliver raw materials and goods from Rotterdam to the plant site.
- Adequate site and facility services should be accessible to the integrated steel mill to make it self sufficient.
- The breakeven price reported in this study should represent the gate price (i.e. excluding cost for delivery to customers)

2 Plant Life

The integrated steel mill is assumed to have an economic life of 25 years as the basis for appraisal.

3 Design and Construction Period

Plant design and construction will be completed within 60 months starting from issue of "Notice to Proceed" to the EPC contractor. Operations would start after three years of construction with the completion of one blast furnace and full production achieved at the end of second year of operation.

The curve of capital expenditure during construction is assumed to be:

Year	Capital Expenditure (% investment cost)
-3	10
-2	35
-1	30
1	20
2	5

4 Commissioning

The study assumed the start up of steel mill producing 50% of the plant capacity on year 1 and achieving the full capacity on year 4. The commissioning of the plant involves the following schedule of production for the period between 1st and 3rd year as shown below:

Year	Iron and Steel Production (% Capacity)	Power Plant (% Load Factor)
1	50%	42.5%
2	75%	63.8%
3	90%	76.5%
4 and onward	100%	85.0%

5 Decommissioning

Decommissioning and remediation of the land by the end of the steel mill's life is excluded in the cash flow analysis.

6 Capital Charges

- The discounted cash flow analysis is used to evaluate the breakeven price per tonne of hot rolled coil produced. A discount rate of 10% was assumed.

- All capital requirements will be available according to the schedule of capital expenditure as described in Section E2.3. The capital infusion could be assumed as cash available for the construction of the steel mill based on combined equity and debt. However, the level of debt is not considered or accounted for in this study. The Cost of Capital will also use the same discount rate of 10%, which represents the weighted average of capital charges (WACC).

- No interest during construction is applied but the timing of capital expenditure is taken into account in the discounted cash flow analysis (using end of the year as basis).

7 Recurring Capital Expenditure

The steel mill requires the refractory relining of the blast furnaces for every 10-15 years of continuous operation. The study assumed a relining to be done on the 15th year with steel production assumed to maintain at 100% full capacity during this period[1].

8 Working Capital

The storage time for materials and balance of trade were taken according to normal industry practice:

- Stocks - Raw Materials: 63 days
- Stocks - Slabs: 5 days
- HRC: 15 days
- Trade debtors: 15 days
- Trade creditors (excl. raw materials): 30 days

Working capital comprises the value of raw materials (coking coal, iron ores, fluxes, purchased scrap and ferroalloys), slabs and hot rolled coils stored in the stockyard and the balance of the trade between debtors and creditors.

The trade debtors only considered the sale value of the hot rolled coil, whilst the trade creditors only account for the value of goods used by the steel mill excluding the value of raw materials.

[1] Note: This is a simplifying assumption to reduce the complexity in the calculation of the breakeven price of the HRC

9 Currency

The cost evaluation was developed in US$ (2010). Where necessary, the conversion was based on the following exchange rates:

- € 1.00 = US$ 1.34
- £ 1.00 = US$ 1.55

10 Inflation

Inflation assumptions were not included. No allowance has been made for escalation of fuel, reductant, raw materials, labour and other cost relative to each other.

11 Depreciation

Although the study assumed that depreciation of the integrated steel mill is to follow a straight line at 4% rate, this is not included in the calculation of the breakeven price of the Hot Rolled Coil as calculation of HRC breakeven price is based on EBITDA cash flow analysis.

12 Estimate Accuracy

The estimate accuracy is within the range +/- 30%.

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

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Annex V

TECHNO-ECONOMICS - COST BREAKDOWN (OPEX)

Integrated Steel Mill with Post-Combustion CO_2 Capture – EOP-L1 Case

I N D E X

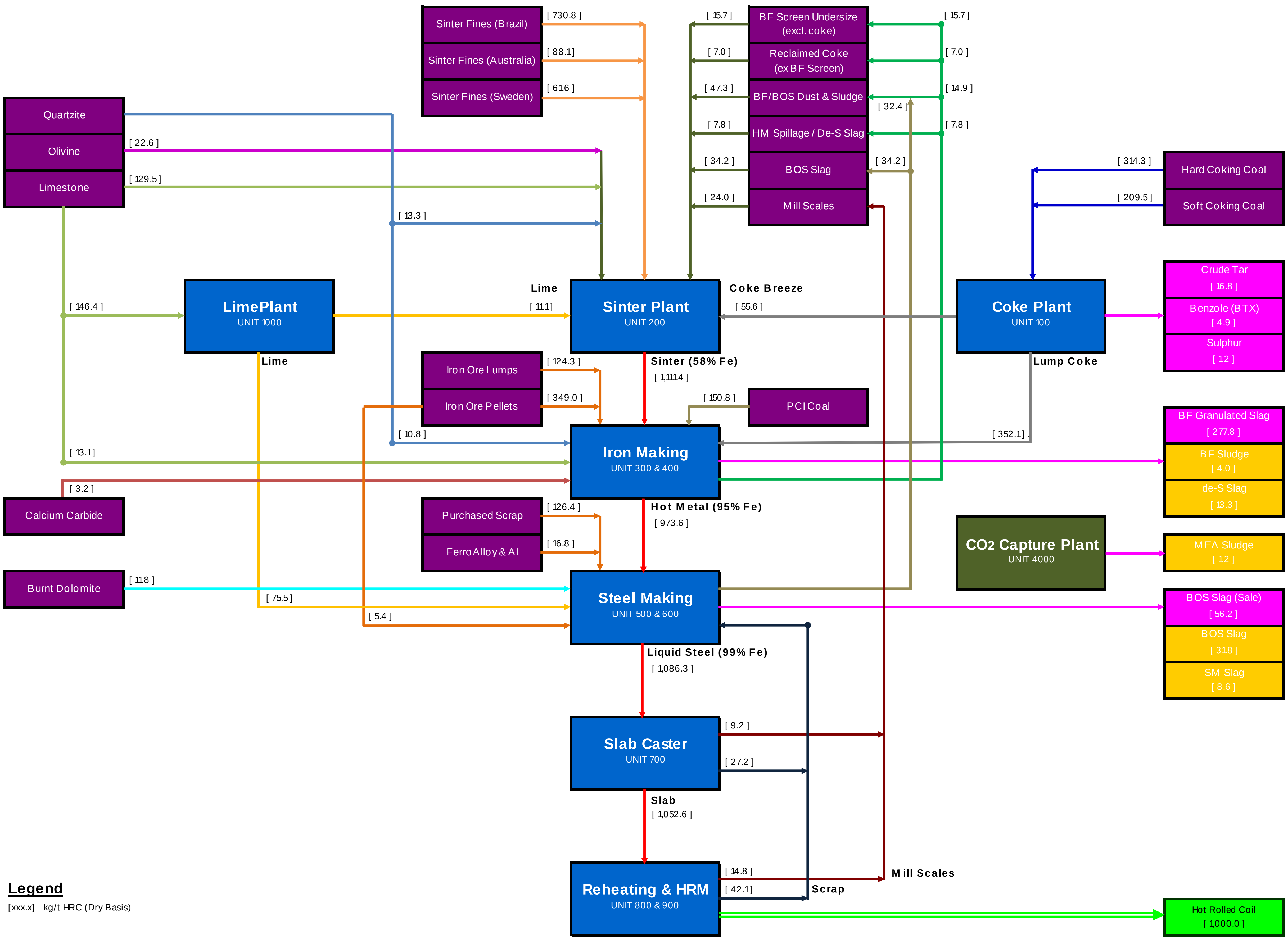
Flow Sheet (Materials)

Application of CO_2 Capture to an Integrated Steelworks

Steel Mill with Post-Combustion CO2 Capture (Case 2A) - EOP-L1

Production: 4,000,000 tonnes HRC/y

(YEAR 06)



Legend

[xxx.x] - kg/t HRC (Dry Basis)

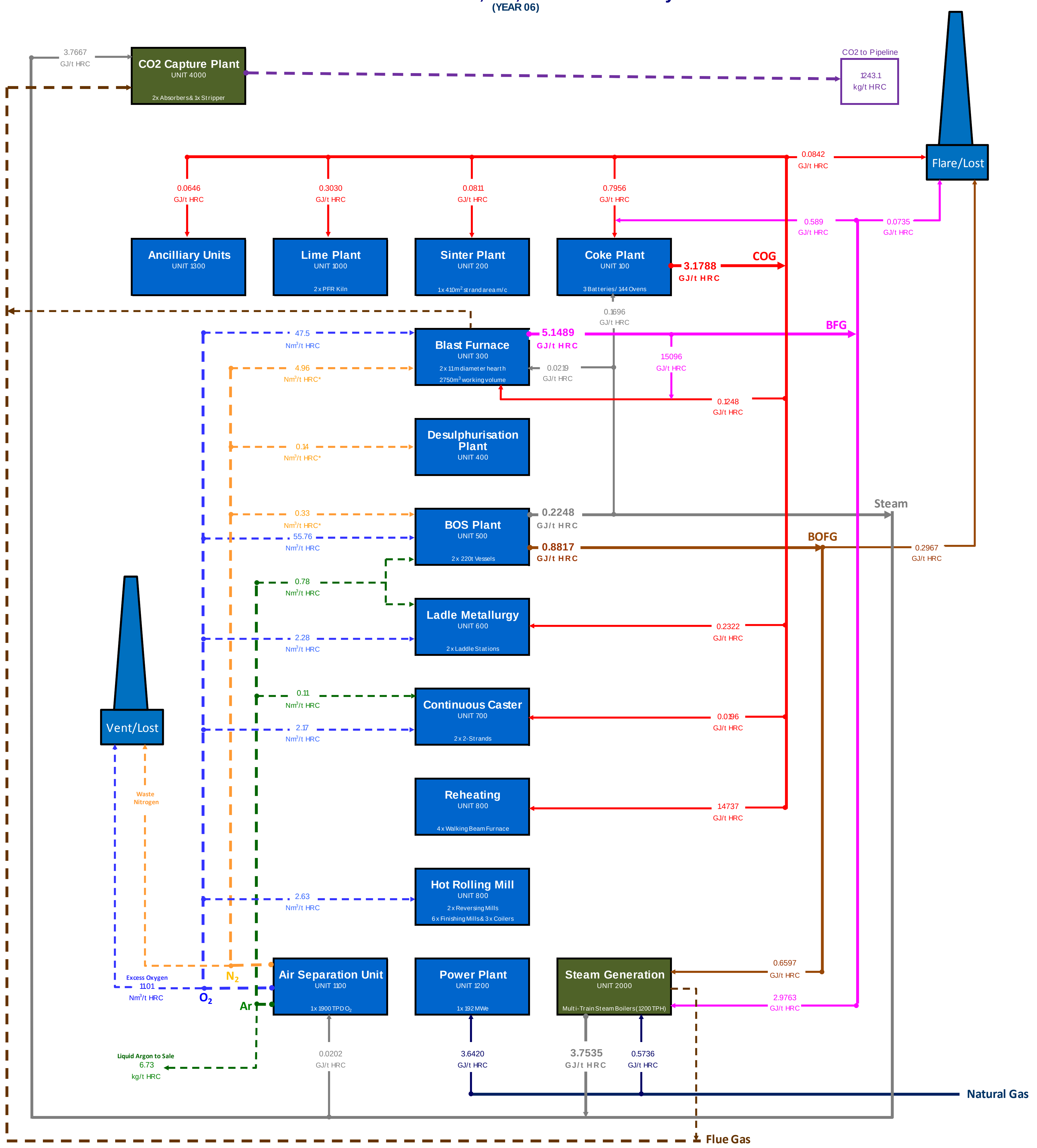
Flow Sheet (Steel Mill Gas Network)

Application of CO_2 Capture to an Integrated Steelworks

Steel Mill with Post-Combustion CO2 Capture (Case 2A) - EOP-L1

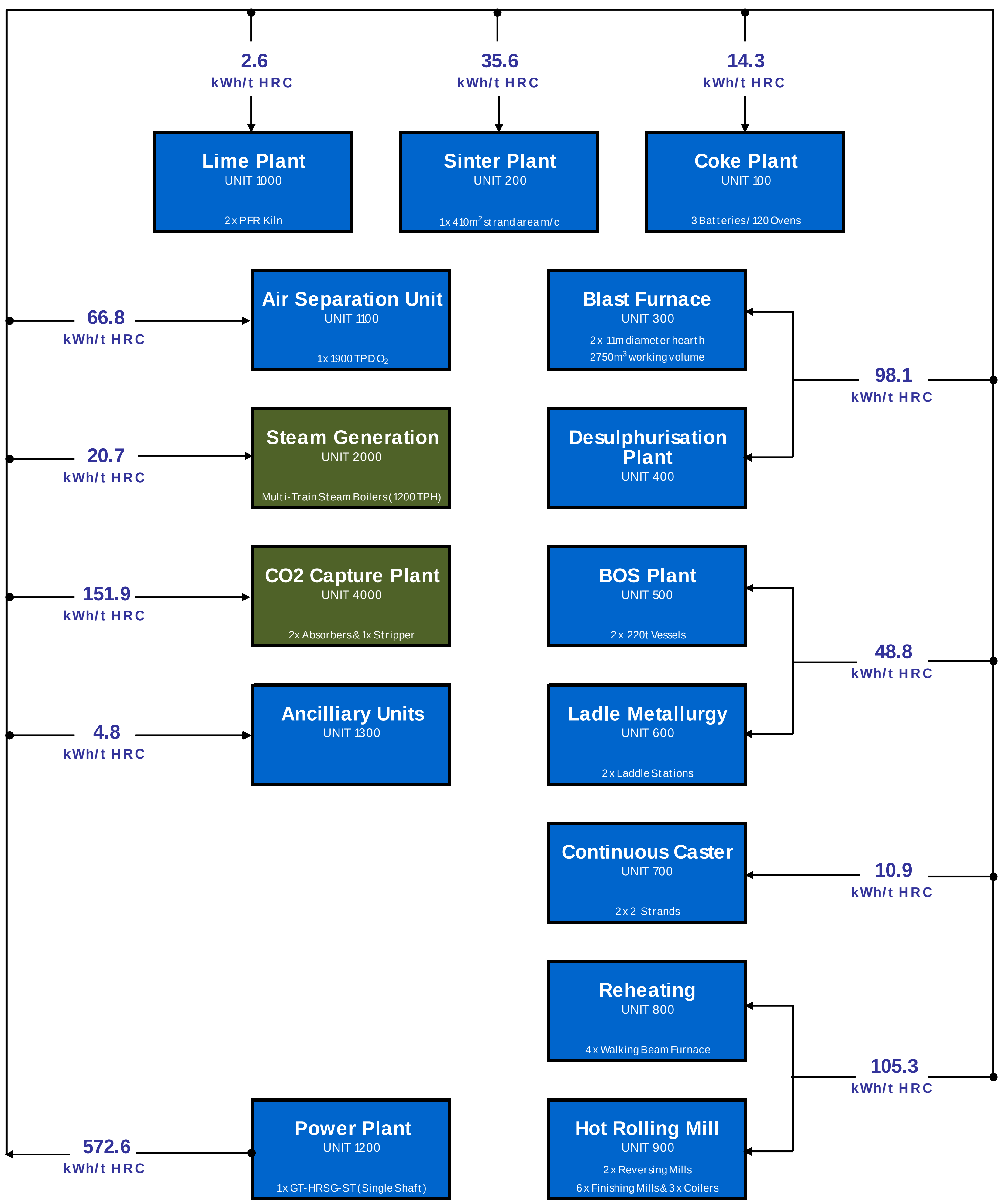
Production: 4,000,000 tonnes HRC/y

(YEAR 06)



Production: 4,000,000 tonnes HRC/y

(YEAR 06)



Product ID	Coke & Coke Breeze	
Annual Production (Year 4 - 25)	1,630,519 t/y	407.63 kg/t HRC
Cost Items	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Hard Coking Coal	1,257,292 t/y	$239.159 Million/y
Soft Coking Coal	838,194 t/y	$122.085 Million/y
Raw Materials & Energy (Internally Sourced)		
Coke Oven Gas (Export)	9,195,703 GJ/y	($89.842) Million/y
Blast Furnace Gas	2,357,936 GJ/y	$23.037 Million/y
Electricity	57,068,151 kWh/y	$4.300 Million/y
Steam	678,378 t/y	$36.091 Million/y
Consumables & Other Utilities		
Raw Water	2,931,317 m^3/y	$0.333 Million/y
By-Product Sales		
Coal Tar	67,080 t/y	($11.806) Million/y
Benzole	19,729 t/y	($9.197) Million/y
Sulphur	4,937 t/y	($0.420) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	240 Operation Staff	$22.560 Million/y
Annual Maintenance Expense	5.0% CAPEX	$20.000 Million/y
Misc. Works Expense		$9.801 Million/y
Misc. OPEX (incl. environmental cleanup)		$3.703 Million/y
Total Operating Cost (Direct Cost of Coke Production)		$369.803 Million/y
Specific Cost (Internal Price of Coke)	**$ 226.80 per tonne coke**	**$ 92.45 per tonne HRC**

Product ID	Sinter	
Annual Production (Year 4 - 25)	4,445,559 t/y	1,111.39 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Iron Ore Fines (Brazil)	2,923,276 t/y	$234.488 Million/y
Iron Ore Fines (Australia)	352,202 t/y	$29.149 Million/y
Iron Ore Fines (Sweden)	246,541 t/y	$20.945 Million/y
Limestone	517,872 t/y	$12.040 Million/y
Quartzite	53,347 t/y	$0.960 Million/y
Olivine	90,349 t/y	$1.536 Million/y
Raw Materials & Energy (Internally Sourced)		
Lime	44,456 t/y	$4.274 Million/y
BF Undersize (excl. Reclaimed Coke)	62,630 t/y	$1.879 Million/y
BF Dust	59,531 t/y	$1.786 Million/y
HM Spillage & de-S Slag	31,167 t/y	$0.935 Million/y
BOS Dust & Sludge	129,700 t/y	$3.891 Million/y
BOS Slag (LD Slag)	136,893 t/y	$4.107 Million/y
Mill Scales	96,159 t/y	$1.923 Million/y
Coke Breeze	222,278 t/y	$50.413 Million/y
Reclaimed Coke (ex BF Screens)	28,165 t/y	$0.845 Million/y
Coke Oven Gas	324,526 GJ/y	$3.171 Million/y
Electricity	142,257,877 kWh/y	$10.719 Million/y
Consumables & Other Utilities		
Raw Water	1,324,616 m^3/y	$0.150 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	270 Operation Staff	$25.380 Million/y
Annual Maintenance Expense	5.0% CAPEX	$11.000 Million/y
Misc. Works Expense		$3.206 Million/y
Misc. OPEX (incl. environmental cleanup)		$1.603 Million/y
Total Operating Cost (Direct Cost of Coke Production)		$424.400 Million/y
Specific Cost (Internal Price of Sinter)	**$ 95.47 per tonne sinter**	**$ 106.10 per tonne HRC**

Product ID	Hot Metal (Desulphurised)	
Annual Production (Year 4 - 25)	3,894,263 t/y	973.57 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
PCI Coal	603,251 t/y	$89.491 Million/y
Lump Ore (Australian)	497,139 t/y	$51.069 Million/y
Pellets (Brazil)	1,396,178 t/y	$154.026 Million/y
Limestone	52,497 t/y	$1.220 Million/y
Quartzite	43,129 t/y	$0.776 Million/y
Calcium Carbide Powder	12,710 t/y	$10.168 Million/y
Raw Materials & Energy (Internally Sourced)		
Sinter	4,445,559 t/y	$424.400 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	190,092,062 Nm^3/y	$7.295 Million/y
BF Undersize (excl. reclaimed coke)	62,630 t/y	($1.859) Million/y
BF Dust (Recycled)	59,531 t/y	($1.767) Million/y
HM Spillage & De-Slag (Recycled)	31,167 t/y	($0.925) Million/y
Lump Coke	1,408,241 t/y	$319.390 Million/y
Reclaimed Coke (ex BF Screens)	28,165 t/y	($0.836) Million/y
Coke Oven Gas (for Hot Stove)	499,108 GJ/y	$4.876 Million/y
Coke Oven Gas (for Ancillary Users)	258,427 GJ/y	$2.525 Million/y
Blast Furnace Gas (Export)	14,263,072 GJ/y	($139.350) Million/y
Electricity (Iron Making incl. HM Desulph.)	392,205,884 kWh/y	$29.553 Million/y
Electricity (Ancillary Users)	19,272,000 kWh/y	$1.452 Million/y
Steam	87,556 t/y	$4.658 Million/y
Consumables & Other Utilities		
Refractories (Torpedo car, HM Desulf, etc...)	5,063 t/y	$4.151 Million/y
Raw Water	3,483,639 m^3/y	$0.396 Million/y
Other Variable O&M Cost		
Slag Processing Fee (De-S Slag)	84,235 t/y	$0.496 Million/y
BF Sludge Disposal Fee	15,875 t/y	$0.318 Million/y
Slag Disposal Fee (De-S Slag)	53,068 t/y	$0.288 Million/y
Other Variable O&M Cost (Internally Sourced)		
CO_2 Capture and Compression Charge	1,494,462 t/y	$264.537 Million/y
By-Product Sales		
Granulated BF Slag	1,111,252 t/y	($17.780) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	321 Operation Staff	$30.174 Million/y
Annual Maintenance Expense	4.0% CAPEX	$24.880 Million/y
Misc. Works Expense		$10.403 Million/y
Misc. OPEX (incl. environmental cleanup)		$1.300 Million/y
Total Operating Cost (Direct Cost of Hot Metal Production)		$1,275.324 Million/y
Specific Cost (Internal Price of Hot Metal)	**$ 327.49 per tonne Hot Metal**	**$ 318.83 per tonne HRC**

Product ID	Liquid Steel	
Annual Production (Year 4 - 25)	4,345,228 t/y	1,086.31 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Pellets	21,544 t/y	$2.377 Million/y
Purchased Scrap	505,492 t/y	$115.252 Million/y
FeMnC	47,798 t/y	$67.068 Million/y
FeSi-75	13,036 t/y	$21.513 Million/y
DeOx Aluminium	6,518 t/y	$14.395 Million/y
Burnt Dolomite	47,164 t/y	$4.339 Million/y
Raw Materials & Energy (Internally Sourced)		
Hot Metal	3,894,263 t/y	$1,275.324 Million/y
Lime	301,956 t/y	$29.033 Million/y
Oxygen (Nm^3/y @ 273K)	232,185,679 Nm^3/y	$8.910 Million/y
Scrap (Internal)	320,285 t/y	$53.706 Million/y
LD Slag to Sinter Plant	136,893 t/y	($4.064) Million/y
LD Dust & Sludge	129,700 t/y	($3.851) Million/y
Coke Oven Gas (Ladle Metallurgy)	928,613 GJ/y	$9.073 Million/y
Basic Oxygen Furnace Gas (Export)	2,638,853 GJ/y	($25.782) Million/y
Electricity (Steel Making incl. Ladle Metallurgy)	195,097,244 kWh/y	$14.701 Million/y
Steam	899,361 t/y	($47.848) Million/y
Consumables & Other Utilities		
Refractories (BOS furnace, Ladle vessels)	15,208 t/y	$12.881 Million/y
Electrodes	1,304 t/y	$5.289 Million/y
Raw Water	1,673,679 m^3/y	$0.190 Million/y
Other Variable O&M Cost		
Slag Processing Fee (LD Slag)	488,920 t/y	$2.880 Million/y
Slag Processing Fee (Ladle Slag)	34,412 t/y	$0.203 Million/y
Disposal Fee (LD Slag)	127,124 t/y	$0.690 Million/y
Disposal Fee (Ladle Slag)	34,412 t/y	$3.040 Million/y
By-Product Sales		
LD Slag	224,903 t/y	($0.450) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	396 Operation Staff	$37.224 Million/y
Annual Maintenance Expense	5.0% CAPEX	$22.950 Million/y
Misc. Works Expense		$10.738 Million/y
Misc. OPEX (incl. environmental cleanup)		$2.844 Million/y
Total Operating Cost (Direct Cost of Liquid Steel Production)		$1,632.624 Million/y
Specific Cost (Internal Price of Liquid Steel)	**$ 375.73 per tonne Liquid Steel**	**$ 408.16 per tonne HRC**

Product ID	Slab	
Annual Production (Year 4 - 25)	4,210,526 t/y	1,052.63 kg/t HRC
Cost Components	Annual Consumption	Annual Cost (US $)
Raw Materials & Energy (Internally Sourced)		
Liquid Steel	4,345,228 t/y	$1,632.624 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	8,690,457 Nm^3/y	$0.333 Million/y
Scrap (to BOS furnace)	108,631 t/y	($21.019) Million/y
Scale (to Sinter)	36,772 t/y	($0.724) Million/y
Coke Oven Gas	78,437 GJ/y	$0.766 Million/y
Electricity	43,452,284 kWh/y	$3.274 Million/y
Consumables & Other Utilities		
Refractories (Casters)	8,842 t/y	$5.571 Million/y
Casting Powder	3,368,421 t/y	$2.257 Million/y
Raw Water	3,655,576 m^3/y	$0.415 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	360 Operation Staff	$33.840 Million/y
Annual Maintenance Expense	8.0% CAPEX	$15.636 Million/y
Misc. Works Expense		$5.905 Million/y
Misc. OPEX (incl. environmental cleanup)		$0.956 Million/y
Total Operating Cost (Direct Cost of Slab Production)		$1,679.835 Million/y
Specific Cost (Internal Price of Slab)	$ 398.96 per tonne Slab	$ 419.96 per tonne HRC

Product ID	Lime	
Annual Production (Year 4 - 25)	346,412 t/y	86.60 kg/t HRC
Cost Components	Annual Consumption	Annual Cost (US $)
Raw Materials & Energy (Externally Sourced)		
Limestone	585,449 t/y	$13.611 Million/y
Raw Materials & Energy (Externally Sourced)		
Coke Oven Gas (Lime Kiln)	1,211,856 GJ/y	$11.840 Million/y
Electricity	10,392,357 kWh/y	$0.783 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	34 Operation Staff	$3.196 Million/y
Annual Maintenance Expense	8.0% CAPEX	$1.280 Million/y
Misc. Works Expense		$2.598 Million/y
Total Operating Cost (Direct Cost of Lime Production)		$33.308 Million/y
Specific Cost (Internal Price of Lime)	$ 96.15 per tonne Lime	$ 8.33 per tonne HRC

Product ID	Oxygen	
Annual Production (Year 4 - 25)	485,515,709 Nm3/y	121.38 Nm3/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Electricity	267,033,640 kWh/y	$20.121 Million/y
Steam	80,800 GJ/y	$4.299 Million/y
By-Product Sales		
Argon (Nm^3/y @ 273K and 1 Bar)	15,073,913 Nm^3/y	($14.018) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	35 Operation Staff	$3.290 Million/y
Annual Maintenance Expense	2.5% CAPEX	$3.250 Million/y
Total Operating Cost (Direct Cost of Oxygen Production)		$16.942 Million/y
Specific Cost	**$ 0.03490 per Nm3 Oxygen**	**$ 4.24 per tonne HRC**
Adjustment Factor	**1.09971**	
Adjusted Internal Price of Oxygen	**$ 0.03838 per Nm3 Oxygen**	

Product ID	Electricity	
Annual Production (Year 4 - 25)	2,290,444 MWh/y	572.61 MWh/t HRC
Cost Components	Annual Consumption	Annual Cost (US $)
Raw Materials & Energy (Externally Sourced)		
Natural Gas	14,568,197 GJ/y	$142.331 Million/y
Consumables & Other Utilities		
Chemicals and Consumables	3.440 $/MWh	$7.880 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	42 Operation Staff	$3.948 Million/y
Annual Maintenance Expense	4.0% CAPEX	$14.469 Million/y
Total Operating Cost (Direct Cost of Electricity Production)		$168.628 Million/y
Specific Cost (Internal Price of Electricity)	**$ 0.0736 per kWh Electricity**	**$ 42.16 per tonne HRC**
Adjustment Factor	**1.02349**	
Adjusted Internal Price of Oxygen	**$ 0.0754 per kWh Electricity**	

Product ID	Steam (9 Bar_a, Sat.)	
Annual Production (Year 4 - 25)	15,014,125 GJ/y	3.75 GJ/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Natural Gas	2,294,279 GJ/y	$22.415 Million/y
Raw Materials & Energy (Internally Sourced)		
Blast Furnace Gas	11,905,137 GJ/y	$116.313 Million/y
Basic Oxygen Furnace Gas	2,638,853 GJ/y	$25.782 Million/y
Electricity	82,653,525 kWh/y	$6.228 Million/y
Other Variable O&M Cost (Internally Sourced)		
CO_2 Capture and Compression Charge	3,478,063 t/y	$615.656 Million/y
Consumables & Other Utilities		
Chemicals and Consumables	0.500 $/GJ Steam	$7.500 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	15 Operation Staff	$1.410 Million/y
Annual Maintenance Expense	2.5% CAPEX	$3.475 Million/y
Total Operating Cost (Direct Cost of Steam Production)		$798.779 Million/y
Specific Cost (Internal Price of Steam)	**$ 53.20 per GJ Steam**	**$ 199.69 per tonne HRC**
Specific Cost (Internal Price of Steam)	**$ 147.56 per tonne Steam**	

Product ID	Carbon Dioxide	
Annual Production (Year 4 - 25)	4,972,525 t/y	1,243.13 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)		
Electricity	607,401,683 kWh/y	$45.769 Million/y
Steam (9 Bar_a sat.)	15,066,752 GJ/y	$801.579 Million/y
Consumables & Other Utilities		
MEA (Make Up)	4,973 t/y	$8.379 Million/y
Raw Water	20,110,931 m^3/y	$2.283 Million/y
Other Variable O&M Cost		
Disposal Fee (MEA Sludge)	4,973 t/y	$3.153 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	22 Operation Staff	$2.068 Million/y
Annual Maintenance Expense	2.5% CAPEX	$16.963 Million/y
Total Operating Cost (Direct Cost of CO2 Capture & Compression)		$880.193 Million/y
Specific Cost (Internal Price of CO2 Capture)	**$ 177.01 per tonne CO2 captured**	**$ 220.05 per tonne HRC**

Product ID	Hot Rolled Coil	
Annual Production (Year 4 - 25)	4,000,000 t/y	1,000.00 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)		
Slab	4,210,526 t/y	$1,679.835 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	10,526,316 Nm^3/y	$0.404 Million/y
Scrap (to Steelmaking)	168,421 t/y	($32.588) Million/y
Mill Scales (to Sinter)	59,387 t/y	($1.169) Million/y
Coke Oven Gas (Reheating Furnace)	5,894,737 GJ/y	$57.592 Million/y
Electricity (Reheating & Rolling Mills)	421,052,632 kWh/y	$31.727 Million/y
Consumables & Other Utilities		
Works and Back Up Rolls	1 Unit	$9.000 Million/y
Banding	1 Unit	$0.360 Million/y
Raw Water	8,000,000 m^3/y	$0.908 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	480 personnel	$45.157 Million/y
Annual Maintenance Expense	8.0% CAPEX	$36.000 Million/y
Misc. Works Expense		$7.747 Million/y
Other OPEX (incl. environmental cleanup)		$1.443 Million/y
Total Operating Cost (Direct Cost of Hot Rolled Coil Production)		$1,836.415 Million/y
Specific Cost (Internal Price of Hot Rolled Coil)	**$ 459.10 per tonne Hot Rolled Coil**	

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

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Annex III

TECHNO-ECONOMICS - COST BREAKDOWN (OPEX)

Integrated Steel Mill with Post-Combustion CO_2 Capture – EOP-L2 Case

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TATA STEEL

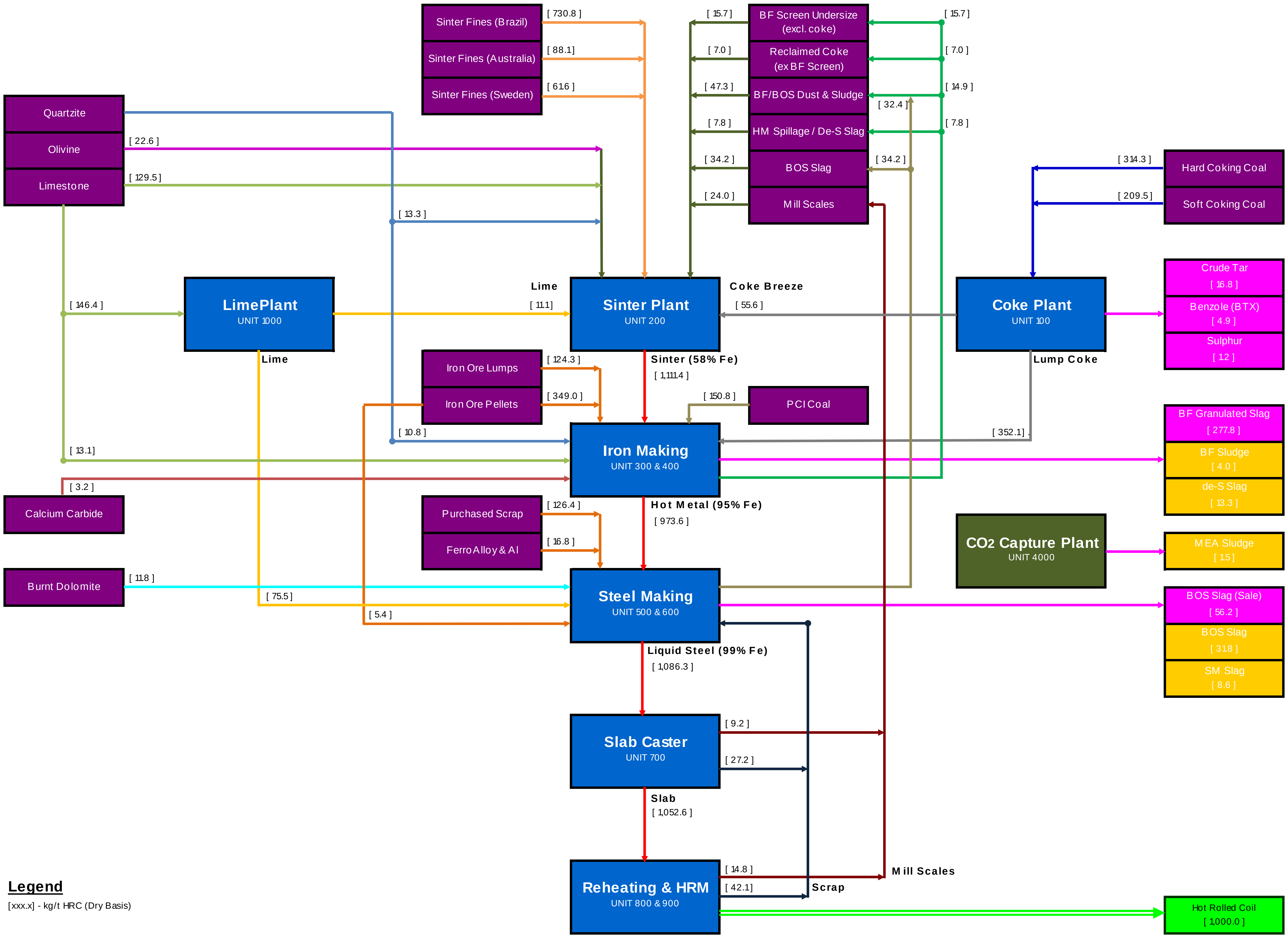
Flow Sheet (Materials)

Application of CO_2 Capture to an Integrated Steelworks

Steel Mill with Post-Combustion CO2 Capture (Case 2B) - EOP-L2

Production: 4,000,000 tonnes HRC/y

(YEAR 06)



TATA STEEL

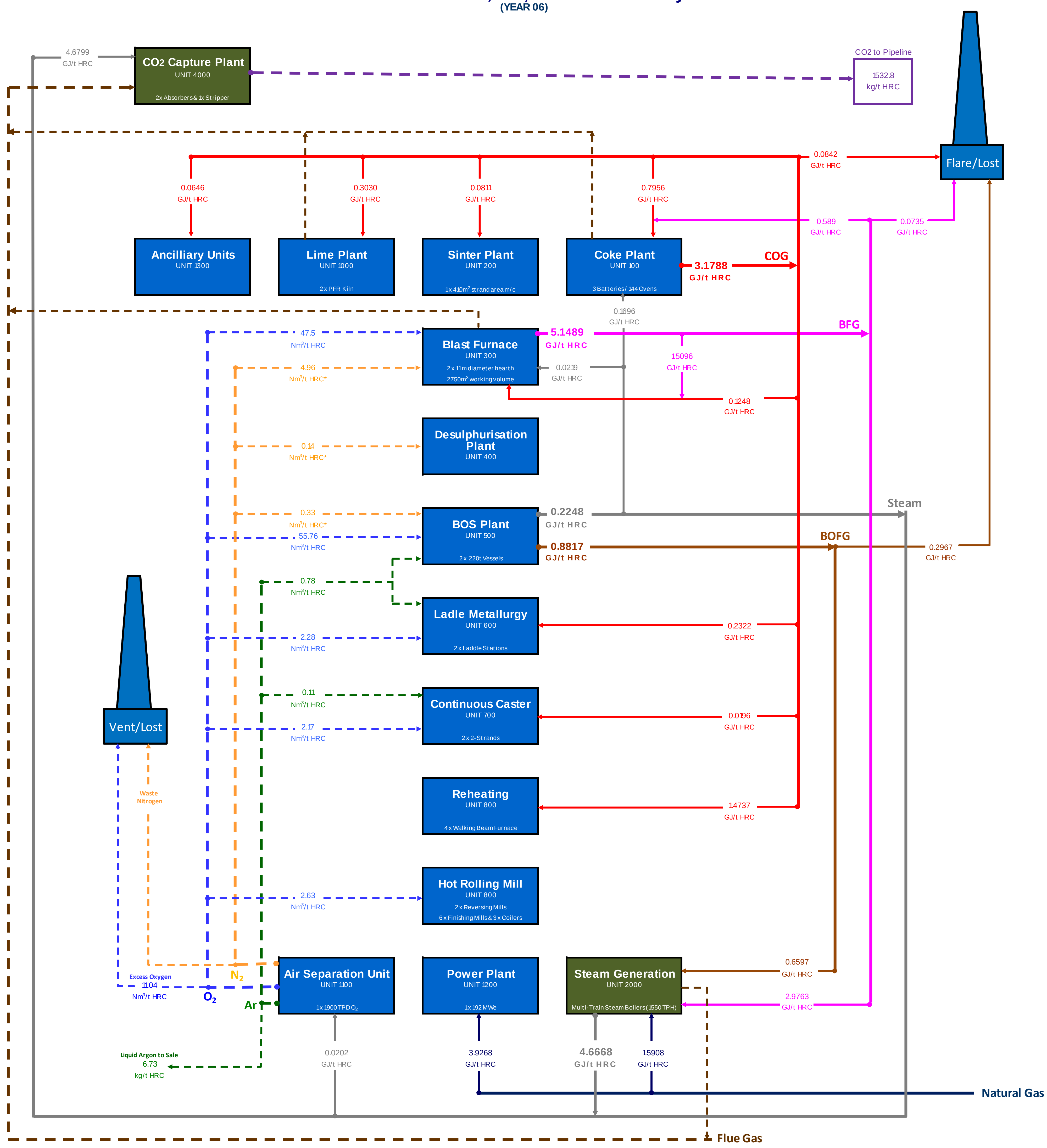
Flow Sheet (Steel Mill Gas Network)

Application of CO_2 Capture to an Integrated Steelworks

Steel Mill with Post-Combustion CO2 Capture (Case 2B) - EOP-L2

Production: 4,000,000 tonnes HRC/y

(YEAR 06)

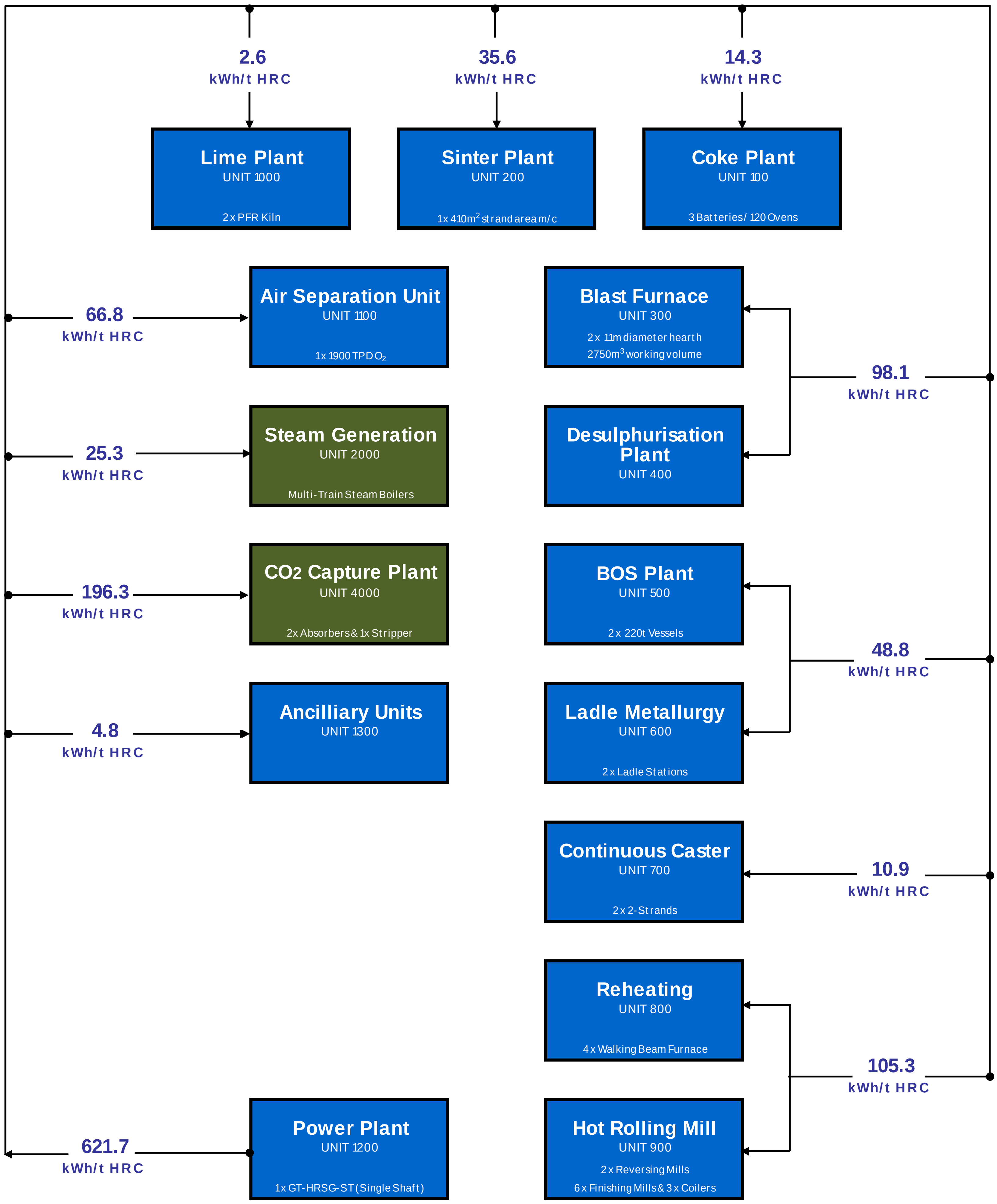


Flow Sheet (Electricity Network)

Application of CO_2 Capture to an Integrated Steelworks
Steel Mill with Post-Combustion CO2 Capture (Case 2B) - EOP-L2

Production: 4,000,000 tonnes HRC/y

(YEAR 06)



Product ID	Coke & Coke Breeze	
Annual Production (Year 4 - 25)	1,630,519 t/y	407.63 kg/t HRC
Cost Items	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Hard Coking Coal	1,257,292 t/y	$239.159 Million/y
Soft Coking Coal	838,194 t/y	$122.085 Million/y
Raw Materials & Energy (Internally Sourced)		
Coke Oven Gas (Export)	9,195,703 GJ/y	($89.842) Million/y
Blast Furnace Gas	2,357,936 GJ/y	$23.037 Million/y
Electricity	57,068,151 kWh/y	$4.315 Million/y
Steam	678,378 t/y	$26.241 Million/y
Consumables & Other Utilities		
Raw Water	2,931,317 m^3/y	$0.333 Million/y
Other Variable O&M Cost (Internally Sourced)		
CO_2 Capture and Compression Charge	688,946 t/y	$92.803 Million/y
By-Product Sales		
Coal Tar	67,080 t/y	($11.806) Million/y
Benzole	19,729 t/y	($9.197) Million/y
Sulphur	4,937 t/y	($0.420) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	240 Operation Staff	$22.560 Million/y
Annual Maintenance Expense	5.0% CAPEX	$20.000 Million/y
Misc. Works Expense		$9.801 Million/y
Misc. OPEX (incl. environmental cleanup)		$3.703 Million/y
Total Operating Cost (Direct Cost of Coke Production)		**$452.771 Million/y**
Specific Cost (Internal Price of Coke)	**$ 277.68 per tonne coke**	**$ 113.19 per tonne HRC**

Product ID	Sinter	
Annual Production (Year 4 - 25)	4,445,559 t/y	1,111.39 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Iron Ore Fines (Brazil)	2,923,276 t/y	$234.488 Million/y
Iron Ore Fines (Australia)	352,202 t/y	$29.149 Million/y
Iron Ore Fines (Sweden)	246,541 t/y	$20.945 Million/y
Limestone	517,872 t/y	$12.040 Million/y
Quartzite	53,347 t/y	$0.960 Million/y
Olivine	90,349 t/y	$1.536 Million/y
Raw Materials & Energy (Internally Sourced)		
Lime	44,456 t/y	$8.732 Million/y
BF Undersize (excl. Reclaimed Coke)	62,630 t/y	$1.879 Million/y
BF Dust	59,531 t/y	$1.786 Million/y
HM Spillage & de-S Slag	31,167 t/y	$0.935 Million/y
BOS Dust & Sludge	129,700 t/y	$3.891 Million/y
BOS Slag (LD Slag)	136,893 t/y	$4.107 Million/y
Mill Scales	96,159 t/y	$1.923 Million/y
Coke Breeze	222,278 t/y	$61.723 Million/y
Reclaimed Coke (ex BF Screens)	28,165 t/y	$0.845 Million/y
Coke Oven Gas	324,526 GJ/y	$3.171 Million/y
Electricity	142,257,877 kWh/y	$10.755 Million/y
Consumables & Other Utilities		
Raw Water	1,324,616 m^3/y	$0.150 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	270 Operation Staff	$25.380 Million/y
Annual Maintenance Expense	5.0% CAPEX	$11.000 Million/y
Misc. Works Expense		$3.206 Million/y
Misc. OPEX (incl. environmental cleanup)		$1.603 Million/y
Total Operating Cost (Direct Cost of Coke Production)		$440.204 Million/y
Specific Cost (Internal Price of Sinter)	**$ 99.02 per tonne sinter**	**$ 110.05 per tonne HRC**

Product ID	Hot Metal (Desulphurised)	
Annual Production (Year 4 - 25)	3,894,263 t/y	973.57 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
PCI Coal	603,251 t/y	$89.491 Million/y
Lump Ore (Australian)	497,139 t/y	$51.069 Million/y
Pellets (Brazil)	1,396,178 t/y	$154.026 Million/y
Limestone	52,497 t/y	$1.220 Million/y
Quartzite	43,129 t/y	$0.776 Million/y
Calcium Carbide Powder	12,710 t/y	$10.168 Million/y
Raw Materials & Energy (Internally Sourced)		
Sinter	4,445,559 t/y	$440.204 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	190,092,062 Nm^3/y	$6.821 Million/y
BF Undersize (excl. reclaimed coke)	62,630 t/y	($1.859) Million/y
BF Dust (Recycled)	59,531 t/y	($1.767) Million/y
HM Spillage & De-Slag (Recycled)	31,167 t/y	($0.925) Million/y
Lump Coke	1,408,241 t/y	$391.047 Million/y
Reclaimed Coke (ex BF Screens)	28,165 t/y	($0.836) Million/y
Coke Oven Gas (for Hot Stove)	499,108 GJ/y	$4.876 Million/y
Coke Oven Gas (for Ancillary Users)	258,427 GJ/y	$2.525 Million/y
Blast Furnace Gas (Export)	14,263,072 GJ/y	($139.350) Million/y
Electricity (Iron Making incl. HM Desulph.)	392,205,884 kWh/y	$29.652 Million/y
Electricity (Ancillary Users)	19,272,000 kWh/y	$1.457 Million/y
Steam	87,556 t/y	$3.387 Million/y
Consumables & Other Utilities		
Refractories (Torpedo car, HM Desulf, etc...)	5,063 t/y	$4.151 Million/y
Raw Water	3,483,639 m^3/y	$0.396 Million/y
Other Variable O&M Cost		
Slag Processing Fee (De-S Slag)	84,235 t/y	$0.496 Million/y
BF Sludge Disposal Fee	15,875 t/y	$0.318 Million/y
Slag Disposal Fee (De-S Slag)	53,068 t/y	$0.288 Million/y
Other Variable O&M Cost (Internally Sourced)		
CO_2 Capture and Compression Charge	1,494,462 t/y	$201.309 Million/y
By-Product Sales		
Granulated BF Slag	1,111,252 t/y	($17.780) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	321 Operation Staff	$30.174 Million/y
Annual Maintenance Expense	4.0% CAPEX	$24.880 Million/y
Misc. Works Expense		$10.403 Million/y
Misc. OPEX (incl. environmental cleanup)		$1.300 Million/y
Total Operating Cost (Direct Cost of Hot Metal Production)		$1,297.916 Million/y
Specific Cost (Internal Price of Hot Metal)	**$ 333.29 per tonne Hot Metal**	**$ 324.48 per tonne HRC**

Product ID	Liquid Steel	
Annual Production (Year 4 - 25)	4,345,228 t/y	1,086.31 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Pellets	21,544 t/y	$2.377 Million/y
Purchased Scrap	505,492 t/y	$115.252 Million/y
FeMnC	47,798 t/y	$67.068 Million/y
FeSi-75	13,036 t/y	$21.513 Million/y
DeOx Aluminium	6,518 t/y	$14.395 Million/y
Burnt Dolomite	47,164 t/y	$4.339 Million/y
Raw Materials & Energy (Internally Sourced)		
Hot Metal	3,894,263 t/y	$1,297.916 Million/y
Lime	301,956 t/y	$59.311 Million/y
Oxygen (Nm^3/y @ 273K)	232,185,679 Nm^3/y	$8.332 Million/y
Scrap (Internal)	320,285 t/y	$53.706 Million/y
LD Slag to Sinter Plant	136,893 t/y	($4.064) Million/y
LD Dust & Sludge	129,700 t/y	($3.851) Million/y
Coke Oven Gas (Ladle Metallurgy)	928,613 GJ/y	$9.073 Million/y
Basic Oxygen Furnace Gas (Export)	2,638,853 GJ/y	($25.782) Million/y
Electricity (Steel Making incl. Ladle Metallurgy)	195,097,244 kWh/y	$14.750 Million/y
Steam	899,361 t/y	($34.789) Million/y
Consumables & Other Utilities		
Refractories (BOS furnace, Ladle vessels)	15,208 t/y	$12.881 Million/y
Electrodes	1,304 t/y	$5.289 Million/y
Raw Water	1,673,679 m^3/y	$0.190 Million/y
Other Variable O&M Cost		
Slag Processing Fee (LD Slag)	488,920 t/y	$2.880 Million/y
Slag Processing Fee (Ladle Slag)	34,412 t/y	$0.203 Million/y
Disposal Fee (LD Slag)	127,124 t/y	$0.690 Million/y
Disposal Fee (Ladle Slag)	34,412 t/y	$3.040 Million/y
By-Product Sales		
LD Slag	224,903 t/y	($0.450) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	396 Operation Staff	$37.224 Million/y
Annual Maintenance Expense	5.0% CAPEX	$22.950 Million/y
Misc. Works Expense		$10.738 Million/y
Misc. OPEX (incl. environmental cleanup)		$2.844 Million/y
Total Operating Cost (Direct Cost of Liquid Steel Production)		$1,698.023 Million/y
Specific Cost (Internal Price of Liquid Steel)	**$ 390.78 per tonne Liquid Steel**	**$ 424.51 per tonne HRC**

Product ID	Slab	
Annual Production (Year 4 - 25)	4,210,526 t/y	1,052.63 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)		
Liquid Steel	4,345,228 t/y	$1,698.023 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	8,690,457 Nm^3/y	$0.312 Million/y
Scrap (to BOS furnace)	108,631 t/y	($21.019) Million/y
Scale (to Sinter)	36,772 t/y	($0.724) Million/y
Coke Oven Gas	78,437 GJ/y	$0.766 Million/y
Electricity	43,452,284 kWh/y	$3.285 Million/y
Consumables & Other Utilities		
Refractories (Casters)	8,842 t/y	$5.571 Million/y
Casting Powder	3,368,421 t/y	$2.257 Million/y
Raw Water	3,655,576 m^3/y	$0.415 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	360 Operation Staff	$33.840 Million/y
Annual Maintenance Expense	8.0% CAPEX	$15.636 Million/y
Misc. Works Expense		$5.905 Million/y
Misc. OPEX (incl. environmental cleanup)		$0.956 Million/y
Total Operating Cost (Direct Cost of Slab Production)		$1,745.224 Million/y
Specific Cost (Internal Price of Slab)	**$ 414.49 per tonne Slab**	**$ 436.31 per tonne HRC**

Product ID	Lime	
Annual Production (Year 4 - 25)	346,412 t/y	86.60 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Limestone	585,449 t/y	$13.611 Million/y
Raw Materials & Energy (Externally Sourced)		
Coke Oven Gas (Lime Kiln)	1,211,856 GJ/y	$11.840 Million/y
Electricity	10,392,357 kWh/y	$0.786 Million/y
Other Variable O&M Cost (Internally Sourced)		
CO_2 Capture and Compression Charge	257,844 t/y	$34.732 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	34 Operation Staff	$3.196 Million/y
Annual Maintenance Expense	8.0% CAPEX	$1.280 Million/y
Misc. Works Expense		$2.598 Million/y
Total Operating Cost (Direct Cost of Lime Production)		$68.043 Million/y
Specific Cost (Internal Price of Lime)	**$ 196.42 per tonne Lime**	**$ 17.01 per tonne HRC**

Product ID	Oxygen	
Annual Production (Year 4 - 25)	485,643,965 Nm3/y	121.41 Nm3/t HRC
Cost Components	Annual Consumption	Annual Cost (US $)
Raw Materials & Energy (Externally Sourced)		
Electricity	267,104,181 kWh/y	$20.194 Million/y
Steam	80,821 GJ/y	$3.126 Million/y
By-Product Sales		
Argon (Nm^3/y @ 273K and 1 Bar)	15,073,913 Nm^3/y	($14.018) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	35 Operation Staff	$3.290 Million/y
Annual Maintenance Expense	2.5% CAPEX	$3.250 Million/y
Total Operating Cost (Direct Cost of Oxygen Production)		$15.843 Million/y
Specific Cost	$ 0.03262 per Nm3 Oxygen	$ 3.96 per tonne HRC
Adjustment Factor	1.10000	
Adjusted Internal Price of Oxygen	$ 0.03588 per Nm3 Oxygen	

Product ID	Electricity	
Annual Production (Year 4 - 25)	2,486,979 MWh/y	621.74 MWh/t HRC
Cost Components	Annual Consumption	Annual Cost (US $)
Raw Materials & Energy (Externally Sourced)		
Natural Gas	15,707,234 GJ/y	$153.460 Million/y
Consumables & Other Utilities		
Chemicals and Consumables	3.440 $/MWh	$8.556 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	42 Operation Staff	$3.948 Million/y
Annual Maintenance Expense	5.0% CAPEX	$18.087 Million/y
Total Operating Cost (Direct Cost of Electricity Production)		$184.050 Million/y
Specific Cost (Internal Price of Electricity)	$ 0.0740 per kWh Electricity	$ 46.01 per tonne HRC
Adjustment Factor	1.02159	
Adjusted Internal Price of Oxygen	$ 0.0756 per kWh Electricity	

Product ID	Steam (9 Bar_a, Sat.)	
Annual Production (Year 4 - 25)	**18,667,135 GJ/y**	**4.67 GJ/t HRC**
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Natural Gas	6,363,123 GJ/y	$62.168 Million/y
Raw Materials & Energy (Internally Sourced)		
Blast Furnace Gas	11,905,137 GJ/y	$116.313 Million/y
Basic Oxygen Furnace Gas	2,638,853 GJ/y	$25.782 Million/y
Electricity	101,268,598 kWh/y	$7.656 Million/y
Other Variable O&M Cost (Internally Sourced)		
CO_2 Capture and Compression Charge	3,690,015 t/y	$497.058 Million/y
Consumables & Other Utilities		
Chemicals and Consumables	0.402 $/GJ Steam	$7.500 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	17 Operation Staff	$1.598 Million/y
Annual Maintenance Expense	2.5% CAPEX	$4.000 Million/y
Total Operating Cost (Direct Cost of Steam Production)		$722.075 Million/y
Specific Cost (Internal Price of Steam)	**$ 38.68 per GJ Steam**	**$ 180.52 per tonne HRC**
Specific Cost (Internal Price of Steam)	**$ 107.29 per tonne Steam**	

Product ID	Carbon Dioxide	
Annual Production (Year 4 - 25)	6,131,267 t/y	1,532.82 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)		
Electricity	785,250,547 kWh/y	$59.367 Million/y
Steam (9 Bar_a sat.)	18,719,740 GJ/y	$724.110 Million/y
Consumables & Other Utilities		
MEA (Make Up)	6,131 t/y	$10.331 Million/y
Raw Water	26,758,937 m^3/y	$3.038 Million/y
Other Variable O&M Cost		
Disposal Fee (MEA Sludge)	6,131 t/y	$3.887 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	24 Operation Staff	$2.256 Million/y
Annual Maintenance Expense	2.5% CAPEX	$22.914 Million/y
Total Operating Cost (Direct Cost of CO2 Capture & Compression)		$825.904 Million/y
Specific Cost (Internal Price of CO2 Capture)	**$ 134.70 per tonne CO2 captured**	**$ 206.48 per tonne HRC**

Product ID	Hot Rolled Coil	
Annual Production (Year 4 - 25)	4,000,000 t/y	1,000.00 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)		
Slab	4,210,526 t/y	$1,745.224 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	10,526,316 Nm^3/y	$0.378 Million/y
Scrap (to Steelmaking)	168,421 t/y	($32.588) Million/y
Mill Scales (to Sinter)	59,387 t/y	($1.169) Million/y
Coke Oven Gas (Reheating Furnace)	5,894,737 GJ/y	$57.592 Million/y
Electricity (Reheating & Rolling Mills)	421,052,632 kWh/y	$31.833 Million/y
Consumables & Other Utilities		
Works and Back Up Rolls	1 Unit	$9.000 Million/y
Banding	1 Unit	$0.360 Million/y
Raw Water	8,000,000 m^3/y	$0.908 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	480 personnel	$45.157 Million/y
Annual Maintenance Expense	8.0% CAPEX	$36.000 Million/y
Misc. Works Expense		$7.747 Million/y
Other OPEX (incl. environmental cleanup)		$1.443 Million/y
Total Operating Cost (Direct Cost of Hot Rolled Coil Production)		$1,901.884 Million/y
Specific Cost (Internal Price of Hot Rolled Coil)	$ 475.47 per tonne Hot Rolled Coil	

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

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Annex VII

Discounted Cash Flow for Each Major Processes

Integrated Steel Mill with Post-Combustion CO_2 Capture – EOP-L1 Case

INDEX

APPENDIX IV-A: ANNUAL CASH FLOW (COKE PRODUCTION)

COKE PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Coke	To: Blast Furnace	tonnes		704,120	1,056,180	1,267,417	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241
Coke Breeze	To: Sinter Plant	tonnes		111,139	166,708	200,050	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278
			Total	815,259	1,222,889	1,467,467	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Hard Coking Coal			$119,579	$179,369	$215,243	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159
Semi-soft Coking Coal			$61,042	$91,564	$109,876	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085
		Sub-Total	**$180,622**	**$270,933**	**$325,119**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**
Consummables and Other Utilities (US$ '000)																											
Raw Water			$166	$250	$300	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333
		Sub-Total	**$166**	**$250**	**$300**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Export)		($44,921)	($67,382)	($80,858)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)
Blast Furnace Gas	(for Oven Underfire Heating)		$11,519	$17,278	$20,733	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037
Electricity			$2,385	$3,343	$3,917	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300	$4,300
Steam			$19,741	$27,916	$32,821	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091	$36,091
		Sub-Total	**($11,277)**	**($18,845)**	**($23,386)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**	**($26,414)**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																											
By-Products (US$ '000)																											
Crude Tar			($5,903)	($8,854)	($10,625)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)
Benzole (BTX)			($4,599)	($6,898)	($8,278)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)
Sulphur			($210)	($315)	($378)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)
		Sub-Total	**($10,711)**	**($16,067)**	**($19,281)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$12,784	$17,672	$20,605	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560
Maintenance & Spares			$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
		Sub-Total	**$32,784**	**$37,672**	**$40,605**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$4,900	$7,351	$8,821	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801
Misc. Operational Expenses			$1,851	$2,777	$3,332	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703
		Sub-Total	**$6,752**	**$10,127**	**$12,153**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**	**$13,503**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
ANNUAL OPERATING COST (COKE PRODUCTION) - $'000	**$198,336**	**$284,069**	**$335,509**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**	**$369,803**

APPENDIX IV-B: ANNUAL CASH FLOW (SINTER PRODUCTION)

SINTER PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Sinter	To: Blast Furnace	Tonnes	2,222,779	3,334,169	4,001,003	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559
		Total	2,222,779	3,334,169	4,001,003	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559

	Period	14	15	16	17	18	19	20	21	22	23	24	25
Sinter	Tonnes	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559
	Total	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Raw Materials (US$ '000)															
Sinter Fines (Brazil)			$117,244	$175,866	$211,039	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488
Sinter Fines (Australia)			$14,575	$21,862	$26,234	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149
Sinter Fines (Sweden)			$10,473	$15,709	$18,851	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945
Limestone			$6,020	$9,030	$10,836	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040
Quartzite			$480	$720	$864	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960
Olivine			$768	$1,152	$1,382	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536
		Sub-Total	**$149,559**	**$224,338**	**$269,206**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**
Consummables and Other Utilities (US$ '000)															
Raw Water			$75	$113	$135	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150
		Sub-Total	**$75**	**$113**	**$135**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Coke Breeze	(ex Coke Plant)		$27,038	$38,725	$45,738	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413
Reclaimed Coke	(ex BF Screens)		$422	$634	$760	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845
Coke Oven Gas	(for Sinter Plant Ignition Fuel)		$1,585	$2,378	$2,854	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171
Electricity			$5,945	$8,332	$9,765	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719
		Sub-Total	**$34,991**	**$50,069**	**$59,116**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**
Raw Materials and Recycled Materials (US$ '000)															
Lime	(ex Lime Plant)		$2,249	$3,262	$3,869	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274
Screenings (excl. Coke)	(ex BF Screens)		$939	$1,409	$1,691	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879
BF Dust	(ex Blast Furnace)		$893	$1,339	$1,607	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786
HM Losses + Desulph. Slag	(ex HM Desulphurisation)		$468	$701	$842	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935
LD Slag	(ex BOF)		$2,053	$3,080	$3,696	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107
LD Dust & Sludge	(ex BOF)		$1,945	$2,918	$3,502	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891
Mill Scale	(ex Continuous Caster)		$368	$552	$662	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735
Mill Scale	(ex HRM)		$594	$891	$1,069	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188
		Sub-Total	**$9,509**	**$14,152**	**$16,938**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**
FIXED O&M COST & MISC. OPEX															
Fixed O&M (US$ '000)															
Labour			$14,335	$19,858	$23,171	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380
Maintenance & Spares			$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000
		Sub-Total	**$25,335**	**$30,858**	**$34,171**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**
Misc. O&M (US$ '000)															
Misc. Works Expenses			$1,603	$2,404	$2,885	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206
Misc. Operational Expenses			$801	$1,202	$1,443	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603
		Sub-Total	**$2,404**	**$3,606**	**$4,328**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**
ANNUAL OPERATING COST (SINTER PRODUCTION) - $'000			**$221,874**	**$323,137**	**$383,895**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**

	Period	14	15	16	17	18	19	20	21	22	23	24	25
Sinter Fines (Brazil)		$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488
Sinter Fines (Australia)		$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149
Sinter Fines (Sweden)		$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945
Limestone		$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040
Quartzite		$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960
Olivine		$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536
	Sub-Total	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**
Raw Water		$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150
	Sub-Total	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**
Coke Breeze		$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413	$50,413
Reclaimed Coke		$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845
Coke Oven Gas		$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171
Electricity		$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719	$10,719
	Sub-Total	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**	**$65,148**
Lime		$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274	$4,274
Screenings (excl. Coke)		$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879
BF Dust		$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786
HM Losses + Desulph. Slag		$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935
LD Slag		$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107
LD Dust & Sludge		$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891
Mill Scale (ex Continuous Caster)		$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735
Mill Scale (ex HRM)		$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188
	Sub-Total	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**	**$18,795**
Labour		$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380
Maintenance & Spares		$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000
	Sub-Total	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**
Misc. Works Expenses		$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206
Misc. Operational Expenses		$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603
	Sub-Total	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**
ANNUAL OPERATING COST (SINTER PRODUCTION) - $'000		**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**	**$424,400**

APPENDIX IV-C: ANNUAL CASH FLOW (HOT METAL PRODUCTION)

HOT METAL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Hot Metal	To: Steelmaking	Tonnes		1,947,131	2,920,697	3,504,836	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263
			Total	1,947,131	2,920,697	3,504,836	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coal (PCI)			$44,745	$67,118	$80,542	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491
		Sub-Total	**$44,745**	**$67,118**	**$80,542**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**
Raw Materials (US$ '000)																											
Lump Ore (Australia)			$25,534	$38,301	$45,962	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069
Pellets (Brazil)			$77,013	$115,520	$138,624	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026
Limestone			$610	$915	$1,098	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220
Quartzite			$388	$582	$699	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776
Calcium Carbide Powder			$5,084	$7,626	$9,151	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168
		Sub-Total	**$108,630**	**$162,944**	**$195,533**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**
Consummables and Other Utilities (US$ '000)																											
Refractories (excl. Blast Furnace)			$2,076	$3,113	$3,736	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151
Raw Water			$198	$297	$356	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396
		Sub-Total	**$2,273**	**$3,410**	**$4,092**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Lump Coke	(ex Coke Plant)		$171,298	$245,344	$289,772	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390	$319,390
Reclaimed Coke	(to Sinter Plant)		($418)	($627)	($753)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)
Coke Oven Gas	(for Hot Stove Heating)		$2,438	$3,657	$4,389	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876
Coke Oven Gas	(for Ancilliary Users)		$1,262	$1,894	$2,272	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525
Blast Furnace Gas	(for Export)		($69,675)	($104,513)	($125,415)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)
Electricity	(for Iron Making incl. HM Desulphurisation & Slag Granulation)		$16,391	$22,972	$26,921	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553	$29,553
Electricity	(for Ancilliary Users)		$805	$1,129	$1,323	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452
Steam			$2,548	$3,603	$4,236	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658	$4,658
		Sub-Total	**$124,649**	**$173,459**	**$202,745**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**	**$222,269**
Raw Materials and Recycled Materials (US$ '000)																											
Sinter	(ex Sinter Plant)		$221,874	$323,137	$383,895	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400	$424,400
Oxygen	(ex ASU)		$5,008	$6,152	$6,838	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295	$7,295
Screenings (excl. Coke)	(to Sinter Plant)		($930)	($1,395)	($1,674)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)
BF Dust	(to Sinter Plant)		($884)	($1,326)	($1,591)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)
HM Losses + Desulph. Slag	(to Sinter Plant)		($463)	($694)	($833)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)
		Sub-Total	**$224,606**	**$325,874**	**$386,635**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**	**$427,142**
Waste Processing and Disposal Cost																											
Waste Processing Fee (US$ '000)																											
Slag Processing Fee (De-S Slag)			$248	$372	$446	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496
BF Sludge Disposal Fee			$159	$238	$286	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318
De-S Slag Disposal Fee			$144	$216	$259	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288
		Sub-Total	**$551**	**$826**	**$991**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																											
By-Products (US$ '000)																											
Granulated BF Slag			($8,890)	($13,335)	($16,002)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)
		Sub-Total	**($8,890)**	**($13,335)**	**($16,002)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$17,155	$23,665	$27,570	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174
Maintenance & Spares			$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880
		Sub-Total	**$42,035**	**$48,545**	**$52,450**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$5,202	$7,803	$9,363	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403
Misc. Operational Expenses			$650	$975	$1,170	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300
CO2 Capture & Compression Expenses			$147,197	$205,867	$241,069	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537	$264,537
		Sub-Total	**$153,049**	**$214,645**	**$251,602**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**	**$276,240**
ANNUAL OPERATING COST (HOT METAL PRODUCTION) - $'000			**$691,648**	**$983,486**	**$1,158,589**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**	**$1,275,324**

APPENDIX IV-D: ANNUAL CASH FLOW (LIQUID STEEL PRODUCTION)

LIQUID STEEL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Liquid Steel	To: Casting	Tonnes	2,172,614	3,258,921	3,910,706	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228
		Total	2,172,614	3,258,921	3,910,706	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Raw Materials (US$ '000)																											
Pellets			$1,188	$1,783	$2,139	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377
Merchant Scrap (Rotterdam - Mixed)			$57,626	$86,439	$103,727	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252
FeMnC			$33,534	$50,301	$60,361	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068
FeSi75			$10,756	$16,134	$19,361	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513
Desox Al			$7,198	$10,796	$12,956	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395
Burnt Dolomite			$2,170	$3,254	$3,905	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339
		Sub-Total	**$112,472**	**$168,708**	**$202,450**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**
Consummables and Other Utilities (US$ '000)																											
Refractories (Steelmaking)			$6,441	$9,661	$11,593	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881
Electrodes (Ladle Metallurgy)			$2,644	$3,966	$4,760	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289
Raw Water			$95	$143	$171	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190
		Sub-Total	**$9,180**	**$13,770**	**$16,524**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Ladle Metallurgy)		$4,536	$6,804	$8,165	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073
Basic Oxygen Furnace Gas	(for Export)		($12,891)	($19,336)	($23,203)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)
Electricity	(for Steelmaking incl. Ladle Metallurgy)		$8,153	$11,427	$13,391	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701	$14,701
Steam	(for Export)		($26,172)	($37,010)	($43,512)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)	($47,848)
		Sub-Total	**($26,373)**	**($38,114)**	**($45,159)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**	**($49,856)**
Raw Materials and Recycled Materials (US$ '000)																											
Hotmetal	(ex Iron Making)		$691,648	$983,486	$1,158,589	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324	$1,275,324
Lime	(ex Lime Plant)		$15,276	$22,154	$26,282	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033	$29,033
Oxygen	(ex ASU)		$6,117	$7,514	$8,352	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910	$8,910
Scrap (Internal)	(ex Ladle Metallurgy, Caster, HRM)		$26,853	$40,280	$48,335	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706
LD Dust & Sludge	(to Sinter Plant)		($1,925)	($2,888)	($3,466)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)
LD Slag	(to Sinter Plant)		($2,032)	($3,048)	($3,658)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)
		Sub-Total	**$735,937**	**$1,047,497**	**$1,234,434**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**	**$1,359,058**
Waste Processing and Disposal Cost																											
Waste Processing Fee (US$ '000)																											
Slag Processing Fee (LD Slag)			$1,440	$2,160	$2,592	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880
Slag Processing Fee (Ladle Slag)			$101	$152	$182	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203
LD Slag Disposal Fee			$345	$517	$621	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690
Ladle Slag Disposal Fee			$1,520	$2,280	$2,736	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040
		Sub-Total	**$3,406**	**$5,109**	**$6,131**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																											
By-Products (US$ '000)																											
LD Slag			($225)	($337)	($405)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)
		Sub-Total	**($225)**	**($337)**	**($405)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$20,727	$28,976	$33,925	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224
Maintenance & Spares			$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950
		Sub-Total	**$43,677**	**$51,926**	**$56,875**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$5,369	$8,053	$9,664	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738
Misc. Operational Expenses			$1,422	$2,133	$2,560	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844
		Sub-Total	**$6,791**	**$10,186**	**$12,223**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**
ANNUAL OPERATING COST (LIQUID STEEL PRODUCTION) - $'000			**$884,864**	**$1,258,744**	**$1,483,072**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**	**$1,632,624**

APPENDIX IV-E: ANNUAL CASH FLOW (SLAB CASTING)

CONTINUOUS CASTING

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

Item		Unit	Period 1	2	3	4	5	6	7	8	9	10	11	12	13
Slab	To: Reheat Furnaces	Tonnes	0	0	0	2,105,263	3,157,895	3,789,474	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526
Total			0	0	0	2,105,263	3,157,895	3,789,474	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526

Item	Period 14	15	16	17	18	19	20	21	22	23	24	25
Slab	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526
Total	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526

EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS / INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS / FIXED O&M COST & MISC. OPEX

Item		Period 1	2	3	4	5	6	7	8	9	10	11	12
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Consummables and Other Utilities (US$ '000)													
Refractories (Casters)		$2,785	$4,178	$5,013	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571
Casting Powder		$1,128	$1,693	$2,031	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257
Raw Water		$208	$311	$374	$415	$415	$415	$415	$415	$415	$415	$415	$415
Sub-Total		**$4,121**	**$6,182**	**$7,418**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Coke Oven Gas	(for Tundish Heating etc...)	$383	$575	$690	$766	$766	$766	$766	$766	$766	$766	$766	$766
Electricity		$1,816	$2,545	$2,983	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274
Sub-Total		**$2,199**	**$3,120**	**$3,672**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**
Raw Materials and Recycled Materials (US$ '000)													
Liquid Steel	(ex Steelmaking)	$884,864	$1,258,744	$1,483,072	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624
Oxygen	(ex ASU)	$229	$281	$313	$333	$333	$333	$333	$333	$333	$333	$333	$333
Scrap (Internal)	(to BOS Furnace)	($10,509)	($15,764)	($18,917)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)
Mill Scales	(to Sinter Plant)	($362)	($543)	($652)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)
Sub-Total		**$874,222**	**$1,242,718**	**$1,463,816**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**
FIXED O&M COST & MISC. OPEX													
Fixed O&M (US$ '000)													
Labour		$19,646	$26,743	$31,001	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840
Maintenance & Spares		$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636
Sub-Total		**$35,282**	**$42,379**	**$46,637**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**
Misc. O&M (US$ '000)													
Misc. Works Expenses		$2,953	$4,429	$5,315	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905
Misc. Operational Expenses		$478	$717	$860	$956	$956	$956	$956	$956	$956	$956	$956	$956
Sub-Total		**$3,431**	**$5,146**	**$6,175**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**
ANNUAL OPERATING COST (CONTINUOUS CASTING) - $'000		**$919,255**	**$1,299,545**	**$1,527,719**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**

Item	Period 13	14	15	16	17	18	19	20	21	22	23	24	25
Refractories (Casters)	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571
Casting Powder	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257
Raw Water	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415
Sub-Total	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**
Coke Oven Gas	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766
Electricity	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274	$3,274
Sub-Total	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**	**$4,041**
Liquid Steel	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624	$1,632,624
Oxygen	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333
Scrap (Internal)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)
Mill Scales	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)
Sub-Total	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**	**$1,611,215**
Labour	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840
Maintenance & Spares	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636
Sub-Total	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**
Misc. Works Expenses	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905
Misc. Operational Expenses	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956
Sub-Total	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**
ANNUAL OPERATING COST (CONTINUOUS CASTING) - $'000	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**	**$1,679,835**

LIME PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lime	To: Steelmaking	Tonnes		150,978	226,467	271,761	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956
	To: Sinter Plant	Tonnes		22,228	33,342	40,010	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456
			Total	173,206	259,809	311,771	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Raw Materials (US$ '000)																											
Limestone			$6,805	$10,208	$12,250	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611
		Sub-Total	**$6,805**	**$10,208**	**$12,250**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Lime Kiln)		$5,920	$8,880	$10,656	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840
Electricity			$434	$609	$713	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783	$783
		Sub-Total	**$6,354**	**$9,489**	**$11,369**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**	**$12,623**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$1,299	$1,949	$2,338	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598
Maintenance & Spares			$1,786	$2,491	$2,914	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196
		Sub-Total	**$3,085**	**$4,440**	**$5,252**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280
		Sub-Total	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**
ANNUAL OPERATING COST (LIME PRODUCTION) - $'000			**$17,525**	**$25,416**	**$30,151**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**	**$33,308**

APPENDIX IV-G: ANNUAL CASH FLOW (AIR SEPARATION UNIT)

OXYGEN PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Oxygen	To: Blast Furnace	nm³		95,046,031	142,569,046	171,082,856	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062
	To: Steelmaking	nm³		116,092,839	174,139,259	208,967,111	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679
	To: Continuous Caster	nm³		4,345,228	6,517,843	7,821,411	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457
	To: HRM	nm³		5,263,158	7,894,737	9,473,684	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316
	Buffer Requirements	nm³		22,010,598	33,015,897	39,619,076	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196	44,021,196
			Total	242,757,854	364,136,782	436,964,138	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709	485,515,709

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																										
Energy and Reductants (US$ '000)																										
Electricity		$11,160	$15,640	$18,329	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121	$20,121
Steam		$2,351	$3,325	$3,909	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299	$4,299
	Sub-Total	**$13,511**	**$18,965**	**$22,238**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**	**$24,420**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																										
By-Products (US$ '000)																										
Liquid Argon		($7,009)	($10,513)	($12,616)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)
	Sub-Total	**($7,009)**	**($10,513)**	**($12,616)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**
FIXED O&M COST & MISC. OPEX																										
Fixed O&M (US$ '000)																										
Labour		$1,880	$2,585	$3,008	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290
Maintenance & Spares		$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250
	Sub-Total	**$5,130**	**$5,835**	**$6,258**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**
ANNUAL OPERATING COST (OXYGEN PRODUCTION) - $'000		**$11,632**	**$14,287**	**$15,880**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**	**$16,942**

ELECTRICITY PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12
Electricity	To: Coke Plant	MWh		28,534	42,801	51,361	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068
	To: Sinter Plant	MWh		71,129	106,693	128,032	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258
	To: Iron Making & Ancilliary	MWh		205,739	308,608	370,330	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478
	To: Steelmaking	MWh		97,549	146,323	175,588	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097
	To: Continuous Casting	MWh		21,726	32,589	39,107	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452
	To: Reheat Furnaces & HRM	MWh		210,526	315,789	378,947	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053
	To: Lime Plant	MWh		5,196	7,794	9,353	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392
	To: Oxygen Plant	MWh		133,517	200,275	240,330	267,034	267,034	267,034	267,034	267,034	267,034	267,034	267,034	267,034
	To: Steam Generation Plant	MWh		41,325	61,988	74,386	82,651	82,651	82,651	82,651	82,651	82,651	82,651	82,651	82,651
	To: CO2 Capture Plant	MWh		303,701	455,551	546,662	607,402	607,402	607,402	607,402	607,402	607,402	607,402	607,402	607,402
	To: Off-Sites & Losses	MWh		26,280	39,420	47,304	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560
			Total	1,145,222	1,717,833	2,061,400	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444

			Period	13	14	15	16	17	18	19	20	21	22	23	24	25
Electricity	To: Coke Plant	MWh		57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068
	To: Sinter Plant	MWh		142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258
	To: Iron Making & Ancilliary	MWh		411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478
	To: Steelmaking	MWh		195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097
	To: Continuous Casting	MWh		43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452
	To: Reheat Furnaces & HRM	MWh		421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053
	To: Lime Plant	MWh		10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392
	To: Oxygen Plant	MWh		267,034	267,034	267,034	267,034	267,034	267,034	267,034	267,034	267,034	267,034	267,034	267,034	267,034
	To: Steam Generation Plant	MWh		82,651	82,651	82,651	82,651	82,651	82,651	82,651	82,651	82,651	82,651	82,651	82,651	82,651
	To: CO2 Capture Plant	MWh		607,402	607,402	607,402	607,402	607,402	607,402	607,402	607,402	607,402	607,402	607,402	607,402	607,402
	To: Off-Sites & Losses	MWh		52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560
			Total	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444	2,290,444

EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS

FIXED O&M COST & MISC. OPEX

	Period	1	2	3	4	5	6	7	8	9	10	11	12
Energy and Reductants (US$ '000)													
Natural Gas		$71,166	$106,748	$128,098	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331
	Sub-Total	**$71,166**	**$106,748**	**$128,098**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**
Consummables and Other Utilities (US$ '000)													
Chemicals & Consummables		$3,940	$5,910	$7,092	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880
	Sub-Total	**$3,940**	**$5,910**	**$7,092**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**
Fixed O&M (US$ '000)													
Labour		$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948
Maintenance & Spares		$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469
	Sub-Total	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**
ANNUAL OPERATING COST (ELECTRICITY PRODUCTION) - $'000		**$93,523**	**$131,076**	**$153,607**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**

	Period	13	14	15	16	17	18	19	20	21	22	23	24	25
Energy and Reductants (US$ '000)														
Natural Gas		$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331	$142,331
	Sub-Total	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**	**$142,331**
Consummables and Other Utilities (US$ '000)														
Chemicals & Consummables		$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880
	Sub-Total	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**
Fixed O&M (US$ '000)														
Labour		$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948
Maintenance & Spares		$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469
	Sub-Total	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**
ANNUAL OPERATING COST (ELECTRICITY PRODUCTION) - $'000		**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**	**$168,628**

APPENDIX IV-I: ANNUAL CASH FLOW (STEAM GENERATION PLANT)

LOW PRESSURE STEAM PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Low Pressure Steam	To: CO2 Capture Plant	GJ		7,533,376	11,300,064	13,560,077	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752
	From: Steelmaking	GJ		26,313	39,470	47,364	52,627	52,627	52,627	52,627	52,627	52,627	52,627	52,627	52,627	52,627
			Total	7,507,063	11,260,594	13,512,713	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125

			Period	14	15	16	17	18	19	20	21	22	23	24	25
Low Pressure Steam	To: CO2 Capture Plant	GJ		15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752	15,066,752
	From: Steelmaking	GJ		52,627	52,627	52,627	52,627	52,627	52,627	52,627	52,627	52,627	52,627	52,627	52,627
			Total	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125	15,014,125

OPERATING COSTS

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Natural Gas		$11,208	$16,811	$20,174	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415
	Sub-Total	**$11,208**	**$16,811**	**$20,174**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**
Consummables and Other Utilities (US$ '000)														
Chemicals & Consummables		$3,750	$5,625	$6,750	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500
	Sub-Total	**$3,750**	**$5,625**	**$6,750**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Basic Oxygen Furnace Gas		$12,891	$19,336	$23,203	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782
Blast Furnace Gas		$58,157	$87,235	$104,682	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313
Electricity		$3,454	$4,841	$5,673	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228
	Sub-Total	**$74,501**	**$111,412**	**$133,558**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour		$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410
Maintenance & Spares		$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475
CO2 Capture & Compression Expenses		$342,572	$479,114	$561,039	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656
	Sub-Total	**$347,457**	**$483,999**	**$565,924**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**
ANNUAL OPERATING COST (LOW PRESSURE STEAM PRODUCTION) - $'000		**$436,916**	**$617,847**	**$726,406**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**

	Period	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Natural Gas		$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415	$22,415
	Sub-Total	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**	**$22,415**
Consummables and Other Utilities (US$ '000)													
Chemicals & Consummables		$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500
	Sub-Total	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Basic Oxygen Furnace Gas		$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782
Blast Furnace Gas		$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313
Electricity		$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228	$6,228
	Sub-Total	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**	**$148,323**
FIXED O&M COST & MISC. OPEX													
Fixed O&M (US$ '000)													
Labour		$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410	$1,410
Maintenance & Spares		$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475	$3,475
CO2 Capture & Compression Expenses		$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656	$615,656
	Sub-Total	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**	**$620,541**
ANNUAL OPERATING COST (LOW PRESSURE STEAM PRODUCTION) - $'000		**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**	**$798,779**

CO_2 CAPTURE & COMPRESSION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12
CARBON DIOXIDE	Ex: Hot Metal Production	tonnes		830,257	1,245,385	1,494,462	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514
	Ex: Steam Generation Plant	tonnes		1,932,257	2,898,386	3,478,063	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515
	Total Gas Processed	tonnes	*Total*	2,762,514	4,143,771	4,972,525	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028
	Total CO2 Captured	tonnes	*Total*	2,486,263	3,729,394	4,475,273	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525

			Period	13	14	15	16	17	18	19	20	21	22	23	24	25
CARBON DIOXIDE	Ex: Hot Metal Production	tonnes		1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514
	Ex: Steam Generation Plant	tonnes		3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515	3,864,515
	Total Gas Processed	tonnes	*Total*	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028	5,525,028
	Total CO2 Captured	tonnes	*Total*	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525	4,972,525

INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS

	Period	1	2	3	4	5	6	7	8	9	10	11	12
Energy and Reductants (US$ '000)													
Electricity		$25,384	$35,576	$41,692	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769
Steam		$438,447	$620,013	$728,952	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579
	Sub-Total	**$463,831**	**$655,589**	**$770,644**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**
Consummables and Other Utilities (US$ '000)													
MEA Solvent		$4,189	$6,284	$7,541	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379
Raw Water		$1,142	$1,713	$2,055	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283
	Sub-Total	**$5,331**	**$7,997**	**$9,596**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**
Waste Processing and Disposal Cost													
Waste Processing Fee (US$ '000)													
MEA Sludge Disposal Fee		$1,576	$2,364	$2,837	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153
	Sub-Total	**$1,576**	**$2,364**	**$2,837**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**
FIXED O&M COST & MISC. OPEX													
Fixed O&M (US$ '000)													
Labour		$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068
Maintenance & Spares		$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963
	Sub-Total	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**
ANNUAL OPERATING COST (CO2 CAPTURE & COMPRESSION) - $'000		**$489,769**	**$684,981**	**$802,108**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**

	Period	13	14	15	16	17	18	19	20	21	22	23	24	25
Energy and Reductants (US$ '000)														
Electricity		$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769	$45,769
Steam		$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579	$801,579
	Sub-Total	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**	**$847,347**
Consummables and Other Utilities (US$ '000)														
MEA Solvent		$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379	$8,379
Raw Water		$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283	$2,283
	Sub-Total	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**	**$10,662**
Waste Processing and Disposal Cost														
Waste Processing Fee (US$ '000)														
MEA Sludge Disposal Fee		$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153	$3,153
	Sub-Total	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**	**$3,153**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour		$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068	$2,068
Maintenance & Spares		$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963	$16,963
	Sub-Total	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**	**$19,031**
ANNUAL OPERATING COST (CO2 CAPTURE & COMPRESSION) - $'000		**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**	**$880,193**

APPENDIX IV-I: ANNUAL CASH FLOW (REHEATING AND HOT ROLLING MILLS)

HOT ROLLED COIL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L1 Case)

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
ANNUAL PRODUCTION:																
Hot Rolled Coil	To: Sales	Tonnes		2,000,000	3,000,000	3,600,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000
			Total	2,000,000	3,000,000	3,600,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000
			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																
Consummables and Other Utilities (US$ '000)																
Works Back Up Rolls	(for HSM)			$4,500	$6,750	$8,100	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000
Banding	(for Finish Products)			$180	$270	$324	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360
Raw Water				$454	$681	$817	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908
			Sub-Total	**$5,134**	**$7,701**	**$9,241**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																
Energy and Reductants (US$ '000)																
Coke Oven Gas	(for Reheating Furnace)			$28,796	$43,194	$51,832	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592
Electricity				$17,596	$24,662	$28,901	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727
			Sub-Total	**$46,392**	**$67,855**	**$80,733**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**
Raw Materials and Recycled Materials (US$ '000)																
Slab	(ex Continuous Casting)			$919,255	$1,299,545	$1,527,719	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835
Oxygen	(ex ASU)			$277	$341	$379	$404	$404	$404	$404	$404	$404	$404	$404	$404	$404
Scrap (Internal)	(to BOS Furnace)			($16,294)	($24,441)	($29,329)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)
Mill Scales	(to Sinter Plant)			($585)	($877)	($1,052)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)
			Sub-Total	**$902,654**	**$1,274,568**	**$1,497,716**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**
FIXED O&M COST & MISC. OPEX																
Fixed O&M (US$ '000)																
Labour				$25,539	$35,348	$41,233	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157
Maintenance & Spares				$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000
			Sub-Total	**$61,539**	**$71,348**	**$77,233**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**
Misc. O&M (US$ '000)																
Misc. Works Expenses				$3,874	$5,810	$6,973	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747
Misc. Operational Expenses				$721	$1,082	$1,298	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443
			Sub-Total	**$4,595**	**$6,892**	**$8,271**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**
ANNUAL OPERATING COST (HOT ROLLED COIL PRODUCTION) - $'000				**$1,020,314**	**$1,428,365**	**$1,673,195**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**

			Period	14	15	16	17	18	19	20	21	22	23	24	25
ANNUAL PRODUCTION:													
Hot Rolled Coil	To: Sales	Tonnes		4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000
			Total	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000
			Period	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Consummables and Other Utilities (US$ '000)															
Works Back Up Rolls	(for HSM)			$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000
Banding	(for Finish Products)			$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360
Raw Water				$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908
			Sub-Total	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Coke Oven Gas	(for Reheating Furnace)			$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592
Electricity				$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727	$31,727
			Sub-Total	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**	**$89,319**
Raw Materials and Recycled Materials (US$ '000)															
Slab	(ex Continuous Casting)			$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835	$1,679,835
Oxygen	(ex ASU)			$404	$404	$404	$404	$404	$404	$404	$404	$404	$404	$404	$404
Scrap (Internal)	(to BOS Furnace)			($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)
Mill Scales	(to Sinter Plant)			($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)
			Sub-Total	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**	**$1,646,482**
FIXED O&M COST & MISC. OPEX															
Fixed O&M (US$ '000)															
Labour				$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157
Maintenance & Spares				$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000
			Sub-Total	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**
Misc. O&M (US$ '000)															
Misc. Works Expenses				$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747
Misc. Operational Expenses				$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443
			Sub-Total	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**
ANNUAL OPERATING COST (HOT ROLLED COIL PRODUCTION) - $'000				**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**	**$1,836,416**

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

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Annex VIII

Discounted Cash Flow for Each Major Processes

Integrated Steel Mill with Post-Combustion CO_2 Capture – EOP-L2 Case

I N D E X

APPENDIX V-A: ANNUAL CASH FLOW (COKE PRODUCTION)

COKE PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Coke	To: Blast Furnace	tonnes		704,120	1,056,180	1,267,417	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241	1,408,241
Coke Breeze	To: Sinter Plant	tonnes		111,139	166,708	200,050	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278	222,278
			Total	815,259	1,222,889	1,467,467	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519	1,630,519

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Hard Coking Coal			$119,579	$179,369	$215,243	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159	$239,159
Semi-soft Coking Coal			$61,042	$91,564	$109,876	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085	$122,085
		Sub-Total	**$180,622**	**$270,933**	**$325,119**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**	**$361,244**
Consummables and Other Utilities (US$ '000)																											
Raw Water			$166	$250	$300	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333	$333
		Sub-Total	**$166**	**$250**	**$300**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**	**$333**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Export)		($44,921)	($67,382)	($80,858)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)	($89,842)
Blast Furnace Gas	(for Oven Underfire Heating)		$11,519	$17,278	$20,733	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037	$23,037
Electricity			$2,629	$3,685	$4,318	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741	$4,741
Steam			$14,882	$21,133	$24,885	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385	$27,385
		Sub-Total	**($15,892)**	**($25,286)**	**($30,921)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**	**($34,679)**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																											
By-Products (US$ '000)																											
Crude Tar			($5,903)	($8,854)	($10,625)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)	($11,806)
Benzole (BTX)			($4,599)	($6,898)	($8,278)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)	($9,197)
Sulphur			($210)	($315)	($378)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)	($420)
		Sub-Total	**($10,711)**	**($16,067)**	**($19,281)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**	**($21,423)**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$12,784	$17,672	$20,605	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560	$22,560
Maintenance & Spares			$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
		Sub-Total	**$32,784**	**$37,672**	**$40,605**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**	**$42,560**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$4,900	$7,351	$8,821	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801	$9,801
Misc. Operational Expenses			$1,851	$2,777	$3,332	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703	$3,703
CO2 Capture & Compression Expenses			$54,006	$75,509	$88,411	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012	$97,012
		Sub-Total	**$60,757**	**$85,636**	**$100,564**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**	**$110,515**
ANNUAL OPERATING COST (COKE PRODUCTION) - $'000			**$247,726**	**$353,138**	**$416,385**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**	**$458,550**

SINTER PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
ANNUAL PRODUCTION:																												
Sinter	To: Blast Furnace	Tonnes		2,222,779	3,334,169	4,001,003	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559
			Total	2,222,779	3,334,169	4,001,003	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559	4,445,559

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Raw Materials (US$ '000)																											
Sinter Fines (Brazil)			$117,244	$175,866	$211,039	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488	$234,488
Sinter Fines (Australia)			$14,575	$21,862	$26,234	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149	$29,149
Sinter Fines (Sweden)			$10,473	$15,709	$18,851	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945	$20,945
Limestone			$6,020	$9,030	$10,836	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040	$12,040
Quartzite			$480	$720	$864	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960	$960
Olivine			$768	$1,152	$1,382	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536
		Sub-Total	**$149,559**	**$224,338**	**$269,206**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**	**$299,118**
Consummables and Other Utilities (US$ '000)																											
Raw Water			$75	$113	$135	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150	$150
		Sub-Total	**$75**	**$113**	**$135**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Breeze	(ex Coke Plant)		$33,893	$48,324	$56,983	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756	$62,756
Reclaimed Coke	(ex BF Screens)		$422	$634	$760	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845	$845
Coke Oven Gas	(for Sinter Plant Ignition Fuel)		$1,585	$2,378	$2,854	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171	$3,171
Electricity			$6,553	$9,185	$10,765	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818	$11,818
		Sub-Total	**$42,454**	**$60,521**	**$71,362**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**	**$78,589**
Raw Materials and Recycled Materials (US$ '000)																											
Lime	(ex Lime Plant)		$4,885	$6,951	$8,191	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018	$9,018
Screenings (excl. Coke)	(ex BF Screens)		$939	$1,409	$1,691	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879	$1,879
BF Dust	(ex Blast Furnace)		$893	$1,339	$1,607	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786
HM Losses + Desulph. Slag	(ex HM Desulphurisation)		$468	$701	$842	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935
LD Slag	(ex BOF)		$2,053	$3,080	$3,696	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107	$4,107
LD Dust & Sludge	(ex BOF)		$1,945	$2,918	$3,502	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891
Mill Scale	(ex Continuous Caster)		$368	$552	$662	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735
Mill Scale	(ex HRM)		$594	$891	$1,069	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188
		Sub-Total	**$12,146**	**$17,842**	**$21,260**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**	**$23,538**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$14,335	$19,858	$23,171	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380
Maintenance & Spares			$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000
		Sub-Total	**$25,335**	**$30,858**	**$34,171**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$1,603	$2,404	$2,885	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206
Misc. Operational Expenses			$801	$1,202	$1,443	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603
		Sub-Total	**$2,404**	**$3,606**	**$4,328**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**
ANNUAL OPERATING COST (SINTER PRODUCTION) - $'000			**$231,973**	**$337,279**	**$400,462**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**	**$442,585**

APPENDIX V-C: ANNUAL CASH FLOW (HOT METAL PRODUCTION)

HOT METAL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Hot Metal	To: Steelmaking	Tonnes		1,947,131	2,920,697	3,504,836	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263
			Total	1,947,131	2,920,697	3,504,836	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263	3,894,263

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coal (PCI)			$44,745	$67,118	$80,542	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491	$89,491
		Sub-Total	**$44,745**	**$67,118**	**$80,542**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**	**$89,491**
Raw Materials (US$ '000)																											
Lump Ore (Australia)			$25,534	$38,301	$45,962	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069	$51,069
Pellets (Brazil)			$77,013	$115,520	$138,624	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026	$154,026
Limestone			$610	$915	$1,098	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220	$1,220
Quartzite			$388	$582	$699	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776	$776
Calcium Carbide Powder			$5,084	$7,626	$9,151	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168	$10,168
		Sub-Total	**$108,630**	**$162,944**	**$195,533**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**	**$217,259**
Consummables and Other Utilities (US$ '000)																											
Refractories (excl. Blast Furnace)			$2,076	$3,113	$3,736	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151
Raw Water			$198	$297	$356	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396	$396
		Sub-Total	**$2,273**	**$3,410**	**$4,092**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**	**$4,547**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Lump Coke	(ex Coke Plant)		$214,730	$306,159	$361,017	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589	$397,589
Reclaimed Coke	(to Sinter Plant)		($418)	($627)	($753)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)	($836)
Coke Oven Gas	(for Hot Stove Heating)		$2,438	$3,657	$4,389	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876	$4,876
Coke Oven Gas	(for Ancilliary Users)		$1,262	$1,894	$2,272	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525	$2,525
Blast Furnace Gas	(for Export)		($69,675)	($104,513)	($125,415)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)	($139,350)
Electricity	(for Iron Making incl. HM Desulphurisation & Slag Granulation)		$18,066	$25,324	$29,679	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582	$32,582
Electricity	(for Ancilliary Users)		$888	$1,244	$1,458	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601	$1,601
Steam			$1,921	$2,728	$3,212	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535	$3,535
		Sub-Total	**$169,212**	**$235,866**	**$275,859**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**	**$302,521**
Raw Materials and Recycled Materials (US$ '000)																											
Sinter	(ex Sinter Plant)		$243,550	$354,645	$421,302	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740	$465,740
Oxygen	(ex ASU)		$5,252	$6,495	$7,242	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739	$7,739
Screenings (excl. Coke)	(to Sinter Plant)		($930)	($1,395)	($1,674)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)	($1,859)
BF Dust	(to Sinter Plant)		($884)	($1,326)	($1,591)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)
HM Losses + Desulph. Slag	(to Sinter Plant)		($463)	($694)	($833)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)
		Sub-Total	**$246,526**	**$357,726**	**$424,446**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**	**$468,926**
Waste Processing and Disposal Cost																											
Waste Processing Fee (US$ '000)																											
Slag Processing Fee (De-S Slag)			$248	$372	$446	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496
BF Sludge Disposal Fee			$159	$238	$286	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318	$318
De-S Slag Disposal Fee			$144	$216	$259	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288
		Sub-Total	**$551**	**$826**	**$991**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																											
By-Products (US$ '000)																											
Granulated BF Slag			($8,890)	($13,335)	($16,002)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)	($17,780)
		Sub-Total	**($8,890)**	**($13,335)**	**($16,002)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**	**($17,780)**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$17,155	$23,665	$27,570	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174
Maintenance & Spares			$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880	$24,880
		Sub-Total	**$42,035**	**$48,545**	**$52,450**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**	**$55,054**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$5,202	$7,803	$9,363	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403
Misc. Operational Expenses			$650	$975	$1,170	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300
CO2 Capture & Compression Expenses			$117,149	$163,794	$191,780	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438	$210,438
		Sub-Total	**$123,001**	**$172,571**	**$202,314**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**	**$222,142**
ANNUAL OPERATING COST (HOT METAL PRODUCTION) - $'000			**$728,083**	**$1,035,672**	**$1,220,226**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**	**$1,343,262**

LIQUID STEEL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

ANNUAL PRODUCTION:

Item		Unit	Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Liquid Steel	To: Casting	Tonnes		2,172,614	3,258,921	3,910,706	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228
			Total	2,172,614	3,258,921	3,910,706	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228

EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS

Item		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Raw Materials (US$ '000)																											
Pellets			$1,188	$1,783	$2,139	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377	$2,377
Merchant Scrap (Rotterdam - Mixed)			$57,626	$86,439	$103,727	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252
FeMnC			$33,534	$50,301	$60,361	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068
FeSi75			$10,756	$16,134	$19,361	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513
Desox Al			$7,198	$10,796	$12,956	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395
Burnt Dolomite			$2,170	$3,254	$3,905	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339
		Sub-Total	**$112,472**	**$168,708**	**$202,450**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**	**$224,944**
Consummables and Other Utilities (US$ '000)																											
Refractories (Steelmaking)			$6,441	$9,661	$11,593	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881
Electrodes (Ladle Metallurgy)			$2,644	$3,966	$4,760	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289
Raw Water			$95	$143	$171	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190
		Sub-Total	**$9,180**	**$13,770**	**$16,524**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**

INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS

Item			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Ladle Metallurgy)		$4,536	$6,804	$8,165	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073
Basic Oxygen Furnace Gas	(for Export)		($12,891)	($19,336)	($23,203)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)	($25,782)
Electricity	(for Steelmaking incl. Ladle Metallurgy)		$8,987	$12,597	$14,763	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207	$16,207
Steam	(for Export)		($19,729)	($28,018)	($32,991)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)	($36,306)
		Sub-Total	**($19,097)**	**($27,953)**	**($33,266)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**	**($36,808)**
Raw Materials and Recycled Materials (US$ '000)																											
Hotmetal	(ex Iron Making)		$730,843	$1,039,813	$1,225,194	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782	$1,348,782
Lime	(ex Lime Plant)		$33,182	$47,216	$55,637	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251	$61,251
Oxygen	(ex ASU)		$6,415	$7,934	$8,845	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453	$9,453
Scrap (Internal)	(ex Ladle Metallurgy, Caster, HRM)		$26,853	$40,280	$48,335	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706
LD Dust & Sludge	(to Sinter Plant)		($1,925)	($2,888)	($3,466)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)
LD Slag	(to Sinter Plant)		($2,032)	($3,048)	($3,658)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)	($4,064)
		Sub-Total	**$793,336**	**$1,129,306**	**$1,330,888**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**	**$1,465,277**

Waste Processing and Disposal Cost

Item		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Waste Processing Fee (US$ '000)																										
Slag Processing Fee (LD Slag)		$1,440	$2,160	$2,592	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880	$2,880
Slag Processing Fee (Ladle Slag)		$101	$152	$182	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203
LD Slag Disposal Fee		$345	$517	$621	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690	$690
Ladle Slag Disposal Fee		$1,520	$2,280	$2,736	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040
	Sub-Total	**$3,406**	**$5,109**	**$6,131**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**	**$6,812**

EXTERNAL REVENUES - SALE OF BY-PRODUCTS

Item		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
By-Products (US$ '000)																										
LD Slag		($225)	($337)	($405)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)	($450)
	Sub-Total	**($225)**	**($337)**	**($405)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**	**($450)**

FIXED O&M COST & MISC. OPEX

Item		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Fixed O&M (US$ '000)																										
Labour		$20,727	$28,976	$33,925	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224
Maintenance & Spares		$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950
	Sub-Total	**$43,677**	**$51,926**	**$56,875**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**
Misc. O&M (US$ '000)																										
Misc. Works Expenses		$5,369	$8,053	$9,664	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738
Misc. Operational Expenses		$1,422	$2,133	$2,560	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844
	Sub-Total	**$6,791**	**$10,186**	**$12,223**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
ANNUAL OPERATING COST (LIQUID STEEL PRODUCTION) - $'000	**$949,539**	**$1,350,715**	**$1,591,420**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**	**$1,751,890**

APPENDIX V-E: ANNUAL CASH FLOW (SLAB CASTING)

CONTINUOUS CASTING

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Slab	To: Reheat Furnaces	Tonnes		0	0	0	2,105,263	3,157,895	3,789,474	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526
			Total	0	0	0	2,105,263	3,157,895	3,789,474	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526

			Period	14	15	16	17	18	19	20	21	22	23	24	25
Slab	To: Reheat Furnaces	Tonnes		4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526
			Total	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Consummables and Other Utilities (US$ '000)															
Refractories (Casters)			$2,785	$4,178	$5,013	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571
Casting Powder			$1,128	$1,693	$2,031	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257
Raw Water			$208	$311	$374	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415
		Sub-Total	**$4,121**	**$6,182**	**$7,418**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Coke Oven Gas	(for Tundish Heating etc...)		$383	$575	$690	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766
Electricity			$2,002	$2,806	$3,288	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610
		Sub-Total	**$2,385**	**$3,380**	**$3,978**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**
Raw Materials and Recycled Materials (US$ '000)															
Liquid Steel	(ex Steelmaking)		$951,580	$1,353,776	$1,595,094	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972
Oxygen	(ex ASU)		$240	$297	$331	$354	$354	$354	$354	$354	$354	$354	$354	$354	$354
Scrap (Internal)	(to BOS Furnace)		($10,509)	($15,764)	($18,917)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)
Mill Scales	(to Sinter Plant)		($362)	($543)	($652)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)
		Sub-Total	**$940,949**	**$1,337,766**	**$1,575,856**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**
FIXED O&M COST & MISC. OPEX															
Fixed O&M (US$ '000)															
Labour			$19,646	$26,743	$31,001	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840
Maintenance & Spares			$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636
		Sub-Total	**$35,282**	**$42,379**	**$46,637**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**
Misc. O&M (US$ '000)															
Misc. Works Expenses			$2,953	$4,429	$5,315	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905
Misc. Operational Expenses			$478	$717	$860	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956
		Sub-Total	**$3,431**	**$5,146**	**$6,175**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**
ANNUAL OPERATING COST (CONTINUOUS CASTING) - $'000			**$986,168**	**$1,394,853**	**$1,640,065**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**

		Period	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Consummables and Other Utilities (US$ '000)														
Refractories (Casters)			$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571
Casting Powder			$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257
Raw Water			$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415
		Sub-Total	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Coke Oven Gas	(for Tundish Heating etc...)		$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766
Electricity			$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610	$3,610
		Sub-Total	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**	**$4,376**
Raw Materials and Recycled Materials (US$ '000)														
Liquid Steel	(ex Steelmaking)		$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972	$1,755,972
Oxygen	(ex ASU)		$354	$354	$354	$354	$354	$354	$354	$354	$354	$354	$354	$354
Scrap (Internal)	(to BOS Furnace)		($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)
Mill Scales	(to Sinter Plant)		($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)
		Sub-Total	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**	**$1,734,583**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour			$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840
Maintenance & Spares			$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636
		Sub-Total	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**
Misc. O&M (US$ '000)														
Misc. Works Expenses			$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905
Misc. Operational Expenses			$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956
		Sub-Total	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**
ANNUAL OPERATING COST (CONTINUOUS CASTING) - $'000			**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**	**$1,803,539**

APPENDIX V-F: ANNUAL CASH FLOW (LIME PRODUCTION)

LIME PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lime	To: Steelmaking	Tonnes		150,978	226,467	271,761	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956
	To: Sinter Plant	Tonnes		22,228	33,342	40,010	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456	44,456
			Total	173,206	259,809	311,771	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412	346,412

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Raw Materials (US$ '000)																											
Limestone			$6,805	$10,208	$12,250	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611	$13,611
		Sub-Total	**$6,805**	**$10,208**	**$12,250**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**	**$13,611**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Lime Kiln)		$5,920	$8,880	$10,656	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840	$11,840
Electricity			$479	$671	$786	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863	$863
		Sub-Total	**$6,399**	**$9,551**	**$11,442**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**	**$12,703**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$1,299	$1,949	$2,338	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598	$2,598
Maintenance & Spares			$1,786	$2,491	$2,914	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196
		Sub-Total	**$3,085**	**$4,440**	**$5,252**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**	**$5,794**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280
CO2 Capture & Compression Expenses			$20,212	$28,260	$33,088	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307	$36,307
		Sub-Total	**$21,492**	**$29,540**	**$34,368**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**	**$37,587**
ANNUAL OPERATING COST (LIME PRODUCTION) - $'000			**$37,781**	**$53,738**	**$63,313**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**	**$69,695**

APPENDIX V-G: ANNUAL CASH FLOW (AIR SEPARATION UNIT)

OXYGEN PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Oxygen	To: Blast Furnace	nm³		95,046,031	142,569,046	171,082,856	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062
	To: Steelmaking	nm³		116,092,839	174,139,259	208,967,111	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679
	To: Continuous Caster	nm³		4,345,228	6,517,843	7,821,411	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457
	To: HRM	nm³		5,263,158	7,894,737	9,473,684	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316
	Buffer Requirements	nm³		22,074,726	33,112,088	39,734,506	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451
			Total	242,821,982	364,232,973	437,079,568	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965

			Period	14	15	16	17	18	19	20	21	22	23	24	25
Oxygen	To: Blast Furnace	nm³		190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062	190,092,062
	To: Steelmaking	nm³		232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679	232,185,679
	To: Continuous Caster	nm³		8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457
	To: HRM	nm³		10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316
	Buffer Requirements	nm³		44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451	44,149,451
			Total	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965	485,643,965

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Electricity		$12,303	$17,246	$20,212	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189
Steam		$1,773	$2,518	$2,965	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263
	Sub-Total	**$14,076**	**$19,764**	**$23,177**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS														
By-Products (US$ '000)														
Liquid Argon		($7,009)	($10,513)	($12,616)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)
	Sub-Total	**($7,009)**	**($10,513)**	**($12,616)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour		$1,880	$2,585	$3,008	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290
Maintenance & Spares		$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250
	Sub-Total	**$5,130**	**$5,835**	**$6,258**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**
ANNUAL OPERATING COST (OXYGEN PRODUCTION) - $'000		**$12,198**	**$15,086**	**$16,819**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**

	Period	14	15	16	17	18	19	20	21	22	23	24	25
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Electricity		$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189	$22,189
Steam		$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263	$3,263
	Sub-Total	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**	**$25,452**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS													
By-Products (US$ '000)													
Liquid Argon		($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)	($14,018)
	Sub-Total	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**	**($14,018)**
FIXED O&M COST & MISC. OPEX													
Fixed O&M (US$ '000)													
Labour		$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290
Maintenance & Spares		$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250	$3,250
	Sub-Total	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**	**$6,540**
ANNUAL OPERATING COST (OXYGEN PRODUCTION) - $'000		**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**	**$17,974**

APPENDIX V-H: ANNUAL CASH FLOW (POWER PLANT)

ELECTRICITY PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Electricity	To: Coke Plant	MWh		28,534	42,801	51,361	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068	57,068
	To: Sinter Plant	MWh		71,129	106,693	128,032	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258	142,258
	To: Iron Making & Ancilliary	MWh		205,739	308,608	370,330	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478	411,478
	To: Steelmaking	MWh		97,549	146,323	175,588	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097
	To: Continuous Casting	MWh		21,726	32,589	39,107	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452
	To: Reheat Furnaces & HRM	MWh		210,526	315,789	378,947	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053
	To: Lime Plant	MWh		5,196	7,794	9,353	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392	10,392
	To: Oxygen Plant	MWh		133,552	200,328	240,394	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104	267,104
	To: Steam Generation Plant	MWh		50,633	75,949	91,139	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266	101,266
	To: CO2 Capture Plant	MWh		392,625	588,938	706,725	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251	785,251
	To: Off-Sites & Losses	MWh		26,280	39,420	47,304	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560
			Total	1,243,489	1,865,234	2,238,281	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979	2,486,979

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																										
Energy and Reductants (US$ '000)																										
Natural Gas		$76,730	$115,095	$138,114	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460	$153,460
	Sub-Total	**$76,730**	**$115,095**	**$138,114**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**	**$153,460**
Consummables and Other Utilities (US$ '000)																										
Chemicals & Consummables		$4,278	$6,417	$7,700	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556	$8,556
	Sub-Total	**$4,278**	**$6,417**	**$7,700**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**	**$8,556**
FIXED O&M COST & MISC. OPEX																										
Fixed O&M (US$ '000)																										
Labour		$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948
Maintenance & Spares		$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087	$18,087
	Sub-Total	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**	**$22,035**
ANNUAL OPERATING COST (ELECTRICITY PRODUCTION) - $'000		**$103,042**	**$143,546**	**$167,849**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**	**$184,050**

APPENDIX V-I: ANNUAL CASH FLOW (STEAM GENERATION PLANT)

LOW PRESSURE STEAM PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12
Low Pressure Steam	To: CO2 Capture Plant	GJ		9,359,870	14,039,805	16,847,766	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740
	From: Steelmaking	GJ		26,303	39,454	47,345	52,606	52,606	52,606	52,606	52,606	52,606	52,606	52,606	52,606
			Total	9,333,567	14,000,351	16,800,421	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135

			Period	13	14	15	16	17	18	19	20	21	22	23	24	25
Low Pressure Steam	To: CO2 Capture Plant	GJ		18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740	18,719,740
	From: Steelmaking	GJ		52,606	52,606	52,606	52,606	52,606	52,606	52,606	52,606	52,606	52,606	52,606	52,606	52,606
			Total	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135	18,667,135

	Period	1	2	3	4	5	6	7	8	9	10	11	12
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Natural Gas		$31,084	$46,626	$55,951	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168
	Sub-Total	**$31,084**	**$46,626**	**$55,951**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**
Consummables and Other Utilities (US$ '000)													
Chemicals & Consummables		$3,750	$5,625	$6,750	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500
	Sub-Total	**$3,750**	**$5,625**	**$6,750**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Basic Oxygen Furnace Gas		$12,891	$19,336	$23,203	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782
Blast Furnace Gas		$58,157	$87,235	$104,682	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313
Electricity		$4,665	$6,538	$7,663	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412
	Sub-Total	**$75,712**	**$113,110**	**$135,548**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**
FIXED O&M COST & MISC. OPEX													
Fixed O&M (US$ '000)													
Labour		$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598
Maintenance & Spares		$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000
CO2 Capture & Compression Expenses		$289,256	$404,427	$473,530	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598
	Sub-Total	**$294,854**	**$410,025**	**$479,128**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**
ANNUAL OPERATING COST (LOW PRESSURE STEAM PRODUCTION) - $'000		**$405,400**	**$575,385**	**$677,377**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**

	Period	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Natural Gas		$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168	$62,168
	Sub-Total	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**	**$62,168**
Consummables and Other Utilities (US$ '000)														
Chemicals & Consummables		$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500
	Sub-Total	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**	**$7,500**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Basic Oxygen Furnace Gas		$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782	$25,782
Blast Furnace Gas		$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313	$116,313
Electricity		$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412	$8,412
	Sub-Total	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**	**$150,507**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour		$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598	$1,598
Maintenance & Spares		$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000
CO2 Capture & Compression Expenses		$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598	$519,598
	Sub-Total	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**	**$525,196**
ANNUAL OPERATING COST (LOW PRESSURE STEAM PRODUCTION) - $'000		**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**	**$745,371**

CO_2 CAPTURE & COMPRESSION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
CARBON DIOXIDE	Ex Coke Production	tonnes		382,748	574,122	688,946	765,495	765,495	765,495	765,495	765,495	765,495	765,495	765,495	765,495	765,495
	Ex: Hot Metal Production	tonnes		830,257	1,245,385	1,494,462	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514
	Ex Lime Production	tonnes		143,246	214,870	257,844	286,493	286,493	286,493	286,493	286,493	286,493	286,493	286,493	286,493	286,493
	Ex: Steam Generation Plant	tonnes		2,050,008	3,075,013	3,690,015	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017
	Total Gas Processed	tonnes	*Total*	3,406,259	5,109,389	6,131,267	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519
	Total CO2 Captured	tonnes	*Total*	3,065,633	4,598,450	5,518,140	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267

			Period	14	15	16	17	18	19	20	21	22	23	24	25
CARBON DIOXIDE	Ex Coke Production	tonnes		765,495	765,495	765,495	765,495	765,495	765,495	765,495	765,495	765,495	765,495	765,495	765,495
	Ex: Hot Metal Production	tonnes		1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514	1,660,514
	Ex Lime Production	tonnes		286,493	286,493	286,493	286,493	286,493	286,493	286,493	286,493	286,493	286,493	286,493	286,493
	Ex: Steam Generation Plant	tonnes		4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017	4,100,017
	Total Gas Processed	tonnes	*Total*	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519	6,812,519
	Total CO2 Captured	tonnes	*Total*	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267	6,131,267

INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Energy and Reductants (US$ '000)														
Electricity		$36,170	$50,702	$59,421	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233
Steam		$410,654	$583,175	$686,688	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696
	Sub-Total	**$446,825**	**$633,877**	**$746,108**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**
Consummables and Other Utilities (US$ '000)														
MEA Solvent		$5,166	$7,748	$9,298	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331
Raw Water		$1,519	$2,279	$2,734	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038
	Sub-Total	**$6,685**	**$10,027**	**$12,032**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**

	Period	14	15	16	17	18	19	20	21	22	23	24	25
Energy and Reductants (US$ '000)													
Electricity		$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233	$65,233
Steam		$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696	$755,696
	Sub-Total	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**	**$820,929**
Consummables and Other Utilities (US$ '000)													
MEA Solvent		$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331	$10,331
Raw Water		$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038	$3,038
	Sub-Total	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**	**$13,369**

Waste Processing and Disposal Cost

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Waste Processing Fee (US$ '000)														
MEA Sludge Disposal Fee		$1,944	$2,915	$3,499	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887
	Sub-Total	**$1,944**	**$2,915**	**$3,499**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**

	Period	14	15	16	17	18	19	20	21	22	23	24	25
Waste Processing Fee (US$ '000)													
MEA Sludge Disposal Fee		$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887	$3,887
	Sub-Total	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**	**$3,887**

FIXED O&M COST & MISC. OPEX

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Fixed O&M (US$ '000)														
Labour		$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256
Maintenance & Spares		$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914
	Sub-Total	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**
ANNUAL OPERATING COST (CO2 CAPTURE & COMPRESSION) - $'000		**$480,623**	**$671,989**	**$786,809**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**

	Period	14	15	16	17	18	19	20	21	22	23	24	25
Fixed O&M (US$ '000)													
Labour		$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256	$2,256
Maintenance & Spares		$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914	$22,914
	Sub-Total	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**	**$25,170**
ANNUAL OPERATING COST (CO2 CAPTURE & COMPRESSION) - $'000		**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**	**$863,356**

HOT ROLLED COIL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (EOP-L2 CASE)

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
ANNUAL PRODUCTION:																												
Hot Rolled Coil	To: Sales	Tonnes		2,000,000	3,000,000	3,600,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000
			Total	2,000,000	3,000,000	3,600,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Consummables and Other Utilities (US$ '000)																											
Works Back Up Rolls	(for HSM)		$4,500	$6,750	$8,100	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000
Banding	(for Finish Products)		$180	$270	$324	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360
Raw Water			$454	$681	$817	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908
		Sub-Total	**$5,134**	**$7,701**	**$9,241**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Reheating Furnace)		$28,796	$43,194	$51,832	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592
Electricity			$19,395	$27,186	$31,861	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978	$34,978
		Sub-Total	**$48,190**	**$70,380**	**$83,694**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**	**$92,570**
Raw Materials and Recycled Materials (US$ '000)																											
Slab	(ex Continuous Casting)		$986,199	$1,394,901	$1,640,122	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603	$1,803,603
Oxygen	(ex ASU)		$291	$360	$401	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429	$429
Scrap (Internal)	(to BOS Furnace)		($16,294)	($24,441)	($29,329)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)
Mill Scales	(to Sinter Plant)		($585)	($877)	($1,052)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)
		Sub-Total	**$969,612**	**$1,369,943**	**$1,610,142**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**	**$1,770,274**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$25,539	$35,348	$41,233	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157
Maintenance & Spares			$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000
		Sub-Total	**$61,539**	**$71,348**	**$77,233**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$3,874	$5,810	$6,973	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747
Misc. Operational Expenses			$721	$1,082	$1,298	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443
		Sub-Total	**$4,595**	**$6,892**	**$8,271**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**
ANNUAL OPERATING COST (HOT ROLLED COIL PRODUCTION) - $'000			**$1,089,071**	**$1,526,265**	**$1,788,581**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**	**$1,963,459**

Synthesis Report:

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

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Volume III: Estimating the Cost of Hot Rolled Coil Production from an Integrated Steel Mill with OBF and MDEA CO_2 Capture Technology

Project Partners:

Swedish Energy Agency   swerea | MEFOS   ieaghg

SSAB   LKAB

Project Management, Implementation and Delivery:

swerea | MEFOS   TATA STEEL   SINTEF

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- Swedish Energy Agency
- LKAB
- SSAB
- Members of Swerea MEFOS

The project is managed by a Steering Committee whose members represent the different project partners mentioned above. This committee is chaired by Nils Edberg of SSAB.

The main work was done by Swerea MEFOS team – providing the relevant mass and energy balance information required for the techno-economic evaluation. The project is supported by TATA Steel Consulting - developing the cost estimate model and SINTEF Materials and Chemistry evaluating the CO_2 capture plant model.

IEA Greenhouse Gas R&D Programme would like to acknowledge the work done by the project team members from the following organisations:

- Swerea MEFOS (lead organisation)
- Tata Steel Consulting
- Sintef Materials and Chemistry

Disclaimer:

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

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LIST OF ABBREVIATIONS

ASU	air separation unit (also known as oxygen plant)
BAT	best available technology
BF	blast furnace
BFG	blast furnace gas
BOF	basic oxygen furnace (also known LD or converter)
BOFG	basic oxygen furnace gas (also known as LDG or CG)
BOP	balance of plant
BOS	basic oxygen steelmaking
BREF	Best available technology reference document
BTX	benzene, toluene and xylene (also known as Benzole)
CAPEX	capital expenditure
CDQ	coke dry quenching
CG	converter gas (also known as BOFG or LDG)
COG	coke oven gas
De-S	desulphurised
dmtu	dry metric tonne unit
DRR	direct reduction rate
EAF	electric arc furnace
EBITDA	earnings before interest, tax, depreciation and amortisation
EOS	emission optimised sintering process
ESP	electrostatic precipitator
EU27	European Union (27 member countries)
FeMnC	ferromanganese carbide
FeSi75	ferromanganese silicon (at least 75% silica content)
GAN	gaseous nitrogen
GAR	gaseous argon
GBFS	granulated blast furnace slag
GGBFS	granulated ground blast furnace slag
GOX	gaseous oxygen
GTCC	gas turbine combined cycle
HM	hot metal (also known as pig iron)
HRC	hot rolled coil
HRM	hot rolling mill (also known as HSM)
HS	hot stove
HSM	hot strip mill
IEAGHG	IEA Greenhouse Gas R&D Programme
IPPC	integrated pollution prevention control
JCR	jumbo coke reactor (also known as SCS)
LAR	liquid argon
LDG	Lint-Donawitz gas (also known BOFG or CG)
LIN	liquid nitrogen
LM	ladle metallurgy
LOX	liquid oxygen
MAC	main air compressor
mtpy	million tonnes per year
NG	natural gas
NGCC	natural gas combined cycle
OBF	oxy-blast furnace (oxygen blown blast furnace)
OBF-PG	OBF processed gas

OBF-TG	OBF raw top gas
OHF	open hearth furnace
OPEX	operation expenditure
PCI	pulverized coal injection
PFD	process flow diagram
PFR kiln	parallel flow regenerative kiln
RAR	reducing agent rate
RHF	rotary hearth furnace
SCS	single chamber system (also known as JCR)
SCR	selective catalytic reactor (for NOx removal from flue gases)
SM	secondary metallurgy
SOACT	state of the art clean technology for steel production (REFERENCE Handbook)
tcs	tonne of crude steel
TGR	top gas recycle
thm	tonne of hot metal
tls	tonne of liquid steel
TRT	top gas recycle turbine
WBF	walking beam furnace

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<u>**Section A**</u>

Introduction and Study Objectives

<u>**I N D E X**</u>

1. INTRODUCTION

The Executive Committee of IEA Greenhouse Gas R&D Programme (IEA GHG) has requested a study to be made evaluating the potential for CO_2 capture to reduce greenhouse gas emissions from an integrated steel mill and its associated cost.

In collaboration with Swerea MEFOS AB, this project was developed with co-funding support from theSwedish Energy Agency, SSAB, LKAB and Swerea MEFOS member companies. The project was initiated in January 2010.

Swerea MEFOS AB has retained the service of Corus Consulting PLC (now TATA Steel Consulting) to undertake the cost evaluation and financial modelling; and also engaged SINTEF Materials and Chemistry to undertake the evaluation of post-combustion capture CO_2 modelling.

The primary goal of this project is to specify an integrated steel mill producing hot rolled coil and evaluate the cost and performance of the plant with and without CO_2 capture.

This document is a synthesis of the final report submitted by Swerea MEFOS [1] to IEA Greenhouse Gas R&D Programme (IEA GHG) evaluating the cost of steel production from an integrated steel mill equipped with an Oxy-Blast Furnace (OBF), Top Gas Recycle and CO_2 Capture.

2. OBJECTIVES OF THE STUDY

The project team was requested by the Steering Committee to specify and evaluate the cost and performance of an integrated steel mill producing 4 million tonnes of hot rolled coil per year. The "REFERENCE" integrated steel mill without CO_2 capture would be designed based on specifications typical to an average Western European Steel Mill.

Specifically, the study aims:

- To specify a conceptual "REFERENCE" steel mill typical to Western European configuration and evaluate the techno-economic performance of the integrated steel mill with and without CO_2 capture.

- To determine the techno-economic performance, CO_2 emissions and avoidance cost of the following cases:
    - A conceptual integrated steel mill typical to Western Europe as the "Base Case".
    - An end of pipe CO_2 capture using conventional MEA at two different levels of CO_2 capture rate
    - An Oxygen Blast Furnace (OBF) and using MDEA for CO_2 capture.

3. SCOPE OF THE REPORT

This report presents the techno-economic analysis of the cost of steel production of an Integrated Steel Mill with CO_2 capture based on the use of Oxy-Blast Furnaces with Top Gas Recycle and CO_2 Capture situated in Coastal Region of Western Europe producing 4 million tonnes of Hot Roll Coil

(HRC) per year. The CO_2 Capture process is based on chemical absorption technology using MDEA activated by Piperazine as solvent.

The scope of this report is to define the assumptions used in the techno-economic evaluation and present the main results of the study. These include description of:

- Plant Location
- Battery Limit
- Raw materials, product, by-products and waste
- Process description
- Material balance
- Process gas network
- CO_2 balance

This report presents and highlights the methodology of the Techno-Economic Evaluation, the key assumptions used to estimate CAPEX and OPEX and the key results of the study for Case 3 (i.e. Steel Mill with OBF and CO_2 Capture). It should be noted that it is no intention of this report to present the full engineering detail and design concept, as these are presented in the main report submitted by Swerea MEFOS [1].

4. NOTES TO THE READER

The intention of this study is to simulate the different techno-economic parameters of an average performing integrated steel mill. Therefore, it should be noted that the "REFERENCE" Steel Mill specified in this study is not necessarily to have the best performing steel mill that applies all the Best Available Technologies that are commercially available. Nonetheless, this will be based on a typical configuration that could be found in many European steel mills.

In choosing the technology for CO_2 capture, one of the selection criteria was based on the availability of performance and cost data that could be used for this assessment. In this regard, the choice of using MEA for Cases 2A and 2B, and MDEA/Pz for Case 3 as solvent to capture CO_2 are considered appropriate to demonstrate the cost of an integrated steel mill with CO_2 capture.

Additionally, it is not the objective of this study to optimise the integration of CO_2 capture plant into a steel mill as this could be very site specific. It should be emphasised that this study is focused on establishing a cost evaluation methodology to advance the understanding of the cost implications of deploying CO_2 capture in an integrated steel mill.

Finally, it is the intention of the authors to present every volumes of this report to be self containing. Therefore, all assumptions and the discussion of the background to them are presented in details in Volume 1. However, some of these discussions will be repeated within the text of Volumes 2 and 3 to ensure that these volumes could be read separately.

To summarise, Volume 1 of the report presents the design, assumptions, performance and economic details of a hypothetical steel mill which can be used as a basis to explore and comparing options for CO_2 emission reduction. Volume 2 of the report presents the analysis of a steel mill with conventional post-combustion capture options (i.e. capture of CO_2 from the different flue gases within the steel mill).   Volume 3 presents an option where further efficiency could be gained through the use of novel technology – i.e. using oxy-blast furnace with top gas recycle; that could improve the economics of the capture of CO_2 from an integrated steel mill.

5. REFERENCE

[1] Hooey, L., Boden, A., and Larsson, M. (2011). **"CO_2 Capture Applied to the Integrated Steelmaking".** *MEFOS Report – 560025*

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<u>Section B</u>

Design Basis, Assumptions and Nomenclature

<u>**I N D E X**</u>

1. BOUNDARY LIMIT

The definition of the boundary (battery) limit of the integrated steel mill is essential to formulate a clear account of the overall energy requirements and direct CO_2 emissions per tonne of steel produced (For this study – this should define the total CO_2 emitted per tonne of hot rolled coil).

A schematic representation of the boundary limit, material inputs and outgoing products, by-products and waste is illustrated in Figure B-1.

The steering committee agreed that the boundary limit should include the following unit processes:

- UNIT 100: Coke Plant
- UNIT 200: Sinter Plant
- UNIT 300: Blast Furnace and Hot Stoves (Iron Making Process)
- UNIT 400: Hot Metal Desulphurisation Plant
- UNIT 500: Basic Oxygen Steelmaking
- UNIT 600: Ladle Metallurgy
- UNIT 700: Continuous Casting
- UNIT 800: Reheating Furnace
- UNIT 900: Hot Rolling Mill
- UNIT 1000: Lime Plant
- UNIT 1100: Air Separation Unit – High Purity Oxygen Production
- UNIT 1200: Power Plant
- UNIT 1300: Ancillaries
- UNIT 2000: Steam Generation Plant
- UNIT 3000: Air Separation Unit – Low Purity Oxygen Production
- UNIT 4000: CO_2 Capture and Compression Plant

Raw material handling, utilities, waste water treatment plant and other auxiliary equipment are assumed to be included in each unit.

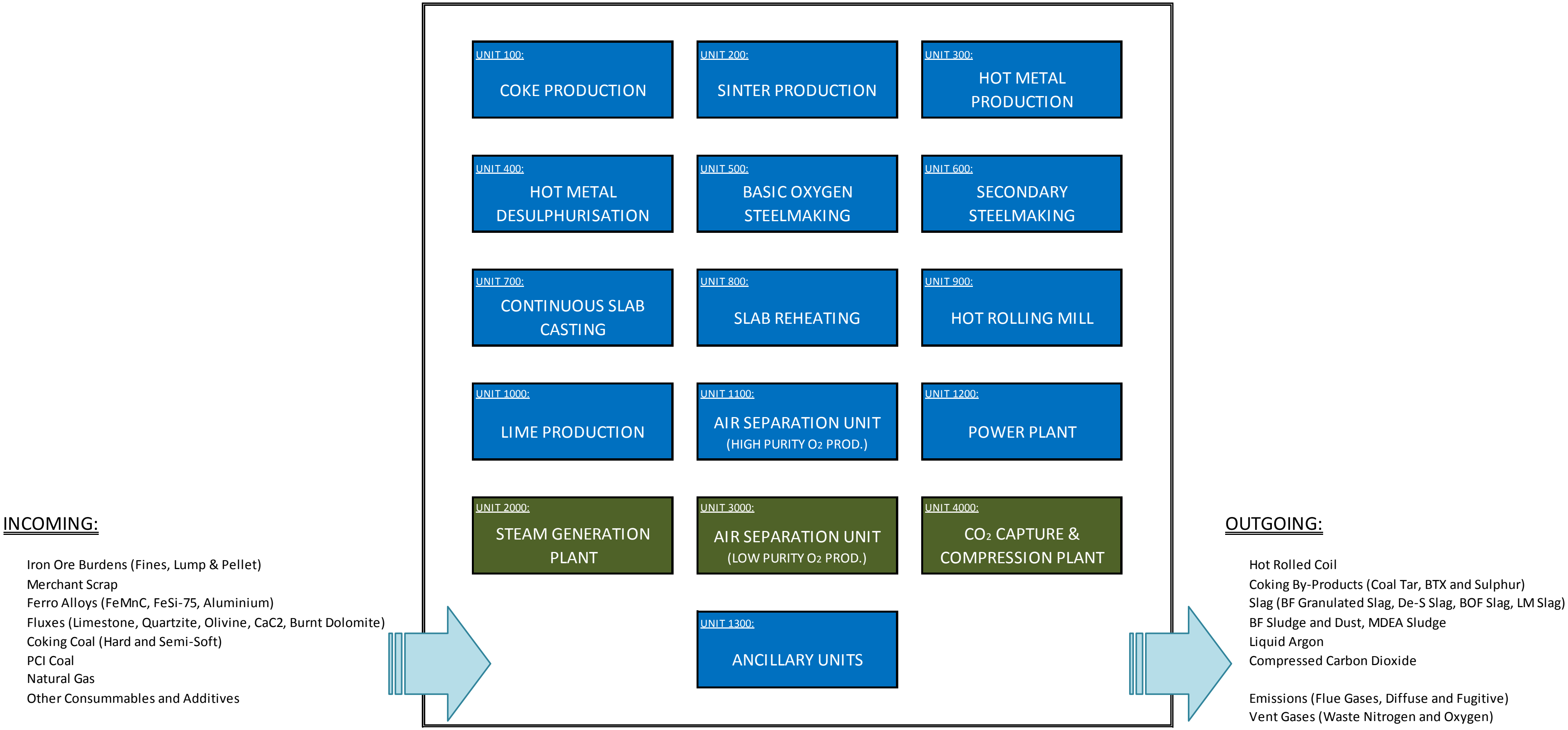

Figure B-1: Schematic representation of the Boundary Limit of the Steel Mill with OBF/MDEA CO_2 Capture. [1]

The major raw materials for the steel production considered in the study are:

- Iron Ore Fines
- Iron Ore Pellets
- Lump Iron Ore
- Coking Coal
- PCI Coal
- Fluxes (Limestone, Quartzite, Olivine, Calcium Carbide, Burnt Dolomite)
- External Scrap (also referred to Merchant or Purchased Scrap)
- Ferro Alloys and Aluminium
- Natural Gas
- Other consumables (as specified in Annex 2).

The product and by-products that are sold outside the boundary limit include:

- Hot Rolled Coil
- Crude Tar
- Benzole
- Sulphur
- Granulated BF Slag
- BOS Slag (also referred to LD Slag)
- Argon

The site will be handling several intermediate products used in the production of steel and these include:

- Coke
- Sinter
- Lime
- Hot Metal
- Liquid Steel
- Slab

Materials that are accounted as waste that goes to the landfill are:

- BF Sludge
- de-S Slag
- BOS Slag (also referred to LD Slag)
- LM Slag (also referred to SM Slag)
- MDEA Sludge

Industrial gases and off-gases handled by the site include:

- OBF Top Gas
- OBF Process Gas
- Basic Oxygen Furnace Gas
- Coke Oven Gas
- High Purity Oxygen (99.9%)
- Low Purity Oxygen (95.0%)
- Nitrogen
- Argon

Utilities that are available or produced within the boundary limit include:

- Steam
- Electricity
- Water (i.e. sea water, potable, machinery cooling water, condensates)

2. PLANT LOCATION AND LAYOUT

The steel mill is located along the Coastal Region of Western Europe. It should be noted that this location is a representative of several integrated steel mills close to the Atlantic Coast of Europe.

The site is assumed to have:

- access to an existing port capable of handling all incoming raw materials
- access to natural gas via a pipeline connected to the main grid
- access to an existing rail line adjacent to the steel mill

It is assumed that the steel mill is situated where there are no exceptional ground conditions that would lead to higher than normal construction costs. It is also assumed to be close to a deep sea, thus limiting the length of the sea water cooling line (both submarine and sea water pump discharge lines).

The site will have adequate road and rail networks for delivery of raw materials, intermediate and final products from stockyards to various points of the steel mill.

The site layout for the REFERENCE Steel Mill without CO_2 Capture and Steel Mill with OBF and MDEA CO_2 Capture is shown in Figures B-3(a) and B-3(b). It should be noted that these figures are not an accurate representation of a real steel mill and the purpose is only to illustrate the minimum land footprint required and to obtain high level estimates for the pipeline lengths needed for transporting CO_2 within the steel mill.

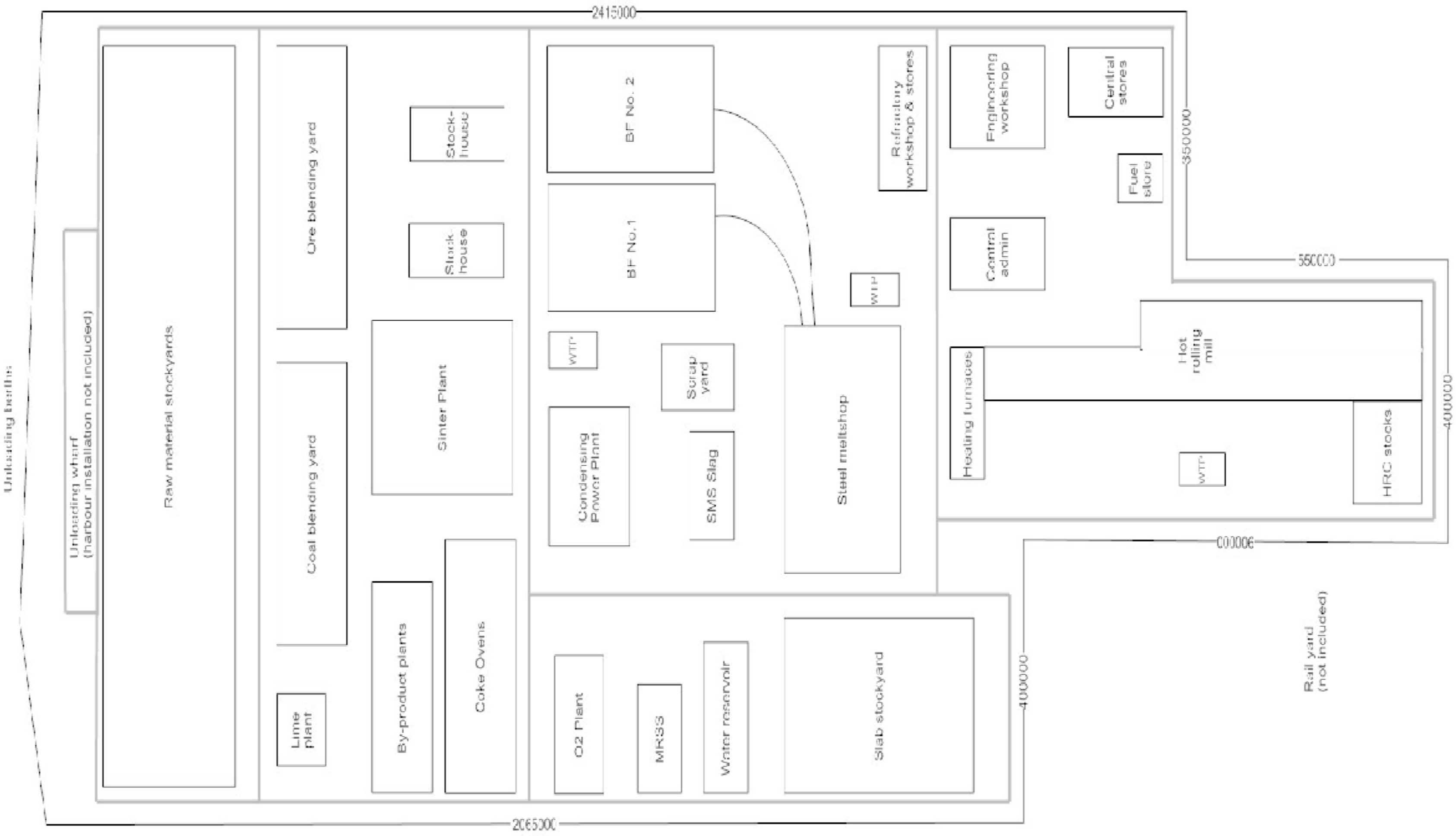

Figure B-2(a): Overview – Plant Layout of the REFERENCE Steel Mill

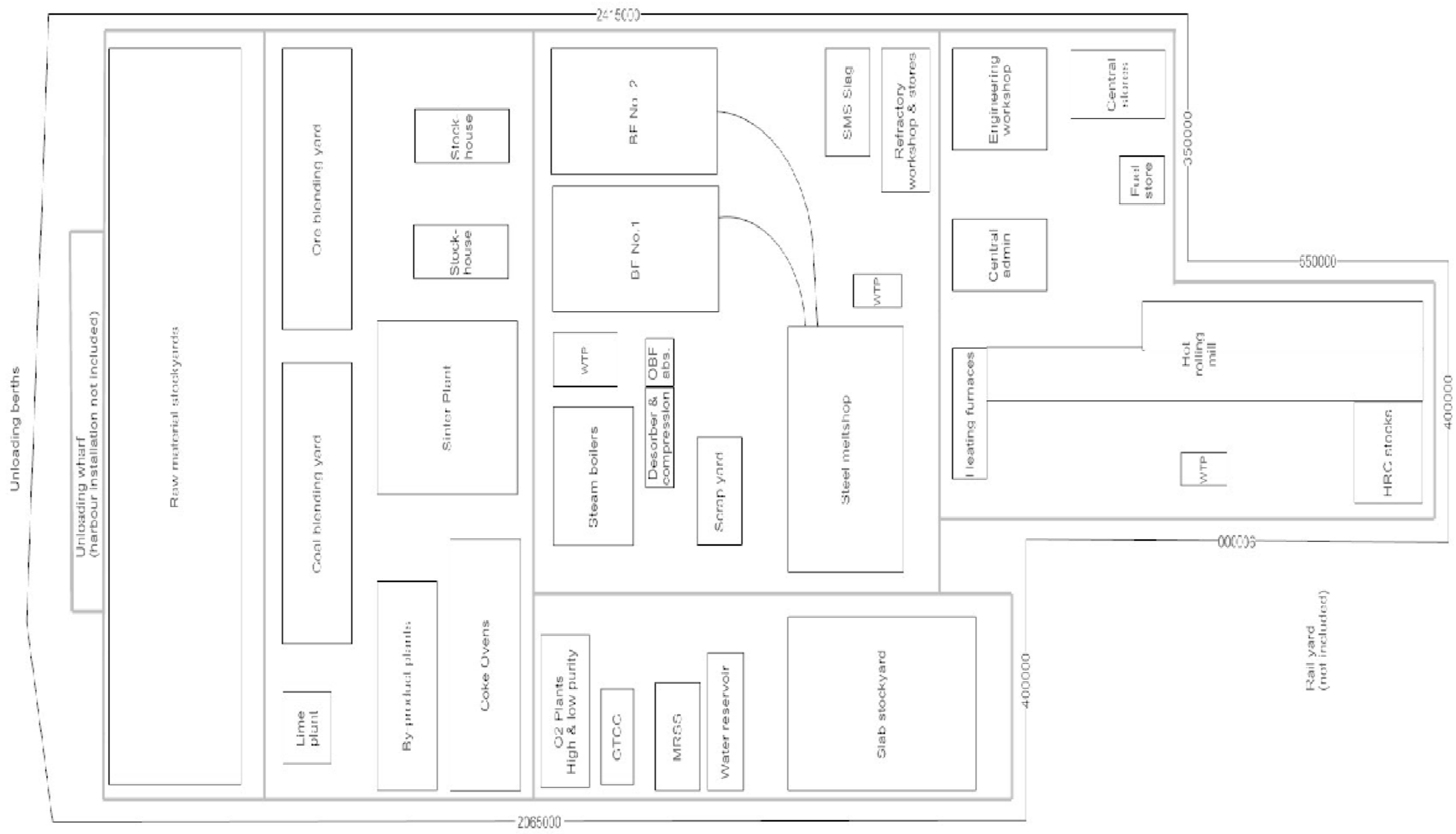

Figure B-2(b): Overview – Plant Layout of the Steel Mill with OBF and MDEA CO2 Capture

3. ASSUMPTIONS: STEEL MILL WITH OBF/MDEA CO_2 CAPTURE

The extra-ordinary assumptions used to evaluate the cost of the REFERENCE Steel Mill were also adopted for the evaluation of the cost of the integrated steel mill with OBF and MDEA CO_2 Capture. This section outlines these assumptions and is described in Volume I (Section B).

3.1. Extra-Ordinary Assumptions

Some assumptions which are classified as extra-ordinary were used to simplify the accounting of the CO_2 emissions, the energy demand, and the cost of steel produced. It should be noted that these assumptions are only used to provide a clear illustration and to establish a comparable cost basis between steel mills with and without CO_2 capture.

It should be emphasized that these assumptions are very idealized and not intended to represent any actual integrated steel mills in operation. These are only used simpliify the accounting of energy imports and exports and the CO_2 emissions associated with these.

The steering committee agreed to the following extra-ordinary assumptions to be used in the study:

a) Only one type of steel product produced and sold.

   It was assumed in the study that a standard grade hot rolled coil will be the only main product to be sold outside the defined boundary limit.

b) Balanced coke production

   The study assumed that coke plant (UNIT 100) will produce lump coke and coke breeze that are sufficient to the demand of the steel mill – i.e. there will be no export or import of coke.

c) Balanced electricity production

   The captive power plant is assumed to produce electricity that is only enough to supply the requirements of the whole steel mill as specified in the boundary limit. The study assumed that only natural gas imported into the boundary limit is the main energy input to the captive power plant. There will no import or export of electricity in and out of the defined boundary limit.

d) Plant ownership structure

   As one of the primary assumptions, there will be no import or export of electricity in or out of the defined boundary limit, this therefore restricted the study to have captive ownership of the power plant.

   The study also assumed captive ownership of the lime plant (UNIT 1000), HP oxygen plant (UNIT 1100), LP oxygen plant (UNIT 3000), and steam generation plant (UNIT 2000).

   In Volume 1, it was noted that it is unusual for the steel mill to have captive ownership of the oxygen plant. However, to maintain the like for like comparison between the

REFERENCE steel mill and Steel Mills with OBF and CO_2 capture, the same assumption of captive ownership has been made.

All other plants (i.e. lime and steam generation plant) mentioned above directly or indirectly use the off-gases of the steel mill as one of their primary energy sources. In order to simplify CO_2 emissions and cost evaluation; and at the same time maintained a like for like comparison, it was assumed that these plants should be also be included in the boundary limit and be owned by the steel mill.

e) Utilisation of the off-gases

The study assumed that all off-gas produced from the coke ovens (UNIT 100) and basic oxygen steel furnaces (UNIT 500) are recovered based on industry norm and used within the steel mill. For the oxy-blast furnace, the amount of OBF top gas recovered was estimated based on the best available data.

All the excess off-gases not used by the integrated steel mill are delivered to the captive steam generation plant as fuel (with the exception to the OBF Process Gas Fired Heaters – UNIT 300 – which uses natural gas to maintain a reliable operation of the process).

There will be no export of off-gases or other form of energy (i.e. steam or hot water) outside the boundary limit.

In case of any surplus off gas produced – this will be assumed to be flared. This should be in addition to flared off-gases which are normal to any operating steel mills. All off-gases that are considered lost or not recovered will also be accounted for as “flared”.

Any deficit to the off-gas will be supplemented by the natural gas imported across the boundary limit.

f) Other operating considerations

- CO_2 emissions due to purchased pellets, burnt dolomites and merchant scrap will not be accounted as direct CO_2 emissions of the steel mill.

- Granulated BF Slag will not be given CO_2 emission credit – even if this could be considered as substitute clinker for the cement industry.

3.2. Key Assumptions

Key technical assumptions used to define the boundary conditions in determining the heat and mass balance are summarized below.

a) The steel mill is assumed to have access to natural gas delivered via pipeline.

b) Iron Ore Burden

The iron ore burden composition for the oxy-blast furnace was fixed at the same level as the iron ore burden requirements for the blast furnace of the REFERENCE Steel Mill. This consisted of: (1.) Sinter ~70%w, (2.) Pellets ~22%w and (3.) Lump ore ~8%w. This distribution is maintained constant over the economic life of the integrated steel mill.

c) Coking Coal and Coke By-Products

The study assumed a By-Product Recovery Coking Plant with Coke Oven Gas, Crude Tar, Benzole and Sulphur as the only coking by-products produced by the Steel Mill. The product yield of the coking plant was fixed at the same level of product yield as the coking plant of the REFERENCE Steel Mill.

It was also assumed that 60%w hard coking coal and 40%w semi-soft coking coal were used. This distribution is maintained constant over the economic life of the integrated steel mill.

d) Key Iron-making Operating Parameters

The following parameters were fixed to determine the overall iron ore requirements, sinter rate and coke rate of the blast furnace.

- PCI Coal Injection rate was kept the same at ~150 kg/t HM as compared to the REFERENCE steel mill.
- Hot metal temperature was set at 1470^{o}C with hot metal Si and C content fixed at 0.5% and 4.7% respectively.

Similar to the REFERENCE Steel Mill, it was also assumed that hot metal loss of ~1.9%Fe at the HM Desulphurisation Plant (UNIT 400).

e) Key Steelmaking Operating Parameters

There will be no changes to the key operating parameters of the Steelmaking operation of the steel mill with OBF and MDEA CO_2 capture. For details, see Volume 1, Section C-3.2 of the report.

f) Fuel Gas Distribution

The compositions of off gases obtained from the coke ovens and basic oxygen furnaces were specified according to industry norms. The composition of the OBF Top Gas was defined based on the best available data obtained from the experience of LKAB and Swerea MEFOS when operating the experimental blast furnace in OBF mode. Furthermore, the distribution of the off-gases to the steel mill was kept constant over the 25 economic life assumed.

This study assumed the following utilisation of off-gases recovered for fuel:

- COG would supply fuel to the following:
  - coke plant (UNIT 100)
  - sinter plant (UNIT 200)
  - reheating furnace (UNIT 800)
  - lime plant (UNIT 1000)
  - ancillaries (UNIT 1300)
- OBF Process Gas delivered by the CO2 capture plant would be used by:
  - coke plant (UNIT 100)
  - oxy-blast furnace (UNIT 300), and
  - steam generation plant (UNIT 2000)
- BOFG would supply fuel to the steam generation plant (UNIT 2000).

4. DESIGN BASIS - SITE SPECIFIC CONDITIONS

The engineering design basis for this study is presented in Annex 1. These include the definition for the following:

(a.) Ambient Conditions
(b.) Raw Water and Seawater properties that are available to the site
(c.) Steam Conditions supplied to the site
(d.) Electricity Grid within the Steel Mill

5. MATERIAL SPECIFICATIONS – RAW MATERIALS, PRODUCTS, INTERMEDIATE PRODUCTS, BY-PRODUCTS AND WASTE

All the materials – as enumerated in Section B-1 - involved in the production of the hot rolled coil are described in Volume 1, Section C of this Report. The specifications of these materials are presented in Annex 2.

6. UNIT PROCESS NOMENCLATURE AND UNITS ARRANGEMENTS

With reference to the different PFD presented in this study, the list below presents the arrangements and nomenclatures used for each processes.

- Unit 100: Coke Production
  - 105: Coal Handling and Blending Facility
  - 110: Coke Oven Batteries
  - 120: Coke Quenching
  - 125: Coke Screening
  - 130: COG Cooling and Tar Separation
  - 131: Primary Gas Cooler
  - 132: Tar ESP
  - 133: Tar Recovery Unit and Tar Dehydrator
  - 140: Naphthalene Scrubber
  - 150: H_2S and NH_3 Scrubber
  - 155: H_2S and NH_3 Stripper
  - 160: Combine Claus Plant and NH_3 Cracker
  - 170: BTX Scrubber
  - 175: BTX Distillation
  - 180: Gas Exhauster and Gas Holder

- Unit 200: Sinter Production
  - 210: Raw Materials Handling and Blending Station
  - 220: Sinter Plant
  - 230: Gas Cleaning (from Sinter Strand) – Fabric Filter and ESP
  - 240: Sinter Crusher, Cooler and Screening
  - 250: Gas Cleaning (from Sinter Cooler) - ESP

- Unit 300: Hot Metal Production
  - 310: Raw Materials Handling, Blending and Feeding
  - 320: Blast Furnace
  - 330: BF Slag Granulation Plant

- 340: OBF Top Gas Cleaning - Cyclone and Scrubber
    - 350: OBF Process Gas Fired Heaters
    - 1310: PCI Coal Preparation (Coal Mill) and Drying – part of ancillary unit

- Unit 400: Hot Metal Desulphurisation
    - 410: Hot Metal Desulphurisation Station
    - 420: Slag & HM Spillage Processing Unit

- Unit 500: Primary Steelmaking
    - 510: Basic Oxygen Furnace
    - 520: Slag Processing Unit
    - 530: Gas Recovery Hood and Waste Heat Boiler
    - 540: BOF Gas Cleaning – Cyclone and Scrubber
    - 550: Gas Holder

- Unit 600: Secondary Steelmaking (Ladle Metallurgy)
    - 610: Ladle Station

- Unit 700: Continuous Casting
    - 710: Continuous Slab Caster

- Unit 800 & 900: Reheating and Rolling Mills
    - 810: Reheating Furnaces
    - 820: Recuperators
    - 910: Hot Rolling Mill

- Unit 1000: Lime Production
    - 1010: Lime Kiln
    - 1020: Gas Cleaning – ESP
    - 1030: Screening

- Unit 1100: Air Separation Unit – High Purity Oxygen Production
    - 1110: Main Air Compressor
    - 1120: Air Pre-Cooling and Treatment
    - 1130: Main Heat Exchanger and Cryogenic Separation Plant
    - 1140: Liquid Product Storage
    - 1150: Product Evaporation and Compression Plant

- Unit 1200: Captive Power Plant
    - 1210: Gas Turbine Island
    - 1220: Electricity Generator
    - 1230: Heat Recovery Steam Generator
    - 1240: Steam Turbine Island

- Unit 2000: Steam Generation Plant
    - 1110: Boiler Island
    - 1120: Steam Delivery Manifolds

- Unit 3000: Air Separation Unit – Low Purity Oxygen Production
    - 3010: Main Air Compressor
    - 3020: Air Pre-Cooling and Treatment

  - 3030: Main Heat Exchanger and Cryogenic Separation Plant
  - 3040: Product Evaporation and Compression Plant

- Unit 4000: CO_2 Capture and Compression Plant
  - 3010: OBF Process Gas Compressors
  - 3020: Direct Contact Coolers
  - 3030: Gas Holder
  - 3110: Absorber Column
  - 3120: Heat Integration and Exchange Networks
  - 3130: Flash Columns
  - 3140: Stripper Columns
  - 3200: CO_2 Compression Train

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Section C

Process Overview & Specifications

Integrated Steel Mill with OBF and MDEA CO_2 Capture

I N D E X

1. INTRODUCTION

The study assumed an integrated steel mill situated in the Coastal Region of the Western Europe producing 4 million tonnes of hot rolled coil per year. This steel works would be equipped with Oxy-Blast Furnace, Top Gas Recycle and MDEA based CO_2 capture Technology to reduce its greenhouse gas emissions.

The production of the hot rolled coil and incorporating OBF and CO_2 capture technology to the steel mill should consist of the following processes:

- Unit 100: Coke Production — based on 3 batteries of coke ovens
- Unit 200: Sinter Production — based on a single fixed bed sintering machine
- Unit 300: Hot Metal Production — based on 2 trains of oxy-blast furnaces
- Unit 400: Hot Metal Desulphurisation — based on 2 stations of HM desulphurisation
- Unit 500: Primary Steelmaking — based on 2 trains of basic oxygen furnaces
- Unit 600: Secondary Steelmaking — based on 2 stations of ladle metallurgy process
- Unit 700: Continuous Casting — based on 2 trains of double strand slab casters
- Unit 800: Slab Reheating — based on 2 furnaces per line of HSM
- Unit 900: Hot Rolling Mills — based on 2 lines of hot strip mills (HSM)
- Unit 1000: Lime Production — based on 2 trains of PFR lime kilns
- Unit 1100: HP Oxygen Production — based on 1 train of Air Separation Unit
- Unit 1200: Electricity Production — based on 1 captive power plant
- Unit 2000: Steam Production — based on 8 trains of packaged water tube boilers
- Unit 3000: LP Oxygen Production — based on 1 train of Air Separation Unit
- Unit 4000: CO_2 Capture Plant — based on 2 trains of absorbers & 1 stripper column
- Ancillaries, off-sites, utilities and balance of plant

This section of the report aims to describe the various changes made to the integrated steel mill equipped with OBF and MDEA CO_2 capture as compared to the REFERENCE Steel Mill without CO_2 capture. A brief background and overview to the Oxy-Blast Furnace Technology is also presented.

This report focuses on providing information on the changes made to the following unit processes:

- Coke Production
- Sinter Production
- Hot Metal Production
- ASU – High Purity Oxygen Production
- Captive Power Plant
- Steam Generation Plant
- ASU – Low Purity Oxygen Production
- CO_2 Capture and Compression Plant

Additionally, this section summarises the changes in the following

- Summary of Electricity and Steam Demand
- Summary of the Off-Gas Demand and Supply

Relevant information regarding the different process flow diagrams and mass balances of the 15 major processes connected to hot rolled coil production are presented in Annex 3.

2. OXY-BLAST FURNACE – AN OVERVIEW

The use of Oxy-Blast Furnace Technology is one of the leading technology options considered to provide significant reduction of CO_2 emissions from iron and steel production based on the blast furnace (BF) and basic oxygen furnace (BOF) route.

In the literature, Oxy-Blast Furnace is also known as “Nitrogen Free Blast Furnace” (NFBF), “Top Gas Recycle Blast Furnace” (TGR-BF) and this technology is also related to Hot Reducing Gas (HGR) Injection Technology.

Development of this technology started in the 1920’s with the primary aim of reducing fuel consumption. An overview of its development is presented in Figure C-1. A review of this technology is presented by van der Stahl [1], Carpenter [2] and Chu et. al. [3].

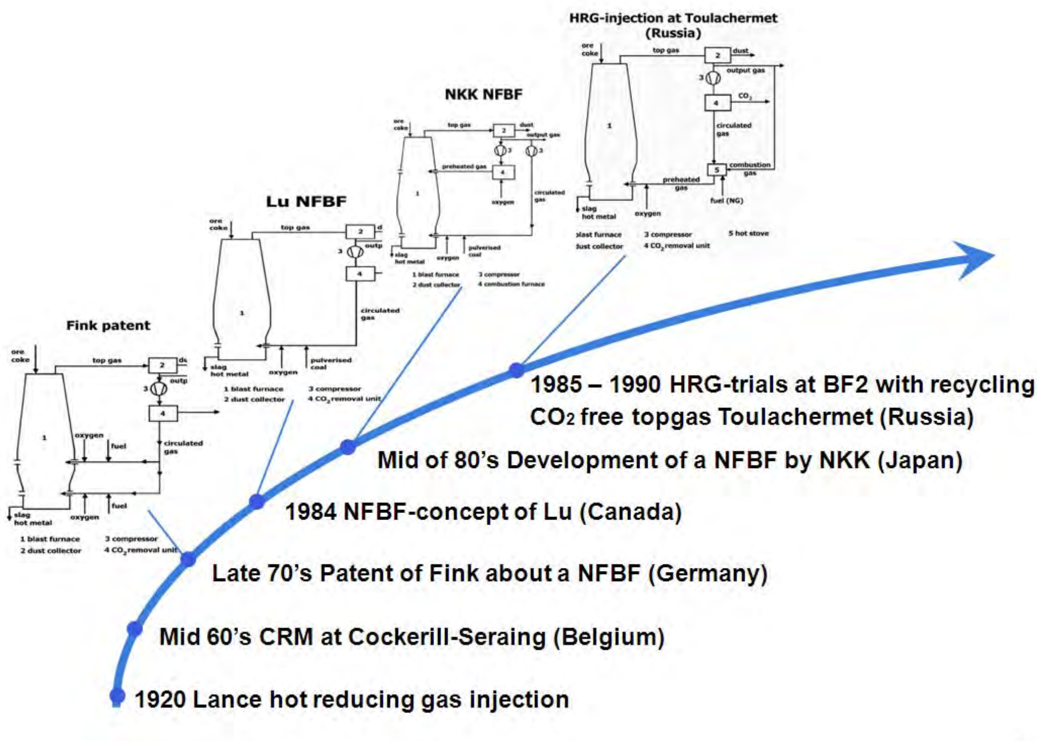

Figure C-1: Overview of the Development of Top Gas Recycle – BF Technology [1]

In the context of reducing greenhouse gas emissions, employing the oxy-blast furnace should provide several advantages for CO_2 capture. Some of these advantages are:

- Top gas with CO_2 removed when recycled to the blast furnace reduces the coke consumption of the hot metal production. This should also translate to lower CO_2 emissions at the coke production plant.
- A higher concentration of CO_2 in top gas and smaller volume of gas to be processed (as compared to flue gases) could be expected. This should lower the energy requirements of the CO_2 capture plant.
- Higher pressure of the OBF Top Gas (and higher partial pressure of CO_2) as compared to flue gases should make it feasible to use alternative solvent - MDEA activated with Piperazine. This is a well established solvent commonly used in natural gas processing industry with

lower regenerative energy requirements (being a tertiary amine) as compared to the standard MEA solvent (primary amine).

The increased concentration of CO_2 in the top gas is accomplished by removing air and replacing it with oxygen. This reduces the amount of nitrogen injected to the furnace thereby leading to higher concentrations of CO_2 in the OBF top gas. To be able to recycle back the top gas to the oxygen blown blast furnace without affecting its productivity, the CO_2 content of the OBF process gas should be reduced to below 3% which should prevent the cooling of the blast furnace heart's temperature. This is also a normal practice, for example, in HYL technologies (gas based DRIs with top gas recycle).

Under the Ultra Low CO_2 Steelmaking (ULCOS) Project led by the consortium of European Steel companies and allied industries, several options for capturing of CO_2 from the iron making process using OBF were evaluated. An overview of their work is summarized in Table C-1. Furthermore, the operation of the oxy-blast furnace comes with several process variants. Under the ULCOS project, 3 different operating versions were evaluated. These are presented in Figure C-2.

Table C-1: Comparison of CO_2 Capture Technologies for an Integrated Steel Mill (BF-BOF Route) ULCOS Project Evaluation Results [2, 4]

		PSA	VPSA	VPSA & Cryo Flash + Compression	Amines + Compression	PSA & Cryo Distil. + Compression
Recycled Top Gas (Process Gas)						
CO yield	%	88.0	90.4	97.3	99.9	100.0
Process Gas Composition						
CO_2	%v	2.7	3.0	3.0	2.9	2.7
CO	%v	71.4	69.2	68.9	67.8	69.5
H_2	%v	12.4	13.0	12.6	12.1	12.4
N_2	%v	13.5	15.7	15.6	15.1	15.4
H_2O	%v	0.0	0.0	0.0	2.1	0.0
Captured CO_2 Rich Gas						
CO_2	%v	79.7	87.2	96.3	100.0	100.0
CO	%v	12.1	10.7	3.3	0.0	0.0
H_2	%v	2.5	0.6	0.1	0.0	0.0
N_2	%v	5.6	1.6	0.3	0.0	0.0
Suitable for CO_2 Transport & Storage?		No	No	Yes (?)	Yes	Yes
Electricity Consumption						
Capture Process	kWh/t CO_2	100	105	292	170	310
CO_2 Compression (110 Bar_a)	kWh/t CO_2	100	105	160	55	195
LP Steam Consumption	GJ/t CO_2	0.0	0.0	0.0	3.2	0.0
Total Energy Consumption	GJ/t CO_2	0.36	0.38	1.05	3.81	1.12

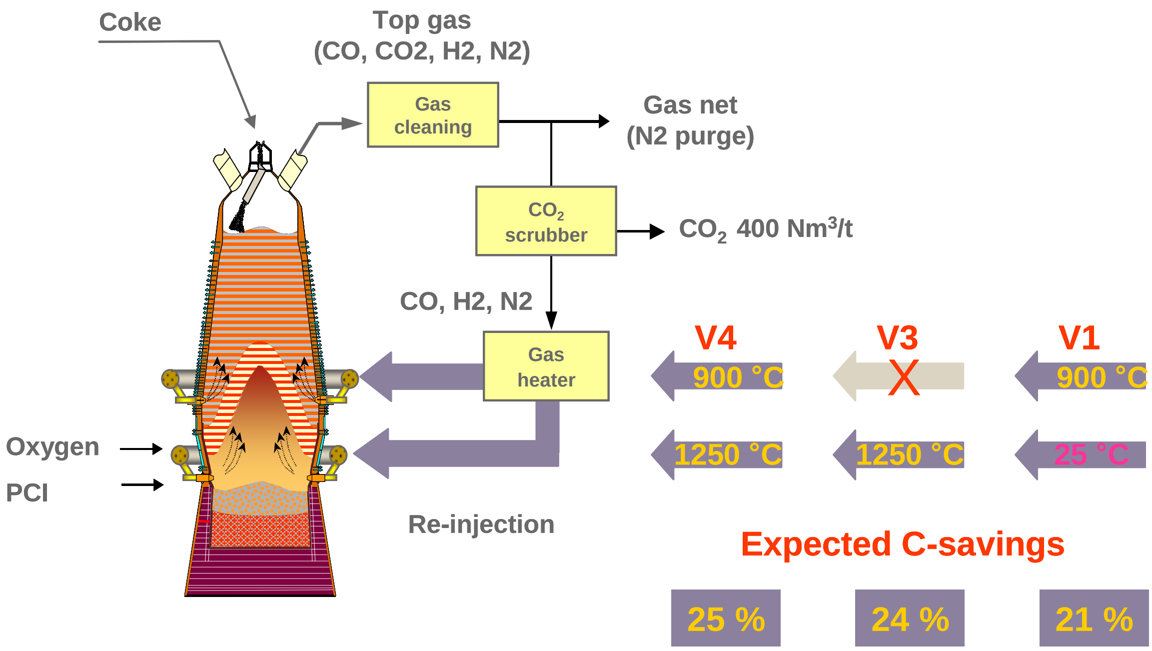

Figure C-2: ULCOS Oxy-Blast Furnace Concepts [1]

This study presents only one of the several options that could be possible for the operation of the Oxy-Blast Furnace. CO_2 capture is based on chemical absorption technology using activated MDEA with Piperazine. The performance (energy and mass balance) of the whole integrated steel mill with CO_2 capture was evaluated. CAPEX and OPEX were estimated.

It is again strongly emphasized that the results presented in this report are limited to the selected operating version of the OBF. The chosen option is considered conservative and with good confidence that enough engineering data is available to allow estimating the cost of the integrated steel mill with CO_2 capture (i.e. within ± 30% accuracy).

Furthermore, it should be stressed that cost estimates reported in this study are specific to an integrated steel mill based on the techno-economic assumptions used. Additionally, it is re-emphasized that this study assumed that there will be no energy import or export in or out of the steel mill's defined boundary limit, except for the input of coke, coal and natural gas. As explained in Volume 1 of the report, this is an assumption undertaken to simplify the accounting and the calculation of the CO_2 avoidance cost for steel mill with CO_2 capture.

3. MODIFICATION TO THE INTEGRATED STEEL MILL

Introducing oxy-blast furnaces instead of conventional blast furnaces presents a significantly more complex set of changes in the steel production site. The assumption of a Greenfield site simplifies the cost analysis compared to a brown field modification or retrofit.

Table C-2 presents a summary of the annual production of all the intermediate products of the different major processes of the steel mill.

In general, it could be noted that the introduction of the OBF and MDEA CO_2 capture technology to the steel mill would result to the following changes:

- Reduced coke production by 24%
- Reduced sinter production by 2%
- Reduced high purity oxygen consumption by 43%
- Increased demand for low purity oxygen by ~260Nm^3/t HRC – this requires extra ASU capacity.
- Increased demand for electricity by 43%.
- Increased demand for low pressure steam by 702kg/t HRC – this should need extra steam generation capacity.
- Required handling of ~860t CO_2/t HRC by the CO_2 capture and compression plant.

In comparison to the REFERENCE Steel Mill without CO_2 capture, it could be noted that production of the hot rolled coil from an integrated steel mill with OBF and MDEA CO_2 Capture would involve several changes to the hot metal production side of the steel worksbut there will be no significant changes to the steelmaking section of the steel works.

This section presents and describes the different changes made to the integrated steel mill. The addition of the CO_2 capture and compression plant is described in Section C-4.

Table C-2: Annual Production of the Different Major Processes of the Steel Mill
(REFERENCE Steel Mill without CO_2 Capture vs. Steel Mill with OBF and MDEA CO_2 Capture Technology)

Description		REFERENCE Steel Mill (Base Case)		Steel Mill with OBF/MDEA CO_2 Capture		
Annual Production: Hot Rolled Coil		**4,000,000 t/y**		**4,000,000 t/y**		**% Change** (Ref. Vs OBF)
100: Coke Production	Coke	1,630,519 t/y	407.6 kg/t HRC	1,243,741 t/y	310.9 kg/t HRC	-24%
200: Sinter Production	Sinter	4,445,559 t/y	1,111.4 kg/t HRC	4,349,045 t/y	1,087.3 kg/t HRC	-2%
300 & 400: Hot Metal Production	Hot Metal (De-S)	3,894,263 t/y	973.6 kg/t HRC	3,894,147 t/y	973.5 kg/t HRC	0%
500 & 600: Liquid Steel	Liquid Steel (Refined)	4,345,228 t/y	1,086.3 kg/t HRC	4,345,228 t/y	1,086.3 kg/t HRC	0%
700: Slab Casting	Slab	4,210,526 t/y	1,052.6 kg/t HRC	4,210,526 t/y	1,052.6 kg/t HRC	0%
800 & 900: Reheating & Hot Rolling	Hot Rolled Coil	4,000,000 t/y	1,000.0 kg/t HRC	4,000,000 t/y	1,000.0 kg/t HRC	0%
1000: Lime Production	Lime	346,412 t/y	86.6 kg/t HRC	345,447 t/y	86.4 kg/t HRC	0%
1100: ASU - High Purity O_2 Production	Oxygen (99%)	485,644 kNm^3/y	121.4 Nm^3/t HRC	276,382 kNm^3/y	69.1 Nm^3/t HRC	-43%
1200: Power Plant	Electricity	1,600,463 kWh/y	400.1 kWh/t HRC	2,293,670 kWh/y	573.4 kWh/t HRC	43%
2000: Steam Generation	Steam (9 Bara, sat.)	- t/y	- kg/t HRC	2,808,253 t/y	702.1 kg/t HRC	NA
3000: ASU - Low Purity O_2 Production	Oxygen (95%)	- Nm^3/y	- Nm^3/t HRC	1,024,252 kNm^3/y	256.1 Nm^3/t HRC	NA
4000: CO_2 Capture and Compression	CO_2 (110 Bara)	- t/y	- kg/t HRC	3,439,360 t/y	859.8 kg/t HRC	NA

3.1. UNIT 300: Hot Metal Production

Central to the modifications to the steel mill for this case is the introduction of the oxy-blast furnace (OBF). All the changes made to other major processes depend on the design and operation of the hot metal production.

In this study it was assumed that two identical OBF's, each with a heart diameter of 8.5m and working volume of 1580m^3 would be used by the steel mill. Each of these would be equipped with bell-less top raw materials charging system, PCI injection system, hot reduction gas injection system, gas cleaning system, and hot metal and slag handling system.

Figure C-3 presents an overview to the schematic flow diagram of the hot metal production for both conventional BF and OBF. This illustrates the carbon balance of the hot metal production for both cases. Table C-3 summarizes the key features and the operating parameters of the OBF used for this study. The complete PFD and mass balance is presented in Annex 3.

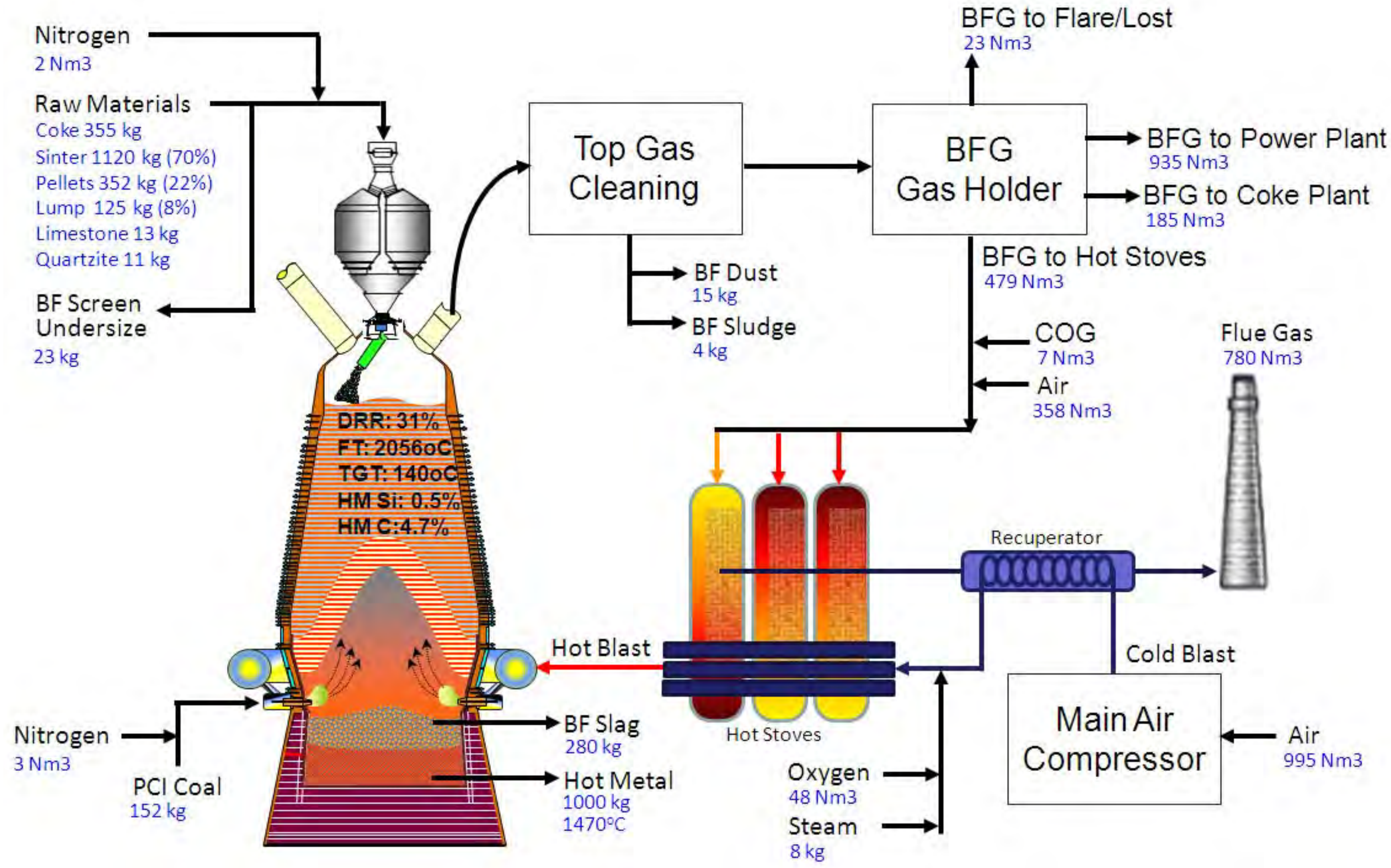

Figure C-3(a): Overview - Schematic Flow Diagram a Conventional Blast Furnace
(Basis for the numbers: per tonne of hot metal produced – ex-BF)

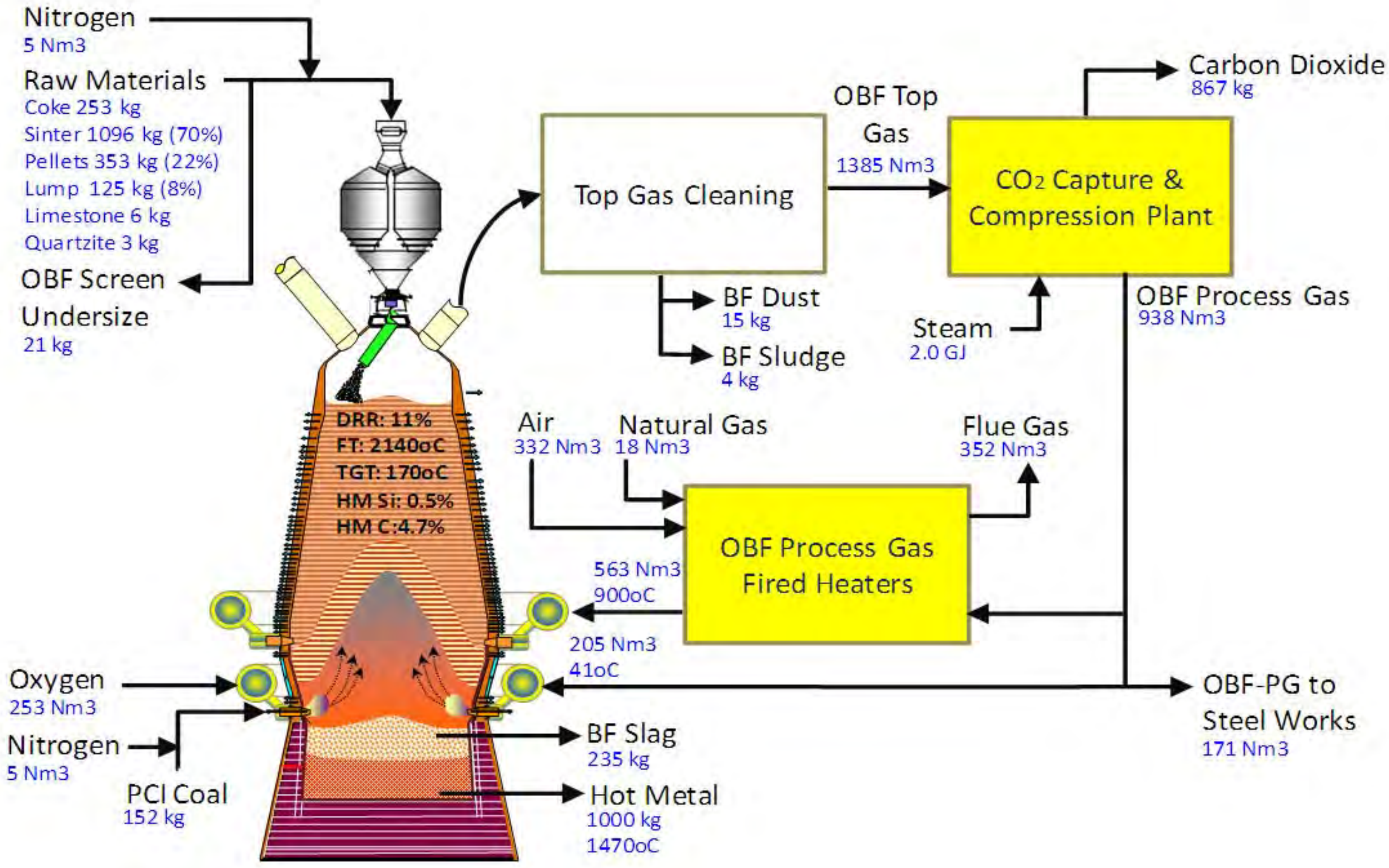

Figure C-3(b): Overview - Schematic Flow Diagram a Oxy-Blast Furnace
(Basis for the numbers: per tonne of hot metal produced – ex-OBF)

Conventional BF – REFERENCE Steel Mill

Carbon Input (kg C/thm)		Carbon Output (kg C/thm)	
Coke	312.4	Hot Metal	47.0
Limestone	1.5	BF Screen Undersize	6.3
PCI Coal	132.2	Dust & Sludge	8.0
COG	1.3	BFG Export	266.4
		BFG Flared	5.4
		Hot Stove's Flue Gas	114.1
Total	**447.5**	**Total**	**447.2**

Oxy-Blast Furnace – Case 3

Carbon Input (kg C/thm)		Carbon Output (kg C/thm)	
Coke	227.7	Hot Metal	47.0
Limestone	0.7	BF Screen Undersize	4.6
PCI Coal	132.2	Dust & Sludge	8.0
Natural Gas	12.0	OBF PG Export	64.5
		PG Heater Flue Gas	12.0
		CO2 Captured	236.3
Total	**372.7**	**Total**	**372.4**

Carbon Balance of the Hot Metal Production

Table C-3: General Information – Study Specification of the BF/OBF
(Unit 300: Hot Metal Production)

Description	REFERENCE Steel Mill (Base Case)	Steel Mill with OBF/MDEA CO_2 Capture
Hot Metal Production (Total) ex-OBF	**3,968,756 t/y (992 kg/t HRC)**	**3,968,639 t/y (992 kg/t HRC)**
No of Blast Furnace	2 (Diameter 11m, Working Volume 2750m^3)	2 (Diameter 8.5m, Working Volume 1580m^3)
No of Hot Stoves	6 (3 hot stoves per BF)	Replaced with 6 OBF PG Fired Heaters (3 per OBF)
No. of Main Air Compressors	2 (1 per BF)	Replaced with 2 OBF PG Compressors (1 per OBF)
Main Air Compressors Drives	Electrically Driven	OBF PG Compressors - also Electrically Driven
PCI Coal Injection Facilities	Yes – 1x PCI coal drying & 2x PCI injection units	Yes – 1x PCI coal drying & 2 PCI injection units
Off-Gas Clean Up	Wet System – 1 cyclone and wet scrubber per BF	Wet System – 1 cyclone and wet scrubber per OBF
No. of Casthouse	1 per BF w/ 2 tapholes for HM & Slag withdrawal	1 per BF w/ 2 tapholes for HM & Slag withdrawal
No. of Slag Granulation Plant	2 (1 per BF w/ dewatering facility)	2 (1 per BF w/ dewatering facility)
Hot Metal Transfer Mode	via torpedo cars to HM Desulphurisation Stations	via torpedo cars to HM Desulphurisation Stations
BF Iron Burden Distribution (wt. Dry)	Sinter (70%w.), Pellets (22%w.), Lump (8%w.)	Sinter (70%w.), Pellets (22%w.), Lump (8%w.)
Sinter Bascity (CaO/SiO_2 Ratio)	1.80	1.65
Reducing Agent Rate	506.8 kg/thm	410.6 kg/thm
Blast Volume	1053 Nm^3/thm	NA - replaced with Recycled OBF-PG & LP O_2
Blast Pressure	3.8 Bara	N/A
Blast Temperature	1118^{o}C	N/A
Blast O_2 Enrichment	24%v.(wet) – addition of 48 Nm^3/thm (HP O_2)	N/A - replaced with addition of 253 Nm^3/thm (LP O_2)
Blast Moisture	16 g/Nm^3 (dry)	N/A
Recycled OBF-PG to Tuyeres - Volume	N/A	205 Nm^3/thm
Recycled OBF PG to Tuyeres - Pressure	N/A	3.8 Bar_a
Recycled OBF PG to Tuyeres - Temperature	N/A	41^{o}C
Recycled OBF PG to Tuyeres - Moisture	N/A	~17 g/Nm^3 (dry)
Recycled OBF PG to Tuyeres - LHV	N/A	9.87 MJ/Nm^3 (wet)
Recycled OBF-PG to Shaft - Volume	N/A	563 Nm^3/thm
Recycled OBF-PG to Shaft - Pressure	N/A	3.8 Bar_a
Recycled OBF PG to Shaft - Temperature	N/A	900^{o}C
Recycled OBF PG to Shaft - Moisture	N/A	~17 g/Nm^3 (dry)
Recycled OBF PG to Shaft - LHV	N/A	9.87 MJ/Nm^3 (wet)
BF/OBF Top Gas - Pressure	2.4 Bar_a	N.R.
BF/OBF Top Gas - Temperature	140^{o}C	170^{o}C
BF/OBF Top Gas - LHV	3.18 MJ/Nm^3 (wet)	6.69 MJ/Nm^3 (wet)
BF/OBF Top Gas Pressure (after gas cleaning)	1.1 Bar_a	1.8 Bar_a
Hot Metal Temperature	1470^{o}C	1470^{o}C
Hot Metal Carbon Content (dry)	4.7%w.	4.7%w.
Hot Metal Silicon Content (dry)	0.5%w.	0.5%w.
Slag Rate (dry)	280 kg/thm	232 kg/thm
Slag Basicity (CaO/SiO2 Ratio)	1.15	1.15
Flame Temperature	2056^{o}C	2140^{o}C
Reserve Zone Temperature	900^{o}C	900^{o}C
Direct Reduction Rate (DRR)	31%	11%
Shaft Efficiency	93%	94%
BF/OBF Productivity	2.5 t/m^3/d	4.0 t/m/d
BF/OBF Heat Loss	600 MJ/thm	550 MJ/thm

PCI Coal (dry)	152.0	kg/thm	150.8	kg/t HRC	152.0	kg/thm	150.8	kg/t HRC
Limestone (dry)	13.2	kg/thm	13.1	kg/t HRC	5.8	kg/thm	5.8	kg/t HRC
Quarzite (dry)	10.9	kg/thm	10.8	kg/t HRC	3.3	kg/thm	3.3	kg/t HRC
COG Consumption – hot stoves (wet)	7.3	Nm^3/thm	7.2	Nm^3/t HRC	-	Nm^3/thm	-	Nm^3/t HRC
COG Consumption – PC drying (wet)	1.4	Nm^3/thm	1.4	Nm^3/t HRC	2.9	Nm^3/thm	2.9	Nm^3/t HRC
BFG Consumption – hot stoves (wet)	479.2	Nm^3/thm	475.4	Nm^3/t HRC	-	Nm^3/thm	-	Nm^3/t HRC
OBF-PG Consumption - Recycled to Tuyeres	-	Nm^3/thm	-	Nm^3/t HRC	562.7	Nm^3/thm	558.3	Nm^3/t HRC
OBF-PG Consumption - Recycled to Shafts	-	Nm^3/thm	-	Nm^3/t HRC	204.6	Nm^3/thm	203.0	Nm^3/t HRC
BFG/OBF-PG Export (wet)	1,119.3	Nm^3/thm	1,110.6	Nm^3/t HRC	172.9	Nm^3/thm	171.5	Nm^3/t HRC
Steam Consumption (9 bar_a, sat.)	8.0	kg/thm	7.9	kg/t HRC	-	kg/thm	-	kg/t HRC
Electricity Consumption - HM Prod. [1]	98.8	kWh/thm	98.1	kWh/t HRC	30.0	kWh/thm	29.8	kWh/t HRC
Electricity Consumption - Ancillary	4.9	kWh/thm	4.8	kWh/t HRC	4.9	kWh/thm	4.8	kWh/t HRC

Hot Metal (dry)	1000.0	kg/thm	992.2	kg/t HRC	1000.0	kg/thm	992.2	kg/t HRC
Coke (dry)	354.8	kg/thm	352.1	kg/t HRC	258.6	kg/thm	256.6	kg/t HRC
Sinter(dry)	1,120.1	kg/thm	1,111.4	kg/t HRC	1095.9	kg/thm	1087.3	kg/t HRC
Lump Ore (dry)	125.3	kg/thm	124.3	kg/t HRC	125.3	kg/thm	124.3	kg/t HRC
Pellets (dry)	351.8	kg/thm	349.0	kg/t HRC	352.6	kg/thm	349.8	kg/t HRC
Granulated Slag (dry)	280.0	kg/thm	277.8	kg/t HRC	235.0	kg/thm	233.2	kg/t HRC

[1] The reported electricity consumption for the OBF case does not include the electricity consumption of the OBF process gas compressors (as these are accounted for in the CO_2 capture and compression plant – Unit 4000)

With regard to the operation of the OBF, the following parameters were used to evaluate the mass and energy balance of the OBF (as compared with the conventional BF of the REFERENCE case):

- Productivity was estimated at 4.0 t/m^3/d for the OBF as compared to 2.5 t/m^3/d for the REFERENCE Steel Mill's Blast Furnace[2]. Due to the higher productivity, the heat loss was assumed to be lower by ~50 MJ/t HM at 550 MJ/thm for the OBF. It should be noted that the increase in productivity would require further validation at demonstration scale.[3]

- Reserve zone temperature was kept constant at 900°C for both REFERENCE and OBF case.

- Flame temperature was maintained slightly higher for the OBF case (at 2140°C) as compared to the REFERENCE case (2056°C). The flame temperature for the OBF case should still be considered moderate for blast furnace operation.

- Shaft efficiency was increased to 94% for the OBF case from 93% for the REFERENCE case. This should account for the higher reduction potential of the process gas (processed top gas) recycled back to the OBF.

- Iron burden composition was maintained at similar level and the ratio of iron units from sinter, lump and pellets was kept the same for both REFERENCE and OBF cases.

- PCI coal injection rate was maintained the same at 152.1 kg/thm for both cases.

- Purity of the oxygen required by the OBF was set at 95%. The use of lower purity oxygen reduces the specific electricity demand of the oxygen supplied to the blast furnace.

- Recycled OBF process gas should have CO_2 content no greater than 3%.

- Hot metal temperature, its carbon and silicon content were kept the same for the REFERENCE and OBF cases. These were set at 1470°C, 4.7%w., and 0.5%w. respectively.

- Slag rate was reduced to 235 kg/thm (OBF Case) from 280 kg/thm (REFERENCE Case). This reflects the changes to the slag chemistry as discussed in Section C-3.3. This changes account for the reduction of coke consumption (therefore changing the ash chemistry) and the adjustment to the sinter's basicity to the OBF case; and at same time maintaining the iron burden composition for both REFERENCE and OBF cases.

- Top gas temperature from the OBF was assumed at 170°C and was considered conservative given that no data is available from full size furnace operation which can be used as a reference.

- Main OBF Process Gas Compressors were installed prior to the CO_2 absorber columns to increase capture efficiency performance of the MDEA/Pz solvent (i.e higher partial pressure of CO_2) and should minimise the size of the absorber column.

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[2] The assumption of productivity at 4.0 t/m^3/d is considered conservative (This is equivalent to nearly 60% increase in productivity). Please note that a couple of BFs operating at high oxygen enrichment has already achieved a productivity of 3.2 t/m^3/d.

[3] ULCOS has reported a higher increase in productivity for TGR-BF version 1. However, for versions 3 and 4, productivity increase should be lower (only up to ~20% productivity increase was reported)

For the purpose of estimating the CAPEX of the OBF (hot metal production), the following changes to the plant and equipment as compared to the conventional blast furnace producing the same amount of hot metal were noted. Some of these changes are summarised:

- OBF has a smaller working volume as compared to conventional blast furnace
  - Est'd. Productivity: 2.5 $t/m^3/d$ (Conventional BF) vs. 4.0 $t/m^3/d$ (OBF)
  - Hearth Diameter: 11.0 m (Conventional BF) vs 8.5 m (OBF)
  - Working Volume: 2750 m^3 (Conventional BF) vs. 1580 m^3 (OBF)

- Bustle pipe at the tuyere level could have a smaller diameter due to smaller volumetric flow rate of the gas mixture (oxygen and the OBF process gas) as compared to the volumetric flow rate of the hot blast for the conventional BF.
  - Flow rate: 1053 Nm^3/thm (Conventional BF) vs. 458 Nm^3/thm (OBF)
  - Pressure: ~4-5 Bar_a (Conventional BF) vs. ~4-5 Bar_a (OBF)
  - Temperature: 1120°C (Conventional BF) vs. 40°C (OBF)[4]

- Raceway and tuyere design is still under development for OBF technology. This also includes development of the PCI coal injection system that could be suitable for the OBF case.
  - Tuyere's design should be able to handle gas mixtures with higher CO and H_2 content and higher percentage of O_2 (~50%v) as compared to the hot blast's composition typical for conventional BF's which have lower O_2 percentage (~24%v) and no CO and H_2.

- Oxygen requirements for the OBF are five times larger in volume as compared to the requirement of the conventional blast furnace.
  - Oxygen demand for conventional BF
    - ~47.9 Nm^3/thm (@ 24% oxygen enrichment)
    - With typical O_2 purity of 99.5% or higher (dependent on availability of O_2 at site but not necessarily a requirement for the conventional BF).
    - Oxygen is mixed together with the hot blast (oxygen enrichment) or part of which is directly introduced to the blast furnace via tuyeres
    - Temperature should be the same with hot blast (~1250°C).
  - Oxygen demand for OBF
    - 253.0 Nm^3/thm
    - Should only require at least 93-95% O_2 purity
    - Oxygen is injected directly to the bustle pipe at the tuyere level.
    - Temperature - assumed at 20-40°C (always cold)

- Additional bustle pipe at the shaft level is required for the OBF to introduce the pre-heated OBF process gas[5].
  - Flow rate: N/A (Conventional BF) vs. 563 Nm^3/thm (OBF)
  - Temperature: N/A (Conventional BF) vs. 900°C (OBF)

- Gas cleaning system for the blast furnace and OBF top gas should be the same for both cases (cyclone and wet scrubber). However, the gas cleaning capacity would be smaller in size for the OBF case – due to smaller top gas volume as compared to the top gas volume of the conventional BF.

[4] Some OBF options for the tuyeres level gas flow would require a temperature of ~1250°C.

[5] Some OBF options will not require the injection of the process gas at shaft level; thus this is dependent on the design and operating principle of the OBF.

- Flow Rate (after gas cleaning):
  - 1622 Nm^3/thm (Conventional BF) vs. 1385 Nm^3/thm (OBF)

- Slag handling equipment would be reduced if iron burden composition remains the same for both conventional BF and OBF. Reduction in coke consumption by 24% would consequently reduce sinter requirements by ~2% due to lower sinter basicity for the OBF case. Consequently, slag rate would be reduced and slag chemistry would also change.
  - Slag Rate: 280 kg/thm (Conventional BF) vs. 232 kg/thm (OBF)

- The switch from the hot blast (for conventional BF) to the recycled OBF Process Gas and oxygen (for OBF) requires the replacement of the hot stoves with other types of heaters to preheat the process gas. This study assumed the use of shell and tube type fired heaters with materials suitable for handling CO rich process gas at 900^{o}C. (It should be recognised that the design and material selection for this piece of equipment could be challenging.)
  - Conventional BF – Cold Blast heating
    - 3 x hot stoves per BF (with operating temperature ~1300 -1400^{o}C)
    - Fuel for hot stove heating – Coke Oven Gas mixed with Blast Furnace Gas
  - OBF – Process Gas heating
    - 3 x OBF Process Gas Fired Heaters per OBF
    - Shell and tube fired heat exchangers (with operating temperature ~900^{o}C-1000^{o}C)
    - Fuel for Fired Heaters – Natural Gas

- The switch from hot blast (for conventional BF) to the recycled OBF Process Gas and oxygen (for OBF) should also eliminate the main air compressors used in the conventional BF to deliver the "Cold Blast".

  This role would be taken over by the Process Gas compressors (Unit 4010) installed at the CO_2 capture plant with a duty to compress the "Cleaned" OBF Top Gas prior to entering the CO_2 absorber columns (Unit 4110). The OBF Process Gas (after CO_2 removal) will be delivered to the OBF at pressure required.
  - Conventional BF: Main Air Compressor (1 train per BF)
    - Cold Blast: Air
    - Gas Flow: 995 Nm^3/thm
    - Inlet Pressure: ~1.0 Bar_a (atmospheric)
    - Outlet Pressure: ~5.0 Bar_a (Operating Pressure of BF ~3.8 Bar_a)
  - OBF: Process Gas Compressor (1 train per BF)
    - OBF Top Gas: approx. with CO 46%, CO_2 34%, 9% H_2 and 10% N_2
    - Gas Flow: 1385 Nm^3/thm
    - Inlet Pressure: ~1.8 Bar_a (Pressure after OBF Top Gas Cleaning)
    - Outlet Pressure: ~5.0 Bara (Operating Pressure of OBF ~4.1 Bar_a)[6]

[6] This should also reduce Electricity Consumption for PG compression as compared to the Main Air Compression of the Hot Blast

3.2. UNIT 100: Coke Production

Due to the introduction of the reducing gas (in the form of OBF Process Gas rich in CO and H_2), the coke consumption of the blast furnace decreases.

Table C-4 presents the operating parameters of the coke production unit for both REFERENCE and OBF cases. The PFD and mass balance of the coke production plant is presented in Annex 3.

Due to the reduced coke demand, this study assumed smaller coke ovens capacity consisting of 3 batteries with number of ovens reduced from a total of 144 ovens (REFERENCE Steel Mill) down to 120 ovens (Steel Mill with CO_2 capture).

Additional changes to the coke oven under-fire heating system and corresponding burners are expected as the volume of the OBF Process Gas is significantly smaller than conventional BFG. This is in addition to lower consumption of the coke oven gas as fuel for oven's under-fire heating.

As expected, corresponding consumption of coking coal, production of coke oven gas and other by-products (tar, benzole and sulphur) are all reduced in line with the reduction of coke produced.

This study assumed that the coke oven gas export for this case was maximised to meet the demand of the steel mill with OBF and MDEA CO_2 Capture.

Table C-4: General Information – Study Specification (Unit 100: Coke Production)

Description	REFERENCE Steel Mill (Base Case)				Steel Mill with OBF/MDEA CO_2 Capture			
Coke Production (Total – dry)	**1,630,519 t/y (408 kg/t HRC)**				**1,243,741 t/y (311 kg/t HRC)**			
No. of Coke Oven Batteries	3 (each battery consists of 48 ovens)				3 (each battery consists of 40 ovens)			
Total No. of Ovens	144				120			
Total Volume per Charge	45 m^3				~40 m^3			
Coking Coal (dry)	1285.2	kg/t coke	523.8	kg/t HRC	1285.2	kg/t coke	399.6	kg/t HRC
• Hard Coking Coal	771.1	kg/t coke	314.3	kg/t HRC	771.1	kg/t coke	239.8	kg/t HRC
• Semi-Soft Coking Coal	514.1	kg/t coke	209.5	kg/t HRC	514.1	kg/t coke	159.8	kg/t HRC
COG Consumption (wet)	112.6	Nm^3/t coke	45.9	Nm^3/t HRC	42.3	Nm^3/t coke	13.2	Nm^3/t HRC
BFG /OBF-PG Consumption (wet)	450.4	Nm^3/t coke	183.6	Nm^3/t HRC	273.1	Nm^3/t coke	84.9	Nm^3/t HRC
COG Export (wet)	327.0	Nm^3/t coke	133.3	Nm^3/t HRC	407.6	Nm^3/t coke	126.7	Nm^3/t HRC
Steam Consumption (9 bar_a, sat.)	150.0	kg/t coke	61.1	kg/t HRC	150	kg/t coke	46.6	kg/t HRC
Electricity Consumption	35.0	kWh/t coke	14.3	kWh/t HRC	35.0	kWh/t coke	10.9	kWh/t HRC
Total Coke Production (dry)	1000.0	kg/t coke	407.6	kg/t HRC	1000.0	kg/t coke	310.9	kg/t HRC
• BF Coke	863.7	kg/t coke	352.0	kg/t HRC	825.2	kg/t coke	256.6	kg/t HRC
• Coke Breeze	136.3	kg/t coke	55.6	kg/t HRC	174.8	kg/t coke	54.4	kg/t HRC
Crude Tar / Naphthalene (dry)	41.1	kg/t coke	16.8	kg/t HRC	41.1	kg/t coke	12.8	kg/t HRC
Benzene, Toluene, Xylene (dry)	12.1	kg/t coke	4.9	kg/t HRC	12.1	kg/t coke	3.8	kg/t HRC
Sulphur (dry)	3.0	kg/t coke	1.2	kg/t HRC	3.0	kg/t coke	0.9	kg/t HRC

3.3. UNIT 200: Sinter Production

The reduction of coke consumption by the OBF also change the slag chemistry and slag rate of the hot metal production. This also impacts the flux requirements.

Reducing the coke consumption of the OBF by 95 kg/thm also reduces the acid components (SiO_2 + Al_2O_3) input to the blast furnace by about 9 kg/thm. Consequently the requirements for the basic fluxes (CaO + MgO) are reduced by approximately the same amount.

In order to keep the iron burden as close to REFERENCE Steel Mill conditions, the Fe units charged into the blast furnace via the sinter and the lump ore are maintained constant, however, there is an insignificant change (slight increase) to the pellet rate to close the material balance.

Additionally, the hot metal specifications are to remain identical to the REFERENCE case. (i.e. Hot Metal Carbon content at 4.7% and Silicon Content at 0.5%).

To achieve these desired conditions, the sinter basicity (CaO/SiO_2) ratio was fixed at 1.65 for the OBF case which is a reduction from 1.80 for the REFERENCE Case. This was considered a reasonable lower limit that would still provide high quality fluxed sinter. Consequently, the OBF's slag rate was also reduced to 235 kg/thm. Then final adjustments to the trim additives were made to meet the specified MgO concentrations of the sinter and the BF slag.

Table C-5 presents the operating parameters of the sinter production. This is compared against sinter production of the REFERENCE Steel Mill. The PFD and mass balance of the sinter plant is presented in Annex 3.

In summary, the following key changes to the sinter production were:

- Sinter delivered to the blast furnace was reduced from 4.44 million t/y (REFERENCE Case) to 4.34 million t/y (OBF Case). Most of these changes are related to flux reduction.
- Sinter plant's limestone consumption was reduced from 116.5 kg/t sinter (REFERENCE Case) to 89.5 kg/t sinter (OBF Case)
- Sinter plant's quartz consumption was reduced from 12.0 kg/t sinter (REFERENCE Case) to 8.0 kg/t sinter (OBF Case)

There was also a very insignificant change to the lime and olivine consumption of the sinter plant (OBF) case. The reduction in the lime consumption is briefly described in Section C-3.4.The olivine consumption decreased marginally from 90,349 t/y (REFERENCE Case) to 90,335 t/y (OBF Case).

The changes made to the operating parameters of the sinter plant only resulted in about 2.2% reduction in terms of its annual sinter production. It should be expected that the sinter plant for the OBF case would be the same plant and equipment as specified for the REFERENCE case.

3.4. UNIT 1000: Lime Production

The adjustment made to the flux requirements of the sinter slightly reduced the overall lime consumption of the steel mill from 346,412 t/y (REFERENCE Case) to 345,447 t/y (OBF Case). Most of the changes are due to the adjustment made to the sinter plant (UNIT 200) and there will no change to the lime consumption of the BOF Steelmaking (UNIT 500). Changes to the annual lime production should not impact to the CAPEX of the Lime Plant (Unit 1000) as capacity of the lime kiln are kept the same for both cases.

Table C-5: General Information – Study Specification (Unit 200: Sinter Production)

Description	REFERENCE Steel Mill (Base Case)		Steel Mill with OBF/MDEA CO_2 Capture	
Coke Production (Total)	**4,445,559 t/y (1,111.4 kg/t HRC)**		**4,349,045 t/y (1,087.3 kg/t HRC)**	
No. of Sinter Plant	1 (Standard Travelling Grate with Rotary Cooler)		1 (Standard Travelling Grate with Rotary Cooler)	
Grate Area	410 m^2 with 90% utilization at 35 t/(m2-24h)		410 m^2 with 90% utilization at 35 t/(m2-24h).	
Flue Gas Clean Up	ESP and Fabric Filter		ESP and Fabric Filter	
Sinter Iron Unit (%)	57.9%		59.1%	
Sinter Basicity (Ratio of CaO/SiO_2)	1.80		1.65	
Coke Breeze (dry)	50.0 kg/t sinter	55.6 kg/t HRC	50.0 kg/t sinter	54.4 kg/t HRC
Lime (dry)	10.0 kg/t sinter	11.1 kg/t HRC	10.0 kg/t sinter	10.9 kg/t HRC
Limestone (dry)	116.5 kg/t sinter	129.5 kg/t HRC	89.7 kg/t sinter	97.6 kg/t HRC
Quartzite (dry)	12.0 kg/t sinter	13.3 kg/t HRC	8.0 kg/t sinter	8.7 kg/t HRC
Olivine (dry)	20.3 kg/t sinter	22.6 kg/t HRC	20.8 kg/t sinter	22.6 kg/t HRC
COG Consumption (wet)	4.2 Nm^3/t sinter	4.7 Nm^3/t HRC	4.2 Nm^3/t sinter	4.6 Nm^3/t HRC
Electricity Consumption	32.0 kWh/t sinter	35.6 kWh/t HRC	32.0 kWh/t sinter	34.8 kWh/t HRC
Sinter (dry)	1000.0 kg/t sinter	1111.4 kg/t HRC	1000.0 kg/t sinter	1087.3 kg/t HRC
Iron Ore Fines (dry)	792.3 kg/t sinter	880.5 kg/t HRC	809.7 kg/t sinter	880.4 kg/t HRC
• Hematite (Brazil)	657.6 kg/t sinter	730.8 kg/t HRC	672.1 kg/t sinter	730.7 kg/t HRC
• Hematite/Goethite (Australia)	79.2 kg/t sinter	88.1 kg/t HRC	81.0 kg/t sinter	88.0 kg/t HRC
• Magnetite (Sweden)	55.5 kg/t sinter	61.6 kg/t HRC	56.7 kg/t sinter	61.6 kg/t HRC

3.5. UNIT 1100 & 3000: ASU – High and Low Purity O_2 Production

The total oxygen demand by the steel mill was increased by ~170%, from 121.4 Nm^3/t HRC (REFERENCE case) to 325.1 Nm^3/t HRC (OBF case).

All of the increase is due to the operation of the oxy-blast furnace which requires about five times more oxygen (256.0 Nm^3/t HRC) than required by the conventional blast furnace (47.5 Nm^3/t HRC).

To supply this demand, this study assumed a separate air separation unit providing low purity oxygen exclusively to the OBF Consequently the capacity of the high purity oxygen production unit is reduced by 43% as compared to the ASU of the REFERENCE Steel Mill.

As a result of reducing the the high purity oxygen capacity, the sale of liquid argon reduces by 77% from 3.77 Nm^3/t HRC (for the REFERENCE Case) to 0.87 Nm^3/t HRC (for the OBF Case).

Table C-6 presents the industrial gas (O_2, N_2 and Ar) demand of the steel mill for both REFERENCE Steel Mill without CO_2 capture and Steel Mill with OBF & MDEA CO_2 Capture Plant. Table C-7 presents the energy demand of the air separation units for both REFERENCE Case and Steel Mill with OBF/MDEA CO_2 Capture.[7]

[7] It should be noted that the energy demand of the ASU assumed in this study are not optimised as these numbers are based on industry average (not the best performing units). Please see comments made by industrial companies (Air Liquide and Air Products)

Table C-6: General Information – Air Separation Units (Unit 1100 & Unit 3000)

ASU - High Purity O2 Prod. (Unit 1100)

Oxygen (99.9%)	REFERENCE Steel Mill	Steel Mill w/ OBF & MDEA
300: HM Production	47.52 Nm^3/t HRC	- Nm^3/t HRC
500/600: Steelmaking	58.05 Nm^3/t HRC	58.01 Nm^3/t HRC
700: Slab Casting	2.17 Nm^3/t HRC	2.17 Nm^3/t HRC
900: Hot Rolling Mill	2.63 Nm^3/t HRC	2.63 Nm^3/t HRC
Buffer requirements / System Losses	11.04 Nm^3/t HRC	6.28 Nm^3/t HRC

Nitrogen	REFERENCE Steel Mill	Steel Mill w/ OBF & MDEA
300: HM Production	4.96 Nm^3/t HRC	7.79 Nm^3/t HRC
400: HM Desulphurisation	0.14 Nm^3/t HRC	0.14 Nm^3/t HRC
500/600: Steelmaking	0.33 Nm^3/t HRC	0.33 Nm^3/t HRC

Argon	REFERENCE Steel Mill	Steel Mill w/ OBF & MDEA
500/600: Steelmaking	0.78 Nm^3/t HRC	0.78 Nm^3/t HRC
700: Continuous Casting	0.11 Nm^3/t HRC	0.11 Nm^3/t HRC
Liquid Argon to Sale	3.77 Nm^3/t HRC	0.87 Nm^3/t HRC

ASU - Low Purity O2 Prod. (Unit 3000)

Oxygen (95.0%)	REFERENCE Steel Mill	Steel Mill w/ OBF & MDEA
300: HM Production	- Nm^3/t HRC	251.04 Nm^3/t HRC
Buffer requirements / System Losses	- Nm^3/t HRC	5.02 Nm^3/t HRC

Table C-7(a): Energy Requirements – Air Separation Units (Unit 1100)

UNIT 1100	REFERENCE Steel Mill (Base Case)		Steel Mill with OBF/MDEA CO_2 Capture	
High Purity O_2 Production (Total)	**485,643,965 Nm3/y (121.4 Nm3/t HRC)**		**276,381,545 Nm3/y (69.1 Nm3/t HRC)**	
Steam Consumption (9 bar_a, sat.)	0.06 kg/Nm3 O2	7.3 kg/t HRC	0.06 kg/Nm3 O2	4.1 kg/t HRC
Electricity Consumption	0.55 kWh/Nm3 O2	66.8 kWh/t HRC	0.55 kWh/Nm3 O2	38.0 kWh/t HRC

Table C-7(b): Energy Requirements – Air Separation Units (Unit 3000)

UNIT 3000	REFERENCE Steel Mill (Base Case)		Steel Mill with OBF/MDEA CO_2 Capture	
Low Purity O_2 Production (Total)	**-**		**1,024,253,677 Nm3/y (256.1 Nm3/t HRC)**	
Steam Consumption (9 bar_a, sat.)	- kg/Nm3 O2	- kg/t HRC	0.02 kg/Nm3 O2	3.8 kg/t HRC
Electricity Consumption	- kWh/Nm3 O2	- kWh/t HRC	0.47 kWh/Nm3 O2	120.3 kWh/t HRC

3.6. UNIT 1200: Power Plant

The switch from conventional BF to OBF and the addition of the CO_2 capture for this case increases the electricity demand of the steel mill by 43% as compared to the REFERENCE Steel Mill without CO_2 Capture. Table C-8 presents the breakdown of the electricity demand for both REFERENCE and OBF cases.

Table C-8: Electricity Demand and Supply of the Steel Mill without and with CO_2 Capture

UNIT 1200	REFERENCE Steel Mill (Base Case)		Steel Mill with OBF/MDEA CO_2 Capture	
Electricity Production (Total)	**1,600,463 MWh/y (400.1 kWh/t HRC)**		**2,293,670 MWh/y (573.4 kWh/t HRC)**	
Power Plant Type	Gas Fired Boiler Power Plant		Natural Gas Combine Cycle	
Fuel Type	BFG (66%), BOFG (15%) , NG (19%)		NG (100%)	
Nominal Capacity	215 MWe		292 MWe	
Average Daily Net Power Output	183 MWe		262 MWe	
Net Efficiency (Fuel Input – LHV)	32.2%		56.6%	
Load Factor	85%		90%	
Electricity Demand				
100: Coke Production	57,068 MWh/y	14.3 kWh/t HRC	43,531 MWh/y	10.9 kWh/t HRC
200: Sinter Plant	142,258 MWh/y	35.6 kWh/t HRC	139,169 MWh/y	34.8 kWh/t HRC
300/400: Iron Making	392,206 MWh/y	98.1 kWh/t HRC	119,061 MWh/y	29.8 kWh/t HRC
500/600: Steelmaking	195,097 MWh/y	48.8 kWh/t HRC	195,097 MWh/y	48.8 kWh/t HRC
700: Continuous Casting	43,452 MWh/y	10.9 kWh/t HRC	43,452 MWh/y	10.9 kWh/t HRC
800/900: Reheating and Rolling	421,053 MWh/y	105.3 kWh/t HRC	421,053 MWh/y	105.3 kWh/t HRC
1000: Lime Production	10,392 MWh/y	2.6 kWh/t HRC	10,363 MWh/y	2.6 kWh/t HRC
1100: ASU - HP Oxygen	267,104 MWh/y	66.8 kWh/t HRC	152,010 MWh/y	38.0 kWh/t HRC
1300: Ancillary (Unit: 300/400)	19,272 MWh/y	4.8 kWh/t HRC	19,272 MWh/y	4.8 kWh/t HRC
2000: Steam Generation Plant	- MWh/y	- kWh/t HRC	44,079 MWh/y	11.0 kWh/t HRC
3000: ASU - LP Oxygen	- MWh/y	- kWh/t HRC	481,399 MWh/y	120.3 kWh/t HRC
4000: CO2 Capture & Compression	- MWh/y	- kWh/t HRC	572,623 MWh/y	143.2 kWh/t HRC
Off Site Users and Losses	52,560 MWh/y	13.1 kWh/t HRC	52,560 MWh/y	13.1 kWh/t HRC

To maintain a like for like analysis for the steel mills without and with CO_2 capture, it was agreed that the use of the steel mill's off-gases should be switched from providing electricity in the REFERENCE Steel Mill case, to providing steam for the steel mill with CO_2 capture.

To provide the electricity required by the steel mill, a natural gas combined cycle (NGCC) based power plant was assumed. The NGCC plant used for this study providing electricity to the Steel Mill with OBF/MDEA CO_2 capture is based on the following features:

- NG fired gas turbine with a single shaft arrangement delivering about ~192MWe.
- Heat from the flue gas of the gas turbine recovered by a heat recovery steam generation (HRSG) unit. This delivers steam to the steam turbine at 3 different pressures and reheats the IP steam.
- Steam turbine based on triple pressure and single reheat arrangement delivering about ~100MWe.

3.7. UNIT 2000: Steam Generation Plant

The steam demand of the steel mill with OBF and MDEA CO_2 capture has increased by 1960 MJ/t HRC (9 Bar_a, saturated) from 211 MJ/t HRC for the REFERENCE steel mill without CO_2 capture to 2172 MJ/t HRC for the steel mill with OBF case. Table C-9 presents the breakdown of the steam demand for both REFERENCE and OBF cases.

Table C-9: Steam Demand and Supply of the Steel Mill without and with CO_2 Capture

UNIT 1200	REFERENCE Steel Mill (Base Case)	Steel Mill with OBF/MDEA CO_2 Capture
Steam Production (Total)	**846,756 GJ/y (211.7 MJ/t HRC)**	**8,688,529 GJ/y (2,172.1 MJ/t HRC)**
500: BOF Waste Heat Boilers	211.7 MJ/t HRC	224.8 MJ/t HRC
2000: Steam Generation Plant	-	1947.3 MJ/t HRC
Steam Demand		
100: Coke Production	169.6 MJ/t HRC	129.4 MJ/t HRC
300/400: Iron Making	21.9 MJ/t HRC	- MJ/t HRC
1100: ASU - HP Oxygen	20.2 MJ/t HRC	11.5 MJ/t HRC
3000: ASU - LP Oxygen	- MJ/t HRC	10.7 MJ/t HRC
4000: CO2 Capture & Compression	- MJ/t HRC	2,020.6 MJ/t HRC

As mentioned in the previous section, to maintain a like for like assessment between steel mill without and with CO_2 capture, the utilisation of the works' off-gases is changed from providing electricity to the steel mill for the REFERENCE Case, to providing steam for the steel mill with CO_2 capture.

To provide the extra steam demand by the CO_2 capture plant, a steam generation plant (SGP) was assumed. This is based on 8 trains of packaged water tube boilers each with a capacity of 60 tph delivering 9 Bar_a saturated steam. These boilers will be fuelled by the OBF Process Gas, Basic Oxygen Furnace Gas and Natural Gas as defined in Table C-10.

Table C-10: Steam Generation Plant Specification (Unit 2000)

UNIT 2000: SGP	Steel Mill with OBF/MDEA CO_2 Capture
Steam Production (Total)	**7,789,103 GJ/y (1.95 GJ/t HRC)**
Steam Generation Plant	8x Packaged Water Tube Boilers (@ 60 tph per boiler)
Boiler Efficiency	90.2%
Fuel Type (Thermal Input)	OBF-PG (39%), BOFG (31%), NG (30%)
Steam Output to CO_2 Capture Plant	1.95 GJ/t HRC (Steam @ 9 Bar_a, saturated)

4. CO_2 CAPTURE AND COMPRESSION PLANT

4.1. CO_2 Capture from OBF Top Gas via Chemical Absorption

The capture of CO_2 from the OBF top gas using chemical absorption has been previously evaluated by SINTEF [5] under the ULCOS programme. Given that OBF Top Gas has higher pressure and higher CO_2 concentration, this should allow the separation of the CO_2 with lower solvent reboiler duty (SRD). Additionally, another advantage comes from the fact that OBF top gas does not contain oxygen therefore should reduce oxidative degradation of the solvent.

SINTEF evaluated two different amine based solvents namely 2-Amino-2-Methyl-1-Propanol (AMP) and Methyl-Di-Ethanol Amine activated with Piperazine (MDEA/Pz). Performance of the AMP was compared against the performance of MDEA/Pz. They concluded that AMP would need a lower solvent reboiler duty, down to 2.0 GJ/t CO_2 as compared to 2.3-2.5 GJ/t CO_2 for MDEA/Pz.

Despite the better performance of the AMP, it was agreed that MDEA/Pz solvent should be used for this study, as the main objective of this work is to establish the baseline cost of capturing CO_2 from an integrated steel mill. Unlike AMP, MDEA/Pz is a solvent which is well established and commercially available (BASF, UOP, Shell, Ineos) with widely published engineering data and accessible cost data.

4.2. Study Specification, PFD and Mass Balance

The Steel Mill's CO_2 capture plant is based on 2 absorber columns and a common stripper column to separate CO_2 from the top gas of the two oxy-blast furnaces. The solvent used for this study is based on 40% MDEA and 10% Pz. The plant would handle ~860 kg CO_2/t HRC (~3.44 million t/y CO_2).

The main plant and equipment items for the CO_2 capture and compressor plants include:

- OBF Process Gas Compressors (1 per OBF)
- Direct Contact Coolers (1 per OBF)
- Absorber Columns (1 per OBF)
- Heat Integration and Exchangers Network (1 per OBF) – including intercoolers, lean/rich amine cross flow heat exchangers, flash columns
- Stripper Column (common to both absorber columns) – including condenser, flash column and reboiler.
- CO_2 drying and compression unit

This study estimated the diameter of the two absorber columns to be about ~9m with packing height ~14m. The stripper column would have a diameter of ~8.5 m and packing height ~6 m. The absorber columns will be equipped with water wash sections to minimise the amine slip. Figure C-4 presents the process flow diagram of the CO_2 capture plant. The details for the mass balance of this process is presented in Annex 3.

The steam and electricity demand of the CO_2 capture and compression plant is presented in Sections C-3.6 and C-3.7.

The CO_2 compression plant consists of 2 trains of 4 stage compressors with intercoolers and knockout drums, CO_2 dehydration unit and liquid CO_2 pump. After the 3rd compressor stage, the CO_2 is dried in a Tri-Ethylene Glycol (TEG) drying unit to ensure that CO_2 is dried to ~40 ppm water prior to the final 4th stage compression and pumping of the CO_2 to 110 bar_a. Figure C-5 presents the process flow diagram of the CO_2 drying and compression unit.

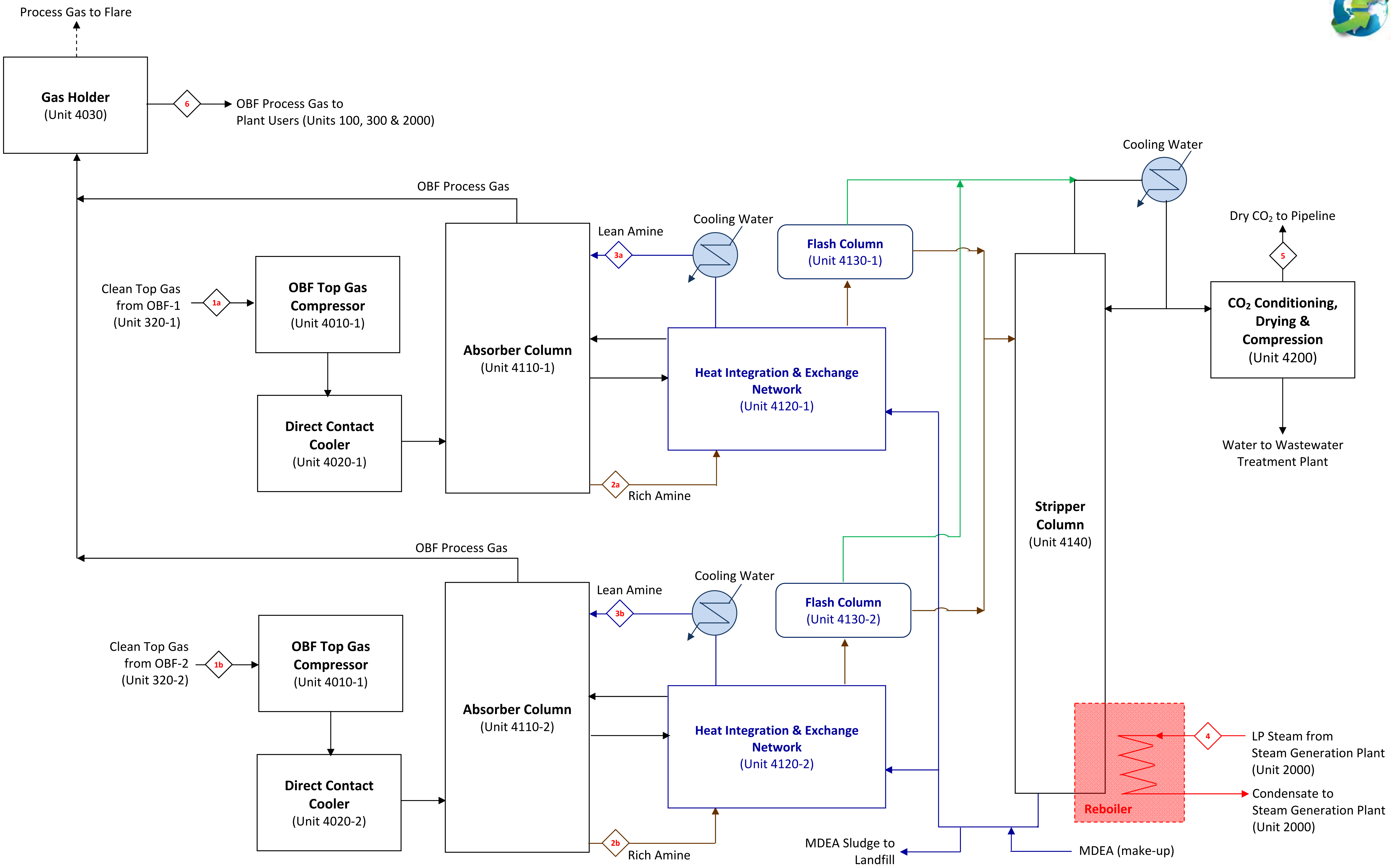

Figure C-4: Process Flow Diagram – CO2 Capture and Compression Plant

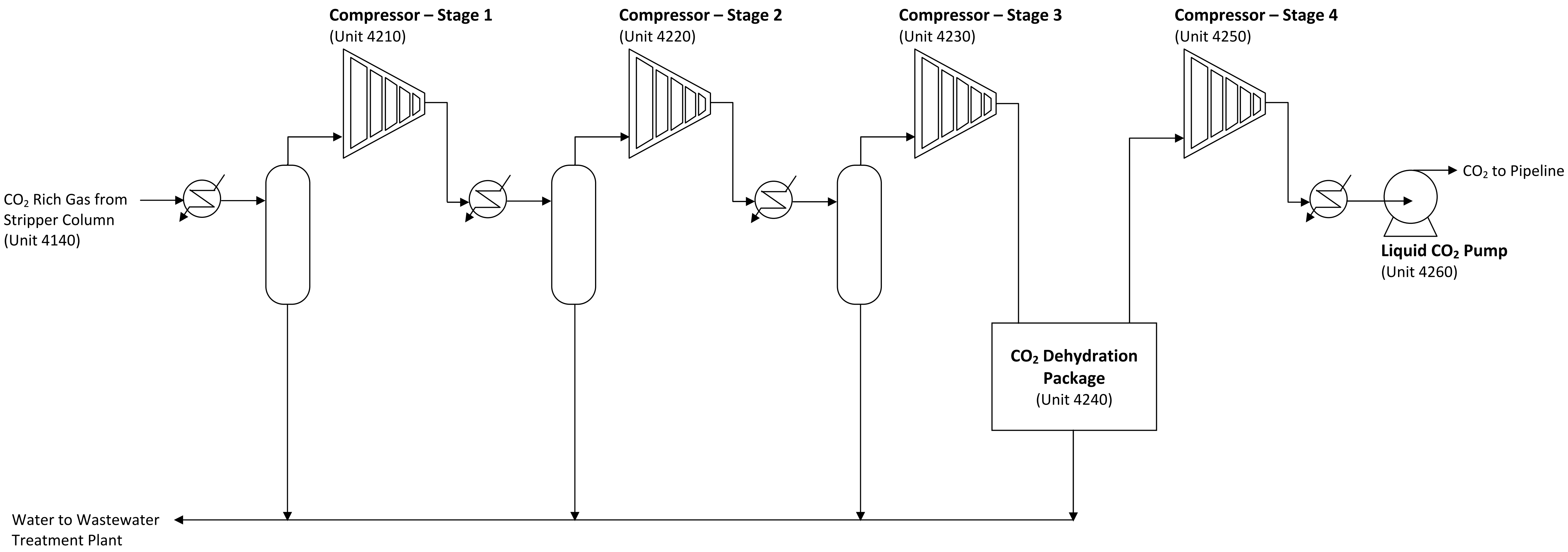

Figure C-5: PFD – CO_2 Compression Plant

5. OFF GASES – DEMAND AND SUPPLY

The introduction of the OBF changes the steel mill's utilisation of off-gases. Particularly, the following changes should be noted:

- Reduction of coke production reduces the coke oven gas supply available to the steel mill by 5% as compared to the REFERENCE Case. It should be noted that COG consumption of the coke plant (UNIT 100) has been reduced significantly from 45.9 Nm^3/t HRC (REFERENCE Case) to 13.2 Nm^3/t HRC (OBF Case) – replaced by OBF-PG export - therefore maximising COG export to the steel mill's other users (as illustrated in Table C-12).

- Introduction of the OBF and CO_2 capture results in the reduction of the off-gas export from the hot metal production. However, the fuel quality improves from that of a low CV off-gas (BFG for the REFERENCE Case 3.32MJ/Nm^3) to a medium CV off-gas (Process Gas for the OBF Case, 10.08 MJ/Nm^3).

To balance the demand and supply of the off-gases to the steel mill, additional natural gas is used. Thus the small amount of flaring of gas required to achieve a gas balance in the REFERENCE case is no longer required and it was assumed that coke oven gas and OBF process gas flaring is effectively zero although a minimal amount will be required to keep the flare alight.

Table C-11 summarised the fuel composition (dry basis) of the different off-gases available to the steel mill. Table C-12 summarise the demand and supply of the off-gases to the steel mill.

Table C-11: Fuel Gases Available to the Steel Mill without and with CO_2 Capture
(Gas Composition - %v Dry Basis)

Gas Composition (%v) Dry Basis	Natural Gas	Coke Oven Gas	Basic Oxygen Furnace Gas	Blast Furnace Gas	OBF Top Gas	OBF Process Gas
	NG	COG	BOFG	BFG	OBF-TG	OBF-PG
Available To:	Both Steel Mill	Both Steel Mill	Both Steel Mill	REF. Steel Mill	OBF Steel Mill	OBF Steel Mill
LHV (MJ/Nm^3 - Dry)	**40.64**	**18.05**	**8.50**	**3.32**	**6.81**	**10.08**
CH4	83.90	24.00	-	-	-	-
C2H6	9.20	-	-	-	-	-
C2.5H5	-	2.80	-	-	-	-
C3H8	3.30	-	-	-	-	-
C4H10	1.20	-	-	-	-	-
C5H12	0.20	-	-	-	-	-
H2	-	62.00	3.00	3.75	8.72	12.90
CO2	1.80	1.00	16.44	22.82	34.51	3.06
CO	-	4.00	64.81	23.07	46.52	68.86
O2	-	0.20	-	-	-	-
N2	0.40	6.00	15.75	50.36	10.25	15.17

Table C-12: Fuel Gases Demand and Supply - Steel Mill without and with CO_2 Capture

Coke Oven Gas	REFERENCE Case	OBF/MDEA Case
Production: COG By-Product Plants (Unit 100)	3,179 MJ/t HRC	2,425 MJ/t HRC
100: Coke Production - Underfiring Heating	796 MJ/t HRC	228 MJ/t HRC
100: Coke Production - Flares	84 MJ/t HRC	- MJ/t HRC
200: Sinter Production - Ignition Burners	81 MJ/t HRC	79 MJ/t HRC
300: Hot Metal Production - Hot Stoves	125 MJ/t HRC	- MJ/t HRC
500/600: Steelmaking - Ladle Heating & Flare	232 MJ/t HRC	232 MJ/t HRC
700: Continuous Casting - Tundish Heating, etc...	20 MJ/t HRC	20 MJ/t HRC
800: Reheating Furnace	1,474 MJ/t HRC	1,474 MJ/t HRC
1000: Lime Prouduction - Kilns	303 MJ/t HRC	302 MJ/t HRC
1300: Ancilliaries - PCI Coal Drying, Torpedo Heating, etc...	65 MJ/t HRC	90 MJ/t HRC

Blast Furnace Gas / OBF Process Gas	REFERENCE Case	OBF/MDEA Case
Production: Blast Furnaces (Unit 300)	5,149 MJ/t HRC	9,191 MJ/t HRC
100: Coke Production - Underfiring Heating	589 MJ/t HRC	829 MJ/t HRC
300: Hot Metal Production - Hot Stoves	1,510 MJ/t HRC	- MJ/t HRC
300: Hot Metal Production - Recycled Back to BF	- MJ/t HRC	7,517 MJ/t HRC
300: Hot Metal Production - Flares	73 MJ/t HRC	- MJ/t HRC
1200: Power Plant	2,976 MJ/t HRC	- MJ/t HRC
2000: Steam Boiler	- MJ/t HRC	845 MJ/t HRC

Basic Oxygen Furnace Gas	REFERENCE Case	OBF/MDEA Case
Production: Basic Oxygen Furnaces (Unit 500)	660 MJ/t HRC	660 MJ/t HRC
1200: Power Plant	660 MJ/t HRC	- MJ/t HRC
2000: Steam Generation Plant	- MJ/t HRC	660 MJ/t HRC

Natural Gas	REFERENCE Case	OBF/MDEA Case
From Pipeline - Import	850 MJ/t HRC	5,045 MJ/t HRC
300: Hot Metal Production - PG Fired Heaters	- MJ/t HRC	745 MJ/t HRC
1200: Power Plant	850 MJ/t HRC	3,647 MJ/t HRC
2000: Steam Generation Plant	- MJ/t HRC	653 MJ/t HRC

6. PERFORMANCE OF THE STEEL MILL WITH OBF & MDEA CO_2 CAPTURE – SYSTEM ENERGY ANALYSIS

6.1. Overall Energy Consumption of the Steel Mill

The reported performance remains based on the key assumption that there will be no import or export of energy in or out of the defined boundary limit.

Table C-13 presents the difference of the total energy consumed by the REFERENCE Steel Mill without CO_2 Capture and the Steel Mill with OBF/MDEA CO_2 Capture based on the difference between the energy content of the coking coal, PCI coal and natural gas as input and the energy content of the coking by-products as output.

Table C-13: Overall Energy Consumption - Steel Mill without and with CO_2 Capture

	REFERENCE Steel Mill without CO_2 Capture		Steel Mill with OBF/MDEA CO_2 Capture	
Energy Input				
Coking Coal	16.292	GJ/t HRC	12.428	GJ/t HRC
PCI Coal	5.032	GJ/t HRC	5.032	GJ/t HRC
Natural Gas	0.849	GJ/t HRC	5.045	GJ/t HRC
Energy Out				
Coking By-Products	0.903	GJ/t HRC	0.689	GJ/t HRC
Total Energy Consumption	**21.270**	**GJ/t HRC**	**21.816**	**GJ/t HRC**

The increase of just ~0.55 GJ/t HRC (only 2.6%) for the total energy consumed between the REFERENCE Steel Mill without CO_2 capture and Steel Mill with OBF/MDEA CO_2 Capture is worthy of note.

This study has identified significant scope for further improvements that could be employed in a steel mill with OBF and MDEA CO_2 capture. Thus it is highly probable that overall energy consumed could be at par or better than that consumed by the REFERENCE Steel Mill.

Improvements that could be employed include:

- Improvement to the energy requirements of the Air Separation Units
- Improvement to the Power and Steam Generation Plant (i.e. employing CHP/COGEN plant)
- Improvement to the CO_2 capture plant (i.e. better solvent such as AMP)
- Incorporating heat integration between steel mill and CO_2 capture plant[8]
- Exploring other options for steam generation by expanding the use of waste heat within the steel mill.
- Employing other CO_2 capture options (i.e. PSA, VPSA, etc...)[9]

[8] These improvements are very site specific; therefore, these are not evaluated in this study.
[9] Employing PSA, VPSA should reduce steam demand but increases the demand of electricity of the steel mill.

6.2. Fuel Balance of the Oxy-Blast Furnace

Considering only the performance of the oxy-blast furnace as compared to the conventional blast furnace, Table C-14 presents the gross and net fuel input of the hot metal production of the steel mill without and with CO_2 capture.

Table C-14: Gross and Net Fuel Input to the Hot Metal Production of the Steel Mill without and with CO_2 capture

	REFERENCE Steel Mill without CO_2 Capture		Steel Mill with OBF/MDEA CO_2 Capture	
Fuel Input				
Coke	10.212	GJ/t HRC	7.442	GJ/t HRC
PCI Coal	5.032	GJ/t HRC	5.032	GJ/t HRC
COG (Hot Stove)	0.125	GJ/t HRC	-	GJ/t HRC
NG (PG Fired Heaters)	-	GJ/t HRC	0.745	GJ/t HRC
Gross Fuel Input	**15.369**	**GJ/t HRC**	**13.219**	**GJ/t HRC**
Fuel Output				
BFG (Export)	(3.566)	GJ/t HRC	-	GJ/t HRC
OBF-PG (Export)	-	GJ/t HRC	(1.674)	GJ/t HRC
BFG/OBF-PG to Flare	(0.073)	GJ/t HRC	-	GJ/t HRC
Net Fuel Input	**11.730**	**GJ/t HRC**	**11.545**	**GJ/t HRC**

6.3. Off-Gas Balance of the Oxy-Blast Furnace

Tables C-15(a) and C-15(b) presents the overall fuel gas balance of the hot metal production of the steel mill without and with CO_2 capture.

Table C-15(a): Net Fuel Gas Export of the Hot Metal Production

	REFERENCE Steel Mill without CO_2 Capture		Steel Mill with OBF/MDEA CO_2 Capture	
BFG / OBF-PG				
BFG/OBF-PG Produced	5.149	GJ/t HRC	9.191	GJ/t HRC
BFG Used by Hot Stoves	(1.510)	GJ/t HRC	-	GJ/t HRC
OBF-PG Recycled Back to BF	-	GJ/t HRC	(7.517)	GJ/t HRC
BFG/OBF-PG to Flare	(0.073)	GJ/t HRC	-	GJ/t HRC
Other Fuel Gas Consumption				
COG to Hot Stoves	(0.125)	GJ/t HRC	-	GJ/t HRC
NG to OBF-PG Fired Heaters	-	GJ/t HRC	(0.745)	GJ/t HRC
Net Export (BF Off-Gas)	**3.441**	**GJ/t HRC**	**0.929**	**GJ/t HRC**

Table C-15(b): Actual Fuel Gas Export of the Hot Metal Production

	REFERENCE Steel Mill without CO_2 Capture		Steel Mill with OBF/MDEA CO_2 Capture	
BFG / OBF-PG				
BFG to Coke Plant	0.589	GJ/t HRC	0.829	GJ/t HRC
BFG to Power Plant	2.976	GJ/t HRC	-	GJ/t HRC
OBF-PG to Steam Gen. Plant	-	GJ/t HRC	0.845	GJ/t HRC
Actual Export (BF Off-Gas)	**3.566**	**GJ/t HRC**	**1.674**	**GJ/t HRC**

6.4. Electricity Consumption of the Oxy-Blast Furnace

Tables C-16 presents the breakdown of the electricity consumption of the hot metal production for the steel mill without and with CO_2 capture.

Table C-16: Breakdown of the Electricity Consumption of the Hot Metal Production

	REFERENCE Steel Mill without CO_2 Capture		Steel Mill with OBF/MDEA CO_2 Capture	
Main Air Compressors (Hot Blast)	68.286	kWh/t HRC	-	kWh/t HRC
OBF Process Gas Compressors	-	kWh/t HRC	54.770	kWh/t HRC
Other Consumers - BF Fans etc...	29.766	kWh/t HRC	29.765	kWh/t HRC
CO_2 Capture (excl. CO_2 Compression)	-	kWh/t HRC	18.481	kWh/t HRC
Sub-Total	98.051	kWh/t HRC	103.015	kWh/t HRC
ASU - Oxygen Production	26.138	kWh/t HRC	120.350	kWh/t HRC
Sub-Total	124.189	kWh/t HRC	223.365	kWh/t HRC
Coke Production for BF	12.322	kWh/t HRC	8.980	kWh/t HRC
Sinter Production for BF	35.564	kWh/t HRC	34.792	kWh/t HRC
Total (Electricity for HM Production)	**172.076**	**kWh/t HRC**	**267.138**	**kWh/t HRC**
CO_2 Compression (110 Bar_a)	-	kWh/t HRC	69.905	kWh/t HRC
Grand Total (incl. CO_2 delivery)	**172.076**	**kWh/t HRC**	**337.043**	**kWh/t HRC**

6.5. CO_2 Emissions of the Steel Mill

The breakdown of the CO_2 emissions from the different major processes of the Integrated Steel Mill without and with CO_2 Capture is summarised in Table C-17.

Table C-17: Breakdown of CO_2 Emissions - Steel Mill without and with CO_2 Capture

		REFERENCE Steel Mill without CO_2 Capture		Steel Mill with OBF/MDEA CO_2 Capture	
UNIT	CO_2 Emissions Breakdown – Major Processes	Emissions (kg/t HRC)	Annual Emission (t/y)	Emissions (kg/t HRC)	Annual Emission (t/y)
100	Flue Gas – Coke Oven	191.37	765,495	125.09	500,350
100	Flare – Coke Oven	3.30	13,196	-	-
200	Flue Gas – Sinter Plant (incl. CO emissions as CO2)	289.46	1,157,825	265.65	1,062,582
300	Flue Gas – Hot Stoves	415.19	1,660,769	-	-
300	Flue Gas - OBF Process Gas Fired Heaters	-	-	43.05	172,215
400/1300	Diffuse Emissions - HM Desulph. & Ancillaries (PCI Drying et. al.)	7.76	31,042	8.74	34,967
300	Flare – Blast Furnace	19.73	78,931	-	-
500/600	Flare (incl. losses) - BOF, Diffuse Emissions from SM	51.02	204,089	51.02	204,084
700	Diffuse Emissions – Continuous Casting	0.80	3,188	0.80	3,183
800	Flue Gas – Reheating Furnaces	57.71	230,833	57.71	230,833
900	Diffuse Emissions – Hot Rolling Mills	0.04	179	0.04	179
1000	Flue Gas – Lime Plant	71.62	286,493	71.43	285,729
1200	Flue Gas – Power Plant	982.13	3,928,513	211.10	844,398
2000	Flue Gas - Steam Generation Plant	-	-	280.12	1,120,487
1300	Ancillaries transport fuel emissions (trucks and rails)	4.00	16,000	4.00	16,000
Total Emissions		**2094.14**	**8,376,554**	**1118.75**	**4,475,007**
Total CO2 Captured		**-**	**-**	**859.80**	**3,439,360**

7. REFERENCES

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Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume III: Estimating the Cost of Steel Production from an Oxy-Blast Furnace with Top Gas Recycle and CO_2 Capture

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Section D

Economic Evaluation of Integrated Steel Mill with OBF and MDEA CO_2 Capture

I N D E X

1. INTRODUCTION

This section of the report describes the assessment of the CAPEX and OPEX of the Integrated Steel Mill equipped with OBF and MDEA CO_2 capture technology. The cost model was developed by Tata Steel Consulting based on the information regarding material usage, specification and capacity of individual processes as presented in Annex 3.

The main results for the cost of the producing HRC from an Integrated Steel Mill with CO_2 capture were compared to the results of the REFERENCE Integrated Steel Mill. The breakdown of the individual cost calculations is presented in Annex 5 and 6. Various sensitivities to the cost of steel production have also been evaluated.

2. FINANCIAL ASSUMPTIONS

The assumptions used in evaluating the cost of HRC production from the REFERENCE Steel Mill are also adopted in estimating the cost of HRC production from the Integrated Steel Mill with OBF and MDEA CO_2 Capture (Case 3). All the information necessary in defining the parameters (as enumerated below) are presented in Annex 4.

- Plant Location
- Plant Life
- Design and Construction Period
- Commissioning
- Decommissioning
- Capital Charges
- Recurring Capital Expenditure
- Working Capital
- Currency
- Inflation
- Depreciation
- Estimate Accuracy

3. FINANCIAL COST MODEL

3.1. Cost Model Overview

The cost model developed by Tata Steel Consulting is shown schematically in Figure D-1 illustrating the evaluation methodology for the direct cost of the steel production.

The model for the Integrated Steel Mill with OBF and MDEA CO_2 capture was adapted from the model developed for the REFERENCE Integrated Steel Mill. This is based on a transfer cost model wherein the operating cost of each major unit is transferred to the users of the intermediate raw materials, finally leading to the direct cost of the hot rolled coil.

The cost of the CO_2 capture and compression plant is transferred to the major units where CO_2 from flue gas or process gas is captured. For this case (steel mill with OBF and MDEA CO_2 Capture), the CO_2 has been captured from the hot metal production, therefore the direct cost of CO_2 capture and compression unit is all paid for by the hot metal production (Unit 300/400).

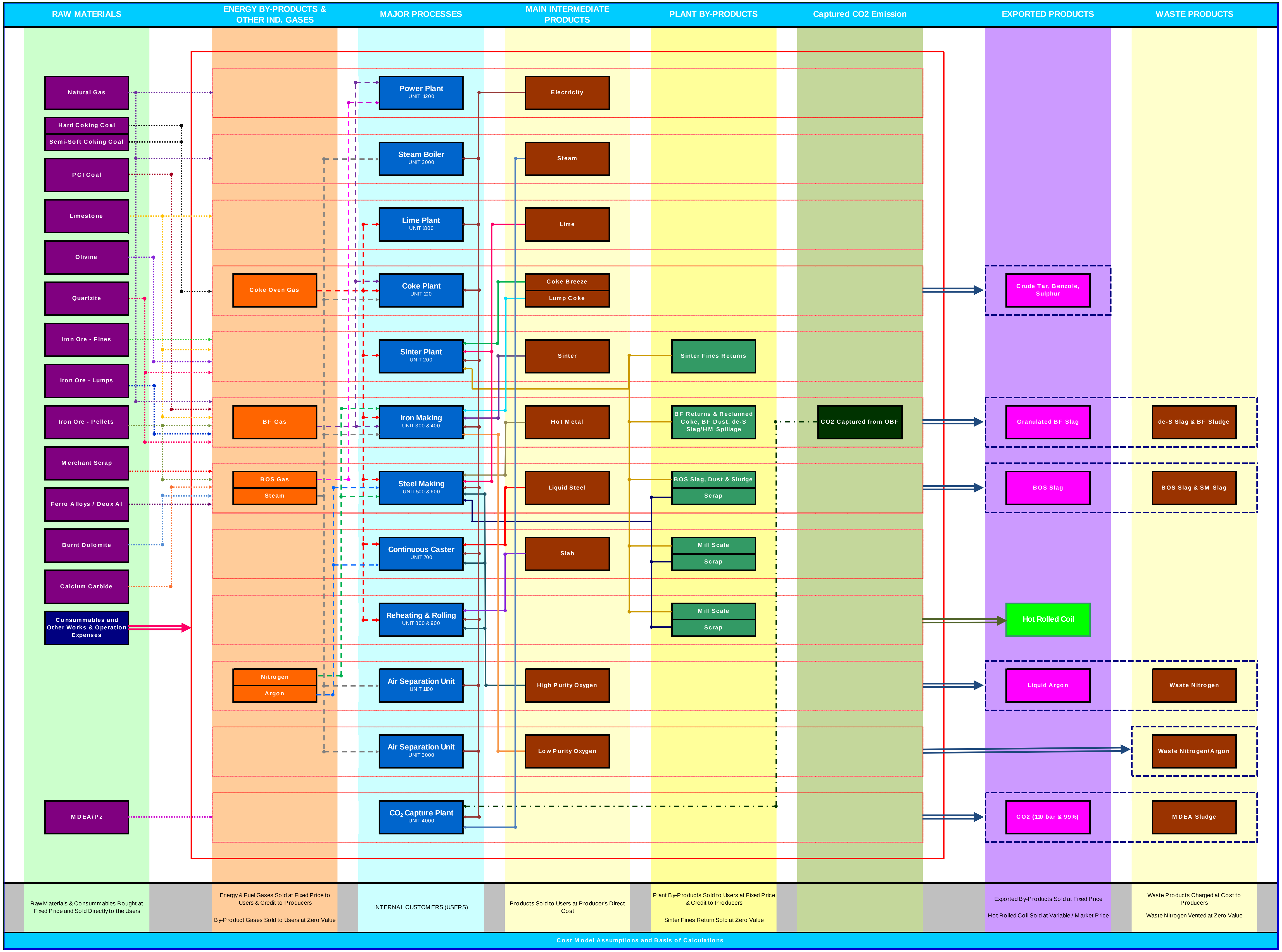

Figure D-1: Schematic representation of the cost model showing the evaluation of the direct cost of the integrated steel mill.

3.2. Database and Input Data

3.2.1. Price Database

The study has made extensive use of various databases from relevant publications and actual steel mill operational data (including information from Tata Steel Consulting Internal Database) to establish the key price inputs of the raw materials, consumables, disposal cost, and by-products – adjusted to reflet long term European price trends.

3.2.2. Summary - Key Price Inputs

Table D-1 presents the key price inputs for the raw materials, consumables, disposal cost, and by-products used in the cost evaluation of the operating expense of the Integrated Steel Mill with CO_2 Capture (OBF/MDEA Case).

Table D-2 presents the key price inputs for the internally traded by-products.

3.2.3. Summary – Annual Operating Data

The operating data used in the evaluation of the annual operating expenses of the Integrated Steel Mill equipped with OBF/MDEA CO_2 Capture is based on the mass balance of each plant/process as presented in Annex 3. The mass flow can be expressed as per unit product of the plant/process or as mass flow per unit of hot rolled coil.

Figures D-2 to D-4 presents an overview of these results. The different processes or units added due to CO_2 capture operation are highlighted as dark green boxes in the block diagrams.

Table D-1: Summary of Key Price Inputs of Raw Materials, Consumables, Disposal and By-Products Integrated Steel Mill with CO_2 Capture (OBF/MDEA Case)

	Unit	Unit Price
Iron Ore		
Fines (fob Brazil) – dry	dmtu of Fe	**$0.97**
Fines (fob Sweden) – dry	dmtu of Fe	**$1.06**
Fines (fob Australia) – dry	dmtu of Fe	**$0.95**
Pellets (fob Brazil) – dry	dmtu of Fe	**$1.44**
Lump (fob Australia) – dry	dmtu of Fe	**$1.23**
Energy		
Natural Gas (delivered)	GJ	**$9.77**
Coal		
Hard Coking Coal (fob Australia)	Tonne	**$148.00**
Semi-Soft Coking Coal (fob Australia)	Tonne	**$107.00**
PCI Coal (fob Australia)	Tonne	**$109.48**
Scrap		
Scrap – Rotterdam (Mixed)	Tonne	**$228.00**
Freight & Handling		
Voyage Rate - Iron Ore (Brazil - Netherlands)	Tonne	**$10.00**
Voyage Rate - Iron Ore (Scandinavia - Netherlands)	Tonne	**$5.00**
Voyage Rate - Iron Ore (Australia - Netherlands)	Tonne	**$22.00**
Voyage Rate - Coal (Australia - Netherlands)	Tonne	**$21.00**
Handling Charges - Iron Ore	Tonne	**$6.00**
Handling Charges - Coal	Tonne	**$6.00**
Fluxes and Ferro Alloys		
Limestone	Tonne	**$23.25**
Quartzite	Tonne	**$18.00**
Olivine	Tonne	**$17.00**
Burnt Dolomite (Dolomet)	Tonne	**$92.00**
Powder Calcium Carbide (CaC2)	Tonne	**$800.50**
FeMnC	Tonne	**$1,403.17**
FeSi75	Tonne	**$1,650.29**
Deox Al	Tonne	**$2,208.58**
By Products		
Crude Tar	Tonne	**$176.00**
Benzole/BTX	Tonne	**$466.17**
Sulphur	Tonne	**$85.00**
Slag (Blast Furnace)	Tonne	**$16.00**
Slag (BOS Furnace)	Tonne	**$2.00**
Argon (Sale)	Nm^3	**$0.93**
Other Consumables, Utilities and Disposal		
Water	m^3	**$0.11**
Refractories (Iron Making Production) – excl. Blast Furnace	Tonne	**$820.00**
Refractories (Steelmaking Production)	Tonne	**$847.00**
Refractories (Continuous Caster)	Tonne	**$630.00**
Electrodes (Secondary Steelmaking)	Tonne	**$4,057.00**
Casting Powder	kg	**$0.67**
Work Rolls - HRM	per tonne	**$2.25**
Banding	Tonne	**$0.09**
MDEA/Pz	Tonne	**$2,757.00**
Slag Processing	Tonne	**$5.89**
Slag Tip / Quench & Dig	Tonne	**$1.55**
BOS Slag Land Fill Tax	Tonne	**$3.87**
SM (Ladle) Slag Land Fill Tax	Tonne	**$86.79**
BF Sludge Disposal Charge	Tonne	**$20.00**
MDEA Sludge Disposal Charge	Tonne	**$634.00**
Site Haulage	Tonne	**$0.31**

Table D-2: Summary of Key Price Inputs of Raw Materials, Consumables, Disposal and By-Products Integrated Steel Mill with CO_2 Capture (OBF/MDEA Case)

	Unit	Unit Price
Energy		
Coke Oven Gas	GJ	**$9.77**
OBF Process Gas	GJ	**$9.77**
BOF Gas	GJ	**$9.77**
Scrap		
Scrap - Internal Arising (@ 85% of purchased scrap price)	Tonne	**$193.80**
Others		
Nitrogen (Internally Used)	Nm^3	**$0.00**
Argon (Internally Used)	Nm^3	**$0.00**
BF Undersize and Reclaimed Coke	Tonne	**$30.00**
BF/BOS Sludges & Dusts, HM Spillage, De-S Slag, etc.	Tonne	**$30.00**
Mill Scales	Tonne	**$20.00**
Slag Processing	Tonne	**$5.89**
Site Haulage	Tonne	**$0.31**

Production: 4,000,000 tonnes HRC/y
(YEAR 06)

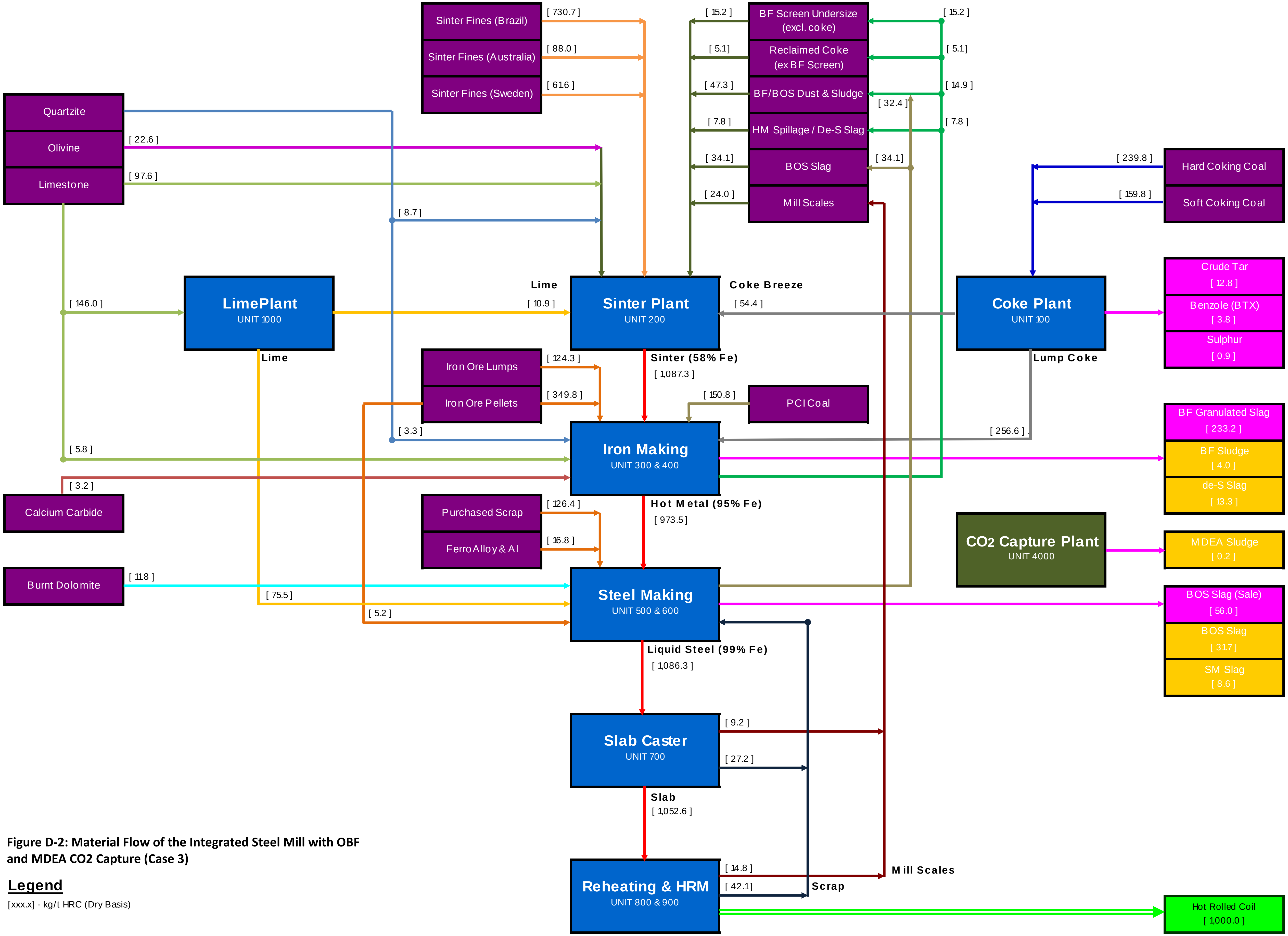

Figure D-2: Material Flow of the Integrated Steel Mill with OBF and MDEA CO2 Capture (Case 3)

Legend

[xxx.x] - kg/t HRC (Dry Basis)

Flow Sheet (Steel Mill Gas Network)
Application of CO_2 Capture to an Integrated Steelworks
Steel Mill with OBF & MDEA CO2 Capture (Case 3)

Production: 4,000,000 tonnes HRC/y
(YEAR 06)

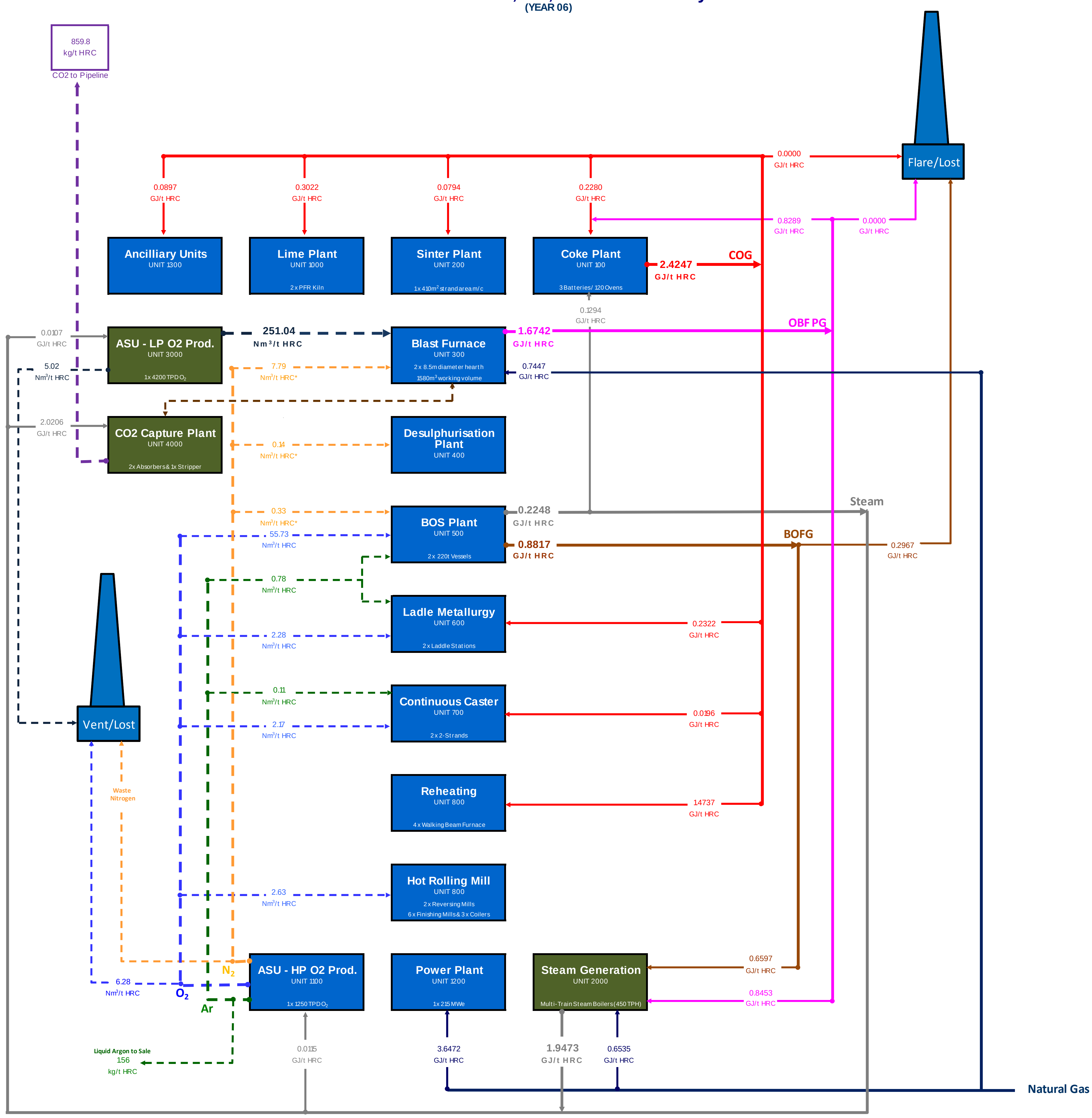

Figure D-3: Gas Network of the Integrated Steel Mill with OBF & MDEA CO_2 Capture (Case 3)
(Note: All numbers quoted in this flow diagram are on dry basis)

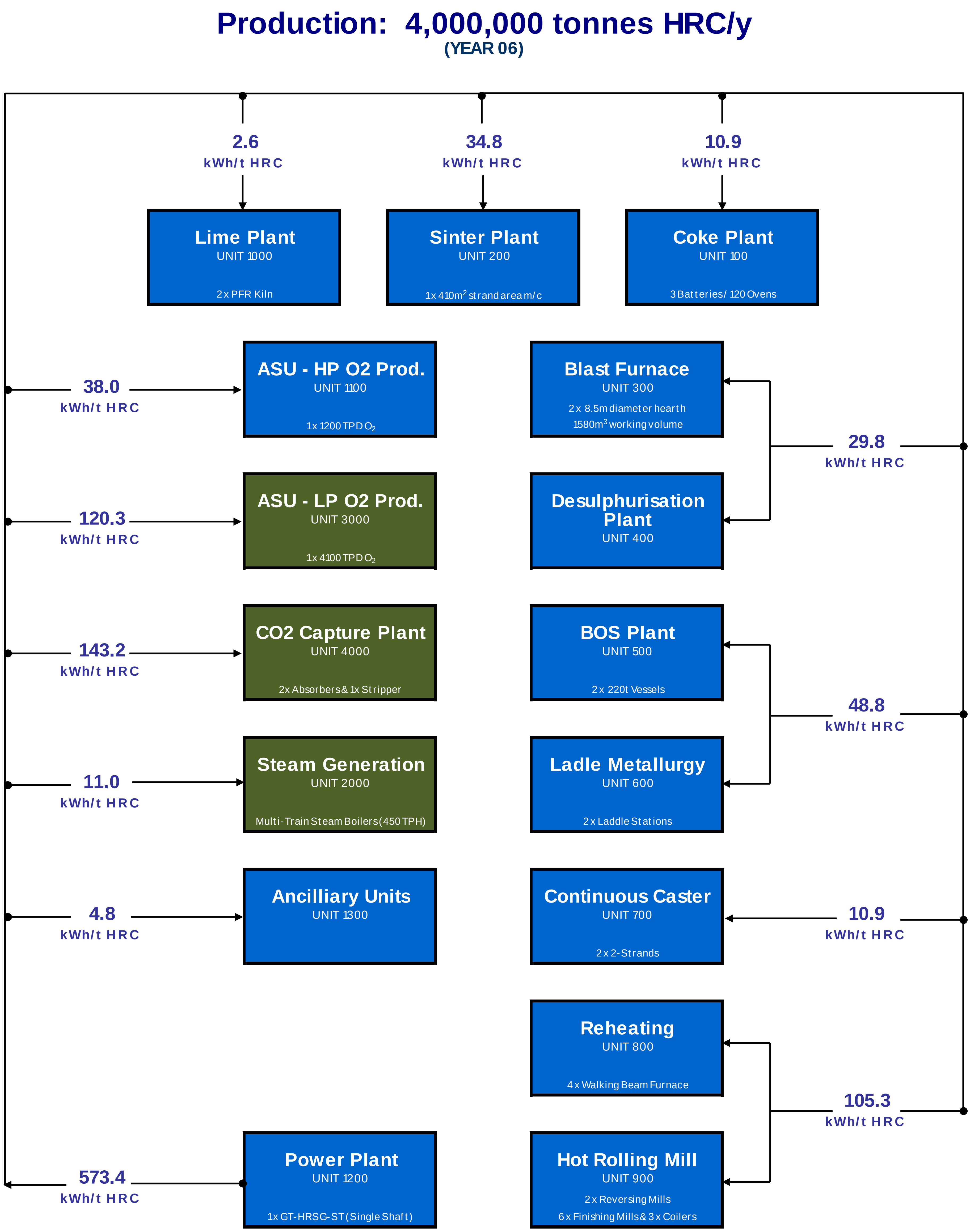

Figure D-4: Electricity Network of the Integrated Steel Mill with OBF and MDEA CO_2 Capture (Case 3)

4. INVESTMENT COST

The basis of estimating the total investment cost accounts for the following:

- Total installed cost for plant and equipment
- Site Development and Construction
- Recurring Capital Expenditure
- Contingency

4.1. Plant and Equipment – Major Processes

The capital cost of the major plant and equipment considered for the Integrated Steel Mill with CO_2 Capture are estimated based on the process specification as described in Section C.

The cost estimates are subdivided according to the following Units or Block of Units:

- UNIT 100: Coke Production
- UNIT 200: Sinter Production
- UNIT 300 & 400: Blast Furnace, Hot Stoves and HM Desulphurisation
- UNIT 500 & 600: Steelmaking, Ladle Metallurgy
- UNIT 700: Continuous Caster
- UNIT 800 & 900: Reheating Furnace and Hot Rolling Mills
- UNIT 1000: Lime Production
- UNIT 1100: High Purity Oxygen Production
- UNIT 1200: Power Plant
- UNIT 2000: Steam Generation Plant
- UNIT 3000: Low Purity Oxygen Production
- UNIT 4000: CO_2 Capture and Compression Plant

The total installed cost for each plant or process accounts for (but is not limited to):

- Direct material – including plant, equipment and bulk materials
- Plant Construction
  - Installation cost includes the mechanical erection, piping installation, etc...;
  - instrumentation, process control automation and electrical installation;
  - civil works, and where necessary other site preparation.
- EPC Services – including contractor's home office and construction supervision.
- Other Costs - including temporary buildings, training and plant start up (excl. spare parts and first fill).

The equipment cost was estimated from quoted prices from equipment suppliers and the database of Tata Steel Consulting, adjusted to 2010 prices. All capital cost estimates are within ±30% accuracy.

Table D-3 summarizes the investment breakdown and the total figures for each major Unit or Block of Units considered within the boundary limit of Steel Mill with CO_2 capture and this is compared with the capital cost of the "REFERENCE" Integrated Steel Mill without CO_2 Capture (as shown in Table D-4).

A list of major plant components accounting for the majority of the total equipment cost reported for each Unit or Block of Units is enumerated for illustration purposes only. A detailed list of the plant and equipment is not provided as this is not part of the scope of this study.

Table D-3: Capital Cost Allocation of the Major Processes
Integrated Steel Mill with CO_2 Capture (OBF and MDEA CO_2 Capture)

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)
100	**Coke Production** • Coke Oven Batteries (3x @ 40 ovens each) • No other changes to the list – See Vol. 1, Section E (Table E-4)	1.3 million tpy	310
200	**Sinter Production** • No changes to the list – See Vol. 1, Section E (Table E-4)	4.5 million tpy	220
300	**Blast Furnace / Hot Stoves (Iron Making)** • Raw material handling – conveyor & feed hoppers within the BF • Blast Furnace (2x BF @ 8.5m diameter/1580 m^3 working volume) o Bell Less Top Feeding System o PCI Coal Injection Facility (including PCI Coal Drying Unit) o Cast House and Dedusting Facility (Fabric Filter) o Hot Metal Tap o Slag Tap and Runner • BF Slag - Wet Granulation Plant o Settling Tank and Pumps o Cooling Tower o Air Compressors o Slag Pit / Stockyard • OBF Process Gas Fired Heater (3x HEX per OBF) o Combustion Air Blowers, FD and ID Fans • OBF Top Gas Processing o Primary Gas Cleaning (Cyclone) o Secondary Gas Cleaning (Wet Scrubber) o Dust and Sludge Handling	3.9 million tpy	610 (estimate incl. Unit 400)
400	**Hot Metal Desulphurization Plant** • No changes to the list – See Vol. 1, Section E (Table E-4)		See Unit 300

Table D-3 (cont'd): Capital Cost Allocation of the Major Processes
Integrated Steel Mill with CO_2 Capture (OBF and MDEA CO_2 Capture)

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)
500	**Basic Oxygen Steelmaking Plant** • No changes to the list – See Vol. 1, Section E (Table E-4)	4.4 million tpy	459 (estimate incl. Unit 600)
600	**Ladle Metallurgy (Secondary Steel Refining)** • No changes to the list – See Vol. 1, Section E (Table E-4)		See Unit 500
700	**Continuous Slab Caster** • No changes to the list – See Vol. 1, Section E (Table E-4)	4.3 million tpy	195
800 / 900	**Reheating Furnace & Hot Rolling Mills** • No changes to the list – See Vol. 1, Section E (Table E-4)	4.0 million tpy	450
1000	**Lime Production** • No changes to the list – See Vol. 1, Section E (Table E-4)	0.4 million tpy	16
1100	**ASU – High Purity Oxygen Production** • No changes to the list – See Vol. 1, Section E (Table E-4)	1100 tpd O_2	94

1200	**Power Plant (NGCC – Single Shaft Arrangement)**
	• Gas Turbine Island
	• Heat Recovery Steam Generation (Triple Pressure & IP Reheat)
	• Steam Turbine Island
	  o Steam Turbines and Condenser
	  o Cooling Water Pumps (seawater once through cooling)
	• Generator Set
		292 MWe	362

2000	**Steam Generation Plant**
	• Boiler Island
	  o 8x Packaged Water Tubes LP Steam Boilers @ 60 tph
	  o Combustion Air Blowers, FD and ID Fans
	  o Boiler Feed Water and Condensate Pumps
	• Steam Drum and Manifold
		450 tph	90

Table D-3 (cont'd): Capital Cost Allocation of the Major Processes Integrated Steel Mill with CO_2 Capture (OBF and MDEA CO_2 Capture)

Unit No.	Plant Section	Production Capacity	Total CAPEX (US$ Million)
3000	**ASU – Low Purity Oxygen Production** • Main Air Compressor • Air Pre-Treatment Plant • Cold Box (Heat Exchangers and Cryogenic Separation) • Product Compression Plant	4000 tpd O_2	134
4000	**CO_2 Capture and Compression Plant** • OBF Top Gas Compressors (2x) • Direct Contact Coolers (2x) • Absorber Columns (2x) – diameter & packing height: 9 x14 m o Rich/Lean MDEA Heat Exchangers o Lean Amine Coolers & Intercoolers, Cooling Water Pumps o Flash Drums o Amine Pumps • Stripper Column (1x) - diameter & packing height: 8.6 x 6 m o Reboiler, Condensate Pumps o Reflux drum o Reflux pump o Condenser, Cooling Water Pumps • CO_2 Compression Trains (2x) o CO_2 Compressors (4 Stages) o TEG Dehydration Unit • Water Treatment Plant and Cooling Water System • Gas Holder – OBF Process Gas o Gas Switch Over Station o Flaring System	3.5 million tpy	503

4.2. Plant and Equipment – Raw Materials Handling and Spare Parts

The total investment cost for raw material handling used in processing of iron ore and other raw materials were estimated at US$ 128 Million. Major components of this cost include the following:

- Ore unloaders (3x @1500 tph each)
- Stacker and Reclaimers (3x)
- Misc. material handling, screens, crushers, etc…
- Conveyors

The total investment costs for primary spare parts, tools, refractories for various furnaces, first fill and consumables used during the commissioning and plant start up were estimated at US$ 114 Million. A small reduction of ~$2 Million as compared to the REFERENCE Steel Mill is primarily due to changes in the coke and hot metal production.

4.3. Plant and Equipment – Auxiliary, Utilities and BOP

The total investment cost for the auxiliary plant and equipment was estimated at US$ 350 Million. It should be noted that there are no changes to this category as compared to the REFERENCE Steel Mill.

This cost category accounts for all utilities and balance of plant which include the following:

- Site Water Treatment Plant (used for cooling water system, demi-water plant, etc…)
- Site Waste Water Treatment Plant (excl. Coke Plant, CO_2 Capture & Compression Plant)
- Substation and HV Distribution Network
- Fire Fighting Systems
- Other Process Control Integration and Site Automation
- Computer Site Networks
- Workshop Equipment
- Laboratory Equipment
- Heavy Duty Cranes
- Light Cranes
- Torpedo Ladles (10x)
- Trains (3x)
- Vehicles & Cars

4.4. Site Development, Construction and Project Engineering

The overall project engineering and management, site construction, civil works and plant commissioning of the Steel Mill with CO_2 capture were estimated at a total cost of US$562 Million.

It should be noted that there are no changes to to this category as compared to the REFERENCE Steel Mill.

This cost breakdown for construction and commissioning includes the following:

- Pre-operating Expenses US$ 21 Million
- Land Preparation, Site Development & Waste Disposal 144 Million
- Project Engineering 201 Million
- Buildings and Site Infrastructure 196 Million

The pre-operating expenses include the feasibility and pre-engineering study, legal and planning activities, permitting, environmental impact assessment study, etc…

Land preparation, site development and waste disposal includes (but is not limited to) ground preparation for foundation work, survey, site preparation related civil works and construction related waste disposal.

Project engineering accounts for the process and engineering design, patent and licensing fees, plant commissioning, consultant's fee, etc...

The buildings and infrastructure accounts for the following development within the site:

- Support Building
- Auxiliary Buildings (10x at 200m^2 each)
- Workshops buildings
- Service Building
- Amenity Building
- Miscellaneous Site Offices
- Control Rooms – In plant and equipment
- Laboratory
- Sub Station
- Ware House
- Car Workshop
- Medical Centre
- Fire Station
- Main Entrance & Security
- Boundary Fence
- Road Network
- Rail Network
- Parking Areas
- Green Area @ 2% of Land
- Gas Station
- Water Storage
- Weigh Bridge
- Lighting (30m high lighting towers)
- Street Lightings
- Stocking Areas / Site Preparation (incl. installation of concrete slab/leachate drainage)

4.5. Recurring Capital Expenditure

The relining of the refractory and the replacement of cooling stave is the only recurring capital expenditure accounted for in this study. It was estimated at US$232 Million and disbursement will be made on every 15th year of the operation.

The study assumed that relining of the blast furnace should not affect the overall steel production capacity. This assumption is made for simplification purpose only.

4.6. Contingency

Contingency is a provisional sum to take into account of any possibility of cost overruns which is meant to cover any estimating errors or omissions. This has been determined on the basis of the estimate quality and methodology adopted to develop the estimates.

The contingency has been estimated at US$ 205 Million (which is approximately 5% of the total installed cost – excluding CAPEX for CO_2 Capture and Compression Plant and Blast Furnace Reline – Recurring CAPEX).

The contingency for the CO_2 capture and compression plant was estimated at US$ 75 Million (which is about 15% of the installed cost of CO_2 capture and compression plant). This high percentage reflects the uncertainty related to integration issues between steel and capture unit. This also includes the provision for the site development related to the CO_2 capture plant.

4.7. Summary of Results

4.7.1. Total Investment Cost

Table D-5 presents the summary of the total investment cost for the Integrated Steel Mill with CO_2 Capture and this is compared against the total investment cost for the REFERENCE Steel Mill.

4.7.2. Capital Expenditure

Capital Investment

The schedule for the infusion of the capital investment was described in Section E2.3.

Year	Capital Expenditure (% investment cost)	Capital Expenditure (US$ Million)
-3	10	903.6
-2	35	1,638.7
-1	30	1,310.4
1	20	839.3
2	5	184.1

Working Capital

The basis of calculation for the working capital is described in Section D2.7. The infusion of the required working/revolving capital to the operation of the steel mill was also assumed to follow the schedule of the ramping up of the operation during the first four years.

Year	Working Capital Investment Schedule (US$ Million)	Working Capital (US$ Million)
1	166	166
2	86	251
3	51	303
4	34	337
5 and onward	0	337

Table D-4: Summary of Results - Total Investment Cost

Unit No.	Plant Section	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
		Cost Breakdown	CAPEX (US$ Million)	Cost Breakdown	CAPEX (US$ Million)
Plant and Equipment – Major Processes			**$ 2,772**		**$ 2,940**
100	Coke Production	400		310	
200	Sinter Production	220		220	
300 & 400	Blast Furnace and Hot Metal Desulphurisation	622		610	
500 & 600	Basic Oxygen Steelmaking and Ladle Metallurgy	459		459	
700	Continuous Slab Caster	195		195	
800 & 900	Reheating Furnace & Hot Rolling Mills	450		450	
1000	Lime Production	16		16	
1100	ASU – High Purity O_2 Production	130		94	
1200	Power Plant	280		362	
2000	Steam Generation Plant	-		90	
3000	ASU – Low Purity O_2 Production	-		134	
Plant and Equipment – Material Handling & Spare Parts			**244**		**242**
	Raw Material Handling	128		128	
	Spare Parts and First Fill	116		114	
Plant and Equipment – Auxiliary, Utilities and BOP			**350**		**350**
Site Development, Construction and Project Engineering			**562**		**562**
	Pre-operating Expenses	21		21	
	Land Preparation, Site Development & Waste Disposal	144		144	
	Buildings and Site Infrastructure	196		196	
	Project Engineering	201		201	
Total Installed Cost - Steel Mill (US$ Million)			**3,928**		**4,094**
Contingency @ 5% of Total Installed Cost - Steel Mill			**196**		**205**
CO_2 Capture and Compression Plant			**-**		**578**
4000	Plant & Equipment, First Fill, Spare Parts, BOP, Site Dev.	-		503	
	Contingency (15% of Installed Cost – CO_2 Capture Plant)	-		75	
Total Investment Cost – excl. Recurring CAPEX (US$ Million)			**4,124**		**4,877**
Recurring CAPEX (Blast Furnace Reline – Every 15th Year)			**232**		**232**
Specific Investment Cost – excl. Recurring CAPEX (US$ / t HRC)			**1,031**		**1,219**

5. ANNUAL OPERATING AND MAINTENANCE COST

The basis of calculation of the annual operating and maintenance cost accounts for the following:

- Fixed Cost
    - Maintenance Cost
    - Direct Labour Cost
    - Indirect Labour, Management and Overhead Cost

- Variable Cost
    - Energy and Reluctant
    - Raw Materials
    - Fluxes
    - Consumables
    - Utilities

- Other Cost
    - Miscellaneous Works Expenses
    - Other Operational Expense (Environmental Clean Up, etc...)
    - On-Site Haulage Fee
    - Slag Processing Fee
    - Disposal and Landfill Cost

The calculation of these cost are described in Volume 1 of this report. The breakdown of these cost for the Steel Mill with OBF and MDEA CO_2 capture are presented in Annex 5.

This section will only highlight the summary of results for the Integrated Steel Mill with OBF and MDEA CO_2 Capture and compared against the annual O&M cost of the REFERENCE Steel Mill without CO_2 capture.

The differences in the cost of annual O&M of the OBF Case as compared to the REFERENCE Case involve the following items:

- Annual Maintenance Cost
- Direct Labour Cost
- Fuel Cost (Coking Coal and Natural Gas)
- Raw Material Cost (Limestone and Quartzite)
- Chemical and Consumables (Power Plant and Steam Generation Plant)
- Annual Water Consumption
- Disposal and Landfill Cost (MDEA Sludge Disposal)

The breakdown of these differences are summarised in Tables D-5 to D-14.

5.1. Fixed Cost

5.1.1. Maintenance

The annual maintenance costs of the Steel Mill with and without CO_2 capture are summarised in Table D-5.

Table D-5: Annual Maintenance Cost of the Integrated Steel Mill without and with CO_2 Capture

Unit No.	Plant / Process	REFERENCE Steel Mill		Steel Mill with OBF/MDEA	
		(% CAPEX)	Maintenance Cost (US$ Million/y)	(% CAPEX)	Maintenance Cost (US$ Million/y)
100	Coke Production	5.0%	20.000	5.0%	15.500
200	Sinter Production	5.0%	11.000	5.0%	11.000
300 & 400	Hot Metal Production & Desulphurisation	4.0%	24.880	4.0%	24.400
500 & 600	BOF Steelmaking and Ladle Metallurgy	5.0%	22.950	5.0%	22.950
700	Continuous Slab Caster	8.0%	15.636	8.0%	15.636
800 & 900	Reheating Furnace & Hot Rolling Mills	8.0%	36.000	8.0%	36.000
1000	Lime Production	8.0%	1.280	8.0%	1.280
1100	ASU – HP O2 Production	2.5%	3.250	2.5%	2.350
1200	Power Plant	2.5%	7.000	4.0%	14.469
2000	Steam Generation Plant	-	-	2.5%	2.250
3000	ASU – HP O2 Production	-	-	2.5%	3.350
4000	CO_2 Capture and Compression Plant	-	-	2.5%	14.448
Annual Maintenance Cost			**$141.996 Million/y**		**$163.333 Million/y**

5.1.2. Direct Labour

Table D-6 presents the number of personnel who are directly engaged in the operation of the steel mill without and with CO_2 capture. The direct labour cost was estimated by assuming that each personnel has an average salary of US$ 94,000 per year (incl. social benefits).

Table D-6: Direct Labour Cost of the Integrated Steel Mill without and with CO_2 Capture

Unit No.	Plant / Process	REFERENCE Steel Mill		Steel Mill with OBF/MDEA	
		No. of Personnel	Direct Labour Cost (US$ Million/y)	No. of Personnel	Direct Labour Cost (US$ Million/y)
100	Coke Production	240	22.560	191	17.954
200	Sinter Production	270	25.380	270	25.380
300 & 400	Hot Metal Production & Desulphurisation	321	30.174	321	30.174
500 & 600	BOF Steelmaking and Ladle Metallurgy	396	37.224	396	37.224
700	Continuous Slab Caster	360	33.840	360	33.840
800 & 900	Reheating Furnace & Hot Rolling Mills	480	45.157	480	45.157
1000	Lime Production	34	3.1960	34	3.1960
1100	ASU – HP O2 Production	35	3.290	25	2.350
1200	Power Plant	40	3.760	42	3.948
2000	Steam Generation Plant	-	-	12	1.128
3000	ASU – LP O2 Production	-	-	35	3.290
4000	CO_2 Capture and Compression Plant	-	-	20	1.880
Annual Direct Labour Cost		**2176**	**$204.581 Million/y**	**2186**	**$205.521 Million/y**

5.1.3. Indirect Labour, Corporate and Management Overheads

The annual fixed indirect labour cost for both Steel Mills without and with CO_2 capture was estimated at US$ 76.14 Million per year for both REFERENCE and OBF Cases. This consists of 810 personnel having an average salary of US$ 94,000 per person per year. The indirect labour cost represents about 37.2% and 37.0% of the direct labour cost of the steel mill without and with CO_2 capture respectively.

5.2. Energy and Reductant (Externally Sourced)

Externally sourced energy and reductants include:

- Coking Coal (Hard and Semi-Soft)
- PCI Coal
- Natural Gas

5.2.1. Coking Coal and PCI Coal

The annual cost of coking and PCI coal consumed by the steel mill without and with CO_2 capture, when operating at full capacity is presented in Table D-7.

It should be re-emphasised that due to the recycling of the OBF Process Gas rich in CO to the blast furnace, the coke consumption of the Hot Metal production for the steel mill with OBF/MDEA CO_2 capture case was reduced by ~27%, consequently also reducing coking coal consumption by ~24% (mass basis).

5.2.2. Natural Gas

The annual cost of natural gas consumed by the steel mill operating with OBF/MDEA CO_2 capture at full production capacity was estimated as US$197.173 Million per year. This is an increase of ~6 fold as compared to the natural gas consumption of the REFERENCE steel mill which was estimated at US$ 33.203 Million per year.

The increase in annual NG bill is illustrated in Table D-8.

It could be noted that increase in natural gas annual bill is due to the pattern of consumption has changed. This include the consumption of the natural gas by the OBF Process Gas Fired Heaters – Hot Metal Production (Unit 300) to preheat the top gas to 900^{o}C; as supplementary fuel used by the Steam Generation Plant (Unit 2000) to meet the steam demand of the CO2 capture plant (Unit 4000); and as primary fuel to the power plant (Unit 1200) to meet electricity demand of the steel mill.

Table D-7: Annual Cost and Consumption of Coking and PCI Coal

Cost Items	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
	Annual Consumption (t/y)	Annual Cost (US$ Million/y)	Annual Consumption (t/y)	Annual Cost (US$ Million/y)
100: Coke Production				
Hard Coking Coal	1,257,292	**239.159**	959,048	**182.428**
Semi-Soft Coking Coal	838,194	**122.085**	639,365	**93.125**
200: Hot Metal Production				
PCI Coal	603,251	**89.491**	603,233	**89.488**
Coal Consumption Cost (US$ Million/y)		**450.735**		**365.041**

Table D-8: Annual Natural Gas Cost of the Integrated Steel Mill without and with CO_2 Capture

Cost Items	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
	Annual Consumption (PJ/y)	Annual Cost (US$ Million/y)	Annual Consumption (PJ/y)	Annual Cost (US$ Million/y)
300: HM Production (OBF PG Fired Heaters)	-	-	2.9789	**29.104**
1200: Power Plant	3.3985	**33.203**	14.5887	**142.532**
2000: Steam Generation Plant	-	-	2.6138	**25.537**
NG Consumption Cost (US$ Million/y)		**33.203**		**197.173**

5.3. Raw Materials (Externally Sourced)

Externally sourced raw materials include:

- Iron Ores (Fines, Lumps and Pellets)
- Purchased Scrap
- Ferroalloys
- Fluxes (Limestone, Quartzite, Olivine, Calcium Carbide Powder)

5.3.1. Iron Ores (Fines, Lumps and Pellets), Purchased Scrap and Ferroalloys

It could be noted that adjustment made in the operation of the sinter production (i.e. CaO/SiO_2 ratio reduction from 1.80 to 1.65) and associated changes in the operation of the blast furnace due to reduction of coke consumption resulted in small adjustments to the consumption of the iron ore fines, lumps and pellets. This caused a small increase in the annual cost of the iron ore by US$ 0.24 Million per year for the steel mill with OBF / MDEA CO_2 capture as compared to the REFERENCE steel mill. This is illustrated in Table D-9.

There are no changes in the consumption and annual cost of the merchant scrap and ferroalloys used by the steel mill without and with CO_2 capture.

5.3.2. Fluxes

The annual cost for the fluxes used by the steel mill without and with CO_2 capture is summarised in Table D-10.

As mentioned earlier, the adjustment made in the operation of the sinter production and associated changes in the operation of the blast furnace reduced the limestone, quartzite and olivine consumption of the steel mill. This caused a cost reduction of US$4.56 million per year for the steel mill with CO_2 capture as compared to the REFERENCE steel mill without CO_2 capture.

There are no changes in the consumption and annual cost of the calcium carbide used by the hot metal desulphurisation (Unit 400) or burnt dolomite used by the liquid steel production (Unit 500/600) for both steel mills without and with CO_2 capture.

Table D-9: Annual Metallic Burden Cost of the Integrated Steel Mill without and with CO_2 Capture

Cost Items	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
	Annual Consumption (t/y)	Annual Cost (US$ Million/y)	Annual Consumption (t/y)	Annual Cost (US$ Million/y)
200: Sinter Production				
Iron Ore Fines (Brazil)	2,923,276	**234.488**	2,922,836	**234.452**
Iron Ore Fines (Australia)	352,202	**29.149**	352,149	**29.145**
Iron Ore Fines (Sweden)	246,541	**20.945**	246,504	**20.942**
200: Hot Metal Production				
Iron Ore Lumps (Australia)	497,139	**51.069**	497,124	**51.067**
Iron Ore Pellets (Brazil)	1,396,178	**154.026**	1,399,333	**154.374**
500 & 600: Liquid Steel Production				
Merchant Scrap	505,492	**115.252**	505,492	**115.252**
Iron Ore Pellets	21,544	**2.377**	20,944	**2.311**
Ferro-Manganese Carbide (FeMnC)	47,798	**67.068**	47,798	**67.068**
Ferro-Silicon (FeSi-75)	13,036	**21.513**	13,036	**21.513**
De-ox Aluminium	6,518	**14.395**	6,518	**14.395**
Annual Cost (US$ Million/y)		**710.28**		**710.52**

Table D-10: Annual Flux Consumption Cost of the Integrated Steel Mill without and with CO_2 Capture

Cost Items	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
	Annual Consumption (t/y)	Annual Cost (US$ Million/y)	Annual Consumption (t/y)	Annual Cost (US$ Million/y)
200: Sinter Production				
Limestone	517,872	**12.040**	390,306	**9.074**
Quartzite	53,347	**0.960**	34,792	**0.626**
Olivine	90,349	**1.536**	90,335	**1.536**
200: Hot Metal Production				
Limestone	52,497	**1.220**	23,164	**0.539**
Quartzite	43,129	**0.776**	13,237	**0.238**
400: Hot Metal Desulphurisation				
Calcium Carbide	12,710	**10.168**	12,708	**10.167**
500 & 600: Liquid Steel Production				
Burnt Dolomite	47,164	**4.339**	47,164	**4.339**
1000: Lime Production				
Limestone	585,449	**13.611**	583,818	**13.573**
Annual Cost (US$ Million/y)		**44.650**		**40.091**

5.4. Consumables and Other Utilities

This section summarizes the annual consumption and cost of various consumables and raw water used by the steel mill when operating at full capacity.

Consumables included in the accounting of annual operating expense are:

- Refractories (iron making, steelmaking, casting)
- Electrodes (ladle metallurgy)
- Casting Powder (continuous casters)
- Works Back Up Rolls (hot rolling mills)
- Banding (hot rolling mills)
- Chemicals and Consumables (power plant and steam generation plant)
- Raw Water

As compared to the REFERENCE steel mill without CO_2 capture, the increase in annual cost for consumables and other utilities are due to the following:

- Added cost for chemical and consumables used by the steam generation plant.
- Added cost for chemical and consumables primarily due to the MDEA/Pz make up solvent of CO_2 capture and compression plant.
- Increase of water bill due to the CO_2 capture and compression plant.

The breakdowns of the annual consumable and raw water cost are presented in Tables D-11 and D-12 respectively.

5.5. Miscellaneous and Other O&M Cost

5.5.1. Miscellaneous Cost

Miscellaneous expenses primarily consist of various services required by the plant to support production operation. This includes services related to – logistics, engineering, analysis, infrastructure, HR, information, etc... The other Misc. Expenses include environmental clean-up related expenses which include reagents used in all water and waste treatment plants, cleaning, etc...

The breakdown of this cost for each plant and process is summarised in Table D-13. These costs were recommended by Tata Steel Consulting based on their internal database.

A small reduction of ~US$ 3.2 Million per year was estimated in the miscellaneous costs for the steel mill with CO_2 capture as compared to the REFERENCE steel mill and this is due to the reduction of coke production.

5.5.2. Other O&M Cost

Other O&M cost includes (a.) Slag Processing Fee, (b.) On-Site Haulage Fee, and (c.) Disposal and Landfill Cost. The breakdown of this cost is summarised in Table D-14.

Added cost for disposal of the MDEA sludge from the CO_2 capture and compression plant is the main reason for the increase of this cost item as compared to the REFERENCE steel mill without CO_2 capture as illustrated in Table D-14.

Table D-11: Annual Consumable Cost of the Integrated Steel Mill without and with CO_2 Capture

Cost Items	REFERENCE Steel Mill	Steel Mill with OBF / MDEA CO_2 Capture
	Annual Cost (US$ Million/y)	Annual Cost (US$ Million/y)
Refractories (Various Users)	22.603	22.603
Electrode (Ladle Metallurgy)	5.289	5.289
Casting Power (Continuous Caster)	2.257	2.257
Works Back Up Rolls (Hot Rolling Mills)	9.000	9.000
Banding (Hot Rolling Mills)	0.360	0.360
Chemical and Consumables (Power Plant)	7.880	7.880
Chemical and Consumables (Steam Generation Plant)	-	4.350
Chemical and Consumables (CO_2 Capture Plant)	-	1.896
Annual Consumables Cost (US$ Million/y)	**47.389**	**53.635**

Table D-12: Annual Raw Water Cost of the Integrated Steel Mill without and with CO_2 Capture

Cost Items	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
	Annual Consumption (m^3/y)	Annual Cost (US$ Million/y)	Annual Consumption (m^3/y)	Annual Cost (US$ Million/y)
100: Coke Production	2,931,317	0.333	2,236,247	0.254
200: Sinter Production	1,324,616	0.150	1,296,015	0.147
300/400: Hot Metal Production	3,483,639	0.396	2,923,682	0.332
500/600: Liquid Steel Production	1,673,679	0.190	1,673,679	0.190
700: Continuous Casting	3,655,576	0.415	3,655,576	0.415
800/900: Hot Rolling Mills	8,000,000	0.908	8,000,000	0.908
4000: CO_2 Capture and Compression Plant	-	-	10,557,185	1.199
Annual Cost (US$ Million/y)		**2.392**		**3.445**

Table D-13: Miscellaneous Expense of the Integrated Steel Mill without and with CO_2 Capture

Cost Items	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
	Misc. Works Expense (US$ Million/y)	Other Misc. OPEX (US$ Million/y)	Misc. Works Expense (US$ Million/y)	Other Misc. OPEX (US$ Million/y)
100: Coke Production	9.801	3.703	7.476	2.824
200: Sinter Production	3.206	1.603	3.206	1.603
300/400: Hot Metal Production	10.403	1.300	10.403	1.300
500/600: Liquid Steel Production	10.738	2.844	10.738	2.844
700: Continuous Casting	5.905	0.956	5.905	0.956
800/900: Hot Rolling Mills	7.747	1.443	7.747	1.443
1000: Lime Production	2.598	-	2.591	-
Annual Cost (US$ Million/y)	50.398	11.849	48.066	10.970

Table D-14: Other O&M Cost of the Steel Mill without and with CO_2 Capture

Cost Items	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
	Tonnage (t/y)	Annual Cost (US$ Million/y)	Tonnage (t/y)	Annual Cost (US$ Million/y)
Slag Processing Fee				
400: HM Spillage and De-S Slag	84,235	**0.496**	84,232	**0.496**
500: BOS (LD Slag)	488,920	**2.880**	487,185	**2.869**
600: Ladle Metallurgy Slag (SM Slag)	34,412	**0.203**	34,412	**0.203**
On-Site Haulage Fee				
300/400: Hot Metal Production	181,493	**0.056**	172,153	**0.053**
500/600: Steelmaking	369,213	**0.114**	368,727	**0.114**
700: Continuous Casting	145,403	**0.045**	145,403	**0.045**
800/900: Reheating & HRM	168,421	**0.052**	168,421	**0.052**
Disposal and Landfill Cost				
300: BF Sludge	15,875	**0.318**	15,875	**0.317**
400: HM Spillage and De-Slag	53,068	**0.288**	53,066	**0.288**
500: Basic Oxygen Steelmaking Slag	127,124	**0.690**	126,673	**0.687**
600: Ladle Metallurgy Slag	34,412	**3.040**	34,412	**3.040**
4000: MDEA Sludge	-	-	688	**0.436**
Annual Cost (US$ Million/y)		**8.181**		**8.602**

5.6. SUMMARY OF RESULTS

Table D-15 presents a summary of the annual O&M cost of the "REFERENCE" integrated steel mill without CO_2 capture (Base Case) and steel mill with OBF /MDEA CO_2 capture.

Table D-15: Summary of Results – Annual O&M Cost

Cost Items	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
	Cost Breakdown	OPEX (US$ Million/y)	Cost Breakdown	OPEX (US$ Million/y)
Fixed O&M Cost		**422.717**		**445.294**
Annual Maintenance Cost	141.996		163.633	
Direct Labour Cost	204.581		205.521	
Indirect Labour Cost	76.140		76.140	
Variable O&M Cost		**1288.650**		**1369.904**
Fuel and Reductant	483.938		562.214	
Iron Ore (Fines, Lumps and Pellets)	492.054		492.291	
Purchased Scrap and Ferroalloys	218.228		218.228	
Fluxes	44.650		40.091	
Consumables & Other Utilities	49.781		57.080	
Other Works Expense and Service Charges		**62.247**		**59.036**
Miscellaneous Works Expense	50.398		48.066	
Other Misc. OPEX (incl. environmental clean-up)	11.849		10.970	
Other O&M Cost		**8.181**		**8.602**
Slag Processing	3.578		3.568	
On-Site Haulage	0.268		0.265	
Disposal and Landfill	4.335		4.769	
Annual O&M Cost (US$ Million/y)		**1,781.795**		**1,882.835**

6. ANNUAL REVENUES FROM SALE OF STEEL MILL'S BY-PRODUCTS

The study assumed that only the following by-products were sold from the steel mill:

- Coke By-Products (Crude Tar, Benzole, Sulphur)
- Granulated BF Slag
- BOS Slag
- Argon

In the cost model developed and presented by Tata Steel Consulting, it was assumed that:

- All by-products are sold at fixed price (as shown in Table D-1)
- All sale of these by-products are credited to the producer

Table D-16 presents a summary of the annual revenues derived from the by-products sale of the "REFERENCE" integrated steel mill without CO_2 capture (Base Case) and steel mill with OBF /MDEA CO_2 capture.

The revenues from the sale of the steel mill's by-products for the steel mill with OBF/MDEA CO_2 capture were significantly reduced by ~35% or US$18.71 Million/y as compared to the REFERENCE case. This is due to the reduced capacity for both the coke production and high purity oxygen production, which reduces the production of the coke by-products and liquid argon respectively. Additionally, the OBF would also have reduced the granulated BF slag production due to the adjustment made to the basicity of the sinter and reduced flux consumption.

Table D-16: Revenues from Sale of Steel Mill's By-Products

Cost Items	REFERENCE Steel Mill		Steel Mill with OBF / MDEA CO_2 Capture	
	Tonnage (t/y)	Annual Sales (US$ Million/y)	Tonnage (t/y)	Annual Sale (US$ Million/y)
100: Coke By-Products				
Crude Tar	67,080	**11.806**	51,168	**9.005**
Benzole	19,729	**9.197**	15,049	**7.016**
Sulphur	4,937	**0.420**	3,766	**0.320**
Steel Mill Slag				
300: Granulated BF Slag	1,111,252	**17.780**	932,630	**14.922**
500: BOS Slag (LD Slag)	224,903	**0.450**	224,105	**0.448**
1100: Liquid Argon	26,918	**14.018**	6,237	**3.248**
Annual Revenues (US$ Million/y)		**53.670**		**34.959**

7. VALUES OF INTERNALLY TRADED BY-PRODUCTS

By-Products that are internally traded include:

- Recycled Materials
  - BF undersize (ex-BF screens)
  - Reclaimed coke (ex-BF screens)
  - BF dust
  - Hot metal spillage & de-S slag
  - BOS dust & sludge (LD dust & sludge)
  - BOS slag (LD slag)
  - Mill scales
  - Scrap (internally generated)
- Off-gases
  - Coke oven gas (COG)
  - Blast furnace gas (BFG)
  - Basic oxygen furnace gas (BOFG)
- Steam
- Industrial gases (internally used)
  - Nitrogen
  - Argon

This section summarised the value of the internally traded by-products.

7.1. Recycled Materials

Table D-17 summarized the value of the internally traded goods when operating at full capacity. These values are balanced by taking into account the on-site haulage fee as described in Table D-14.

7.2. Off-Gases

Table D-18 summarized the value of the internally traded off-gases (fuel gases – COG, BFG & BOFG) when operating at full capacity.

7.3. Steam

Table D-19 summarizes the value of the internally traded steam (produced from the Steelmaking facility @ 9 bar abs. and 175^{o}C) when operating at full capacity.

7.4. Industrial Gases (Internally Used)

Industrial gases such as argon and nitrogen are consumed internally by the steel mill. These gases are primarily used in the blast furnace, hot metal desulphurization, BOS furnace, ladle metallurgy and continuous casting. Consumption of these gases by the different processes is illustrated in Figure D-3. The value of the Nitrogen and Argon used internally are assumed to be zero ($0.00), as the value of these gases are accounted for in the cost of oxygen production.

Table D-17: Summary of the Value of the Internally Traded By-Products (For Year 4 to 25)

From	Tonnage (Tonne/y)	Credit (US$ Million/y)	To	Tonnage (Tonne/y)	Debit (US$ Million/y)
Undersize (ex-BF Screens)	US$ 30.00	per tonne			
300/400: Iron Making	60,932	1.828	200: Sinter Plant	60,932	1.828
- Site Haulage Fees		-0.019			
Total		**1.809**			**1.828**
Reclaimed Coke (ex-BF Screens)	US$ 30.00	per tonne			
300/400: Iron Making	20,526	0.616	200: Sinter Plant	20,526	0.616
- Site Haulage Fees		-0.006			
Total		**0.609**			**0.616**
BF Dust	US$ 30.00	per tonne			
300/400: Iron Making	59,530	1.786	200: Sinter Plant	59,530	1.786
- Site Haulage Fees		-0.018			
Total		**1.767**			**1.786**
HM Spillage & De-S Slag	US$ 30.00	per tonne			
300/400: Iron Making	31,166	0.935	200: Sinter Plant	31,166	0.935
- Site Haulage Fees		-0.010			
Total		**0.925**			**0.935**
BOS Dust & Sludge	US$ 30.00	per tonne			
500/600: Steelmaking	129,700	3.891	200: Sinter Plant	129,700	3.891
- Site Haulage Fees		-0.040			
Total		**3.851**			**3.891**
BOS Slag (LD Slag)	US$ 5.89	per tonne			
500/600: Steelmaking	136,407	4.092	200: Sinter Plant	136,407	4.092
- Site Haulage Fees		-0.042			
Total		**4.050**			**4.092**
Mill Scales	US$ 20.00	per tonne			
700: Continuous Casting	36,772	0.735	200: Sinter Plant	96,159	1.923
800/900: Reheating & Rolling	59,387	1.188			
- Site Haulage Fees		-0.030			
Total		**1.893**			**1.923**
Scrap (Internal Arising)	**US$ 193.00**	**per tonne**			
600: Ladle Metallurgy	43,233	8.379	500/600: Steelmaking	320,285	62.071
700: Continuous Casting	108,631	21.053			
800 & 900: Reheating & Rolling	168,421	32.640			
- Site Haulage Fees		-0.099			
Total		**61.972**			**62.071**
Total Credit (US$ Million/y)	**76.877**		**Total Debit (US$ Million/y)**	**77.142**	

Table D-18: Summary of Internally Traded Fuel (For Year 4 to 25)

From	Energy Export (GJ/y)	Credit (US$ Million/y)	To	Energy Import (GJ/y)	Debit (US$ Million/y)
Coke Oven Gas (COG)	**US$ 9.77**	**per GJ**			
100: Coke Production	8,786,744	85.846	200: Sinter Production	317,480	3.102
			1300: Iron Making (Ancillary Units)	358,719	3.505
			600: Ladle Metallurgy	928,613	9.073
			700: Continuous Casting	78,437	0.766
			800: Reheating Furnace	5,894,737	57.592
			1000: Lime Production	1,208,759	11.810
Total		**85.846**			**85.846**
OBF Process Gas (OBF PG)	**US$ 9.77**	**per GJ**			
100: Iron Making	6,696,713	65.427	100: Coke Production	3,315,590	32.393
			2000: Steam Generation Plant	3,381,123	33.034
Total		**65.427**			**65.427**
Basic Oxygen Furnace Gas (BOFG)	**US$ 9.77**	**per GJ**			
500: Steelmaking	2,638,774	25.781	2000: Steam Generation Plant	2,638,774	25.781
Total		**25.781**			**25.781**
Total (US$ Million/y)		**255.411**	**Total (US$ Million/y)**		**255.411**

*Ancillary unit including PCI Coal drying, torpedo car & ladle heating

Table D-19: Summary of Internally Produced and Consumed Steam (For Year 4 to 25)

From	Tonnage (GJ/y)	Credit (US$ Million/y)	To	Tonnage (GJ/y)	Debit (US$ Million/y)
Steam (9 bar_a / 175^oC)	US$ 12.25	per GJ			
500/600: Steelmaking	899,361	11.015	100: Coke Production	517,459	6.338
			1200: Oxygen Plant - High Purity	45,896	0.563
			3000: Oxygen Plant - Low Purity	42,614	0.522
			4000: CO2 Capture Plant	293,392	3.592
Total (US$ Million/y)		**11.015**	**Total (US$ Million/y)**		**11.015**

8. VALUE OF INTERNALLY TRADED INTERMEDIATE PRODUCTS

Various processes as defined by the boundary limit of the REFERENCE integrated steel mill produced their own intermediate products that are used internally by other processes (also within the boundary of the integrated steel mill).

As illustrated in the cost model developed by Tata Consulting (See Figure D-1), the specific direct cost (i.e. cost per unit product) of producing these intermediate products becomes the price of the intermediate products debited to the users of the product. The cost of any intermediate products produced in excess (i.e. to adjust for system losses, buffer requirements, etc...) should be distributed to all users of the product by using weighted mean according to the level of their utilisation.

Table D-20 summarises the main intermediate products ("internally produced raw materials") produced by the major processes incorporated with the boundary limits of the integrated steel mill.

Table D-20: Main Intermediate Products of the Steel Mill

Unit No.	Major Processes	Intermediate Product(s)
100	Coke Production	Coke & Coke Breeze
200	Sinter Production	Sinter
300 / 400 / 1300	Iron Making (incl. Hot Metal Desulphurization & Ancillary Units*)	Hot Metal
500 / 600	Steel Making (incl. Ladle Metallurgy)	Liquid Steel
700	Continuous Casting	Slab
1000	Lime Production	Lime
1100	ASU – High Purity Oxygen Production	High Purity Oxygen
1200	Power Plant	Electricity
2000	Steam Generation Plant	Steam (9 Bar_a, Sat.)
3000	ASU – Low Purity Oxygen Production	Low Purity Oxygen
4000	CO_2 Capture and Compression Plant	CO2 (110 Bar_a, 30^oC)

***Ancillary unit including PCI coal drying, torpedo car & ladle heating**

Table D-21 summarises the specific production cost of these intermediate products for both Steel Mills without and with CO_2 Capture, whilst Table D-22 presents the flow of these materials from internal producers to internal customers.

The breakdown on how the values of the intermediate products were calculated is presented in Annex 5.

From Tables D-21 and D-22, it could be noted that the annual operating cost of the CO_2 capture and compression plant (Unit 4000) with a value of US$162 Million per year has been paid for or transferred to the hot metal production (Unit 300/400). This could be further illustrated in Table D-23, clearly indicating the differences between the annual operating cost of the hot metal production between REFERENCE Steel Mill and Steel Mill with OBF and MDEA CO_2 capture.

Consequently, the increase in the specific cost for the hot metal produced should translate to higher cost for the liquid steel and slab produced and eventually an increase to the annual operating cost of producing the hot rolled coil. This is illustrated in Table D-24.

Table D-21: Specific Production Cost of Various Intermediate Products of the Steel Mill without and with CO_2 Capture

UNIT	REFERENCE Steel Mill without CO_2 Capture Specific Production Cost (US$ / unit product)	Steel Mill with OBF / MDEA CO_2 Capture Specific Production Cost (US$ / unit product)
100: Coke Production	$ 207.78 per tonne coke	$ 208.55 per tonne coke
200: Sinter Production	$ 96.14 per tonne sinter	$ 95.49 per tonne sinter
300/400: Iron Making	$ 258.65 per tonne hot metal	$ 300.47 per tonne hot metal
500/600: Steelmaking	$ 327.85 per tonne liquid steel	$ 360.78 per tonne liquid steel
700: Continuous Casting	$ 350.11 per tonne slab	$ 383.56 per tonne slab
1000: Lime Production	$ 98.91 per tonne lime	$ 96.19 per tonne lime
1100: ASU High Purity O_2 Prod.	$ 0.05958 per Nm^3 oxygen	$ 0.05360 per Nm^3 oxygen
1200: Power Plant	$ 125.3 per MWh electricity	$ 75.3 per MWh electricity
2000: Steam Generation Plant	-	$ 12.2478 per GJ steam
3000: ASU Low Purity O_2 Prod.	-	$ 0.04240 per Nm^3 oxygen
4000: CO2 Capture and Compression Plant	-	$ 47.10 per tonne CO2 captured

Table D-22: Values and Delivery Point of the Main Intermediate Products of the Steel Mill

From / Intermediate Products	REFERENCE Steel Mill without CO_2 Capture				Steel Mill with OBF / MDEA CO_2 Capture			
	Trade Volume	Production Cost (US$ Million/y)	Delivered To (Customers)	Trade Volume	Trade Volume	Production Cost (US$ Million/y)	Delivered To (Customers)	Trade Volume
100: Coke Production	**$ 207.78 per tonne coke**				**$ 208.55 per tonne coke**			
Lump Coke (t/y) – to Iron Making	1,408,241	292.606	300/400: Iron Making	1,408,241	1,026,289	214.033	300/400: Iron Making	1,026,289
Coke Breeze (t/y) – to Sinter Plant	222,278	46.185	200: Sinter Plant	222,278	217,452	45.350	200: Sinter Plant	217,452
Total (US$ Million/y)		**$338.791**				**$259.383**		
200: Sinter Production	**$ 96.14 per tonne sinter**				**$ 95.49 per tonne sinter**			
Sinter (t/y)	4,445,559	427.399	300/400: Iron Making	4,445,559	4,349,045	415.301	300/400: Iron Making	4,349,045
Total (US$ Million/y)		**$427.399**				**$415.301**		
300/400: Iron Making	**$ 258.65 per tonne hot metal**				**$ 300.47 per tonne hot metal**			
Hot Metal (t/y)	3,894,263	1007.268	500/600: Steelmaking	3,894,263	3,894,147	1170.055	500/600: Steelmaking	3,894,147
Total (US$ Million/y)		**$1,007.268**				**$1,170.055**		
500/600: Steelmaking	**$ 327.85 per tonne liquid steel**				**$ 360.78 per tonne liquid steel**			
Liquid Steel (t/y)	4,345,228	1424.589	700: Continuous Casting	4,345,228	4,345,228	1567.661	700: Continuous Casting	4,345,228
Total (US$ Million/y)		**$1,424.589**				**$1,567.661**		
700: Continuous Casting	**$ 350.11 per tonne slab**				**$ 383.56 per tonne slab**			
Slab (t/y)	4,210,526	1474.154	800/900: Reheating and Rolling	4,210,526	4,210,526	1615.004	800/900: Reheating and Rolling	4,210,526
Total (US$ Million/y)		**$1,474.154**				**$1,615.004**		
1000: Lime Production	**$ 98.91 per tonne lime**				**$ 96.19 per tonne lime**			
Lime (t/y)	346,412	34.263	200: Sinter Plant	44,456	345,447	33.230	200: Sinter Plant	43,490
			500/600: Steelmaking	301,956			500/600: Steelmaking	301,956
Total (US$ Million/y)		**$34.263**				**$33.230**		
1100: ASU High Purity Oxygen Prod.	**$ 0.05958 per Nm3 oxygen**				**$ 0.05360 per Nm3 oxygen**			
Oxygen (Nm^3/y @ 273K)	441,494,513	26.306	300/400: Iron Making	190,092,062	251,255,950	13.465	500/600: Steelmaking	232,039,177
	44,149,451	-	500/600: Steelmaking	232,185,679	25,125,595	-	700: Continuous Casting	8,690,457
			700: Continuous Casting	8,690,457			800/900: Reheating and Rolling	10,526,316
			800/900: Reheating and Rolling	10,526,316				
Total (US$ Million/y)		**$26.306**				**$13.467**		
1200: Power Plant	**$ 125.3 per MWh electricity**				**$ 75.3 per MWh electricity**			
Electricity (MWh/y)	1,547,903	193.938	100: Coke Production	57,068	2,241,110	168.829	100: Coke Production	43,531
	52,560	-	200: Sinter Plant	142,258	52,560	-	200: Sinter Plant	139,169
			300/400: Iron Making	392,206			300/400: Iron Making	119,061
			500/600: Steelmaking	195,097			500/600: Steelmaking	195,097
			700: Continuous Casting	43,452			700: Continuous Casting	43,452
			800/900: Reheating and Rolling	421,053			800/900: Reheating and Rolling	421,053
			1000: Lime Production	10,392			1000: Lime Production	10,363
			1100: Air Separation Unit	267,104			1100: ASU - HP Oxygen	152,010
			1300: Ancillary (Unit: 300/400)	19,272			1300: Ancillary (Unit: 300/400)	19,272
							2000: Steam Generation Plant	44,079
							3000: ASU - LP Oxygen	481,399
							4000: CO2 Capture Plant	572,623
Total (US$ Million/y)		**$193.938**				**$168.829**		
2000: Steam Generation Plant					**$ 12.2478 per GJ steam**			
Steam (GJ/y)					7,789,168	95,400	4000: CO2 Capture Plant	7,789,168
Total (US$ Million/y)						**$95.400**		
3000: ASU Low Purity Oxygen Prod.					**$ 0.0424 per Nm3 oxygen**			
Oxygen (Nm^3/y @ 273K)					1,004,170,271	43.427	300/400: Iron Making	1,004,170,271
					20,083,405	-		
Total (US$ Million/y)						**$43.427**		
4000: CO2 Capture and Compression Plant					**$ 47.10 per tonne CO_2 capture**			
CO2 (110 Bar_a)					3,439,360	161,989	300/400: Iron Making	3,439,360
Total (US$ Million/y)						**$161.989**		

Table D-23: Hot Metal Production Cost of the REFERENCE Steel Mill vs Steel Mill with OBF & MDEA CO_2 Capture

	Hot Metal Production (Base Case)		Hot Metal Production (OBF with CO_2 Capture)	
Annual Production (Year 4 - 25)	3,894,263 t/y	973.57 kg/t HRC	3,894,147 t/y	973.54 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)				
PCI Coal	603,251 t/y	$89.491 Million/y	603,233 t/y	$89.488 Million/y
Natural Gas	- GJ/y	- Million/y	2,978,899 GJ/y	$29.104 Million/y
Lump Ore (Australian)	497,139 t/y	$51.069 Million/y	497,124 t/y	$51.067 Million/y
Pellets (Brazil)	1,396,178 t/y	$154.026 Million/y	1,399,333 t/y	$154.374 Million/y
Limestone	52,497 t/y	$1.220 Million/y	23,164 t/y	$0.539 Million/y
Quartzite	43,129 t/y	$0.776 Million/y	13,237 t/y	$0.238 Million/y
Calcium Carbide Powder	12,710 t/y	$10.168 Million/y	12,708 t/y	$10.167 Million/y
Raw Materials & Energy (Internally Sourced)				
Sinter	4,445,559 t/y	$427.399 Million/y	4,349,045 t/y	$415.301 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	190,092,062 Nm^3/y	$11.326 Million/y	1,004,170,271 Nm^3/y	$43.427 Million/y
BF Undersize (excl. reclaimed coke)	62,630 t/y	($1.859) Million/y	60,932 t/y	($1.809) Million/y
BF Dust (Recycled)	59,531 t/y	($1.767) Million/y	59,530 t/y	($1.767) Million/y
HM Spillage & De-Slag (Recycled)	31,167 t/y	($0.925) Million/y	31,166 t/y	($0.925) Million/y
Lump Coke	1,408,241 t/y	$292.606 Million/y	1,026,289 t/y	$214.033 Million/y
Reclaimed Coke (ex BF Screens)	28,165 t/y	($0.836) Million/y	20,526 t/y	($0.609) Million/y
Coke Oven Gas (for Hot Stove)	499,108 GJ/y	$4.876 Million/y	- GJ/y	- Million/y
Coke Oven Gas (for Ancillary Users)	258,427 GJ/y	$2.525 Million/y	358,719 GJ/y	$3.505 Million/y
BFG or OBF Process Gas (Export)	14,263,072 GJ/y	($139.350) Million/y	6,696,713 GJ/y	($65.427) Million/y
Electricity (Iron Making incl. HM Desulph.)	392,205,884 kWh/y	$49.140 Million/y	119,061,489 kWh/y	$8.969 Million/y
Electricity (Ancillary Users)	19,272,000 kWh/y	$2.415 Million/y	19,272,000 kWh/y	$1.452 Million/y
Steam (9 Bar_a sat.)	87,556 GJ/y	$0.344 Million/y	- t/y	- Million/y
Consumables & Other Utilities				
Refractories (Torpedo car, HM Desulf, etc...)	5,063 t/y	$4.151 Million/y	5,062 t/y	$4.151 Million/y
Raw Water	3,483,639 m^3/y	$0.396 Million/y	2,923,682 m^3/y	$0.332 Million/y
Other Variable O&M Cost				
Slag Processing Fee (De-S Slag)	84,235 t/y	$0.496 Million/y	84,232 t/y	$0.496 Million/y
BF Sludge Disposal Fee	15,875 t/y	$0.318 Million/y	15,875 t/y	$0.317 Million/y
Slag Disposal Fee (De-S Slag)	53,068 t/y	$0.288 Million/y	53,066 t/y	$0.288 Million/y
Other Variable O&M Cost (Internally Sourced)				
CO_2 Capture and Compression Charges	- t/y	- Million/y	3,439,360 t/y	$161.989 Million/y
By-Product Sales				
Granulated BF Slag	1,111,252 t/y	($17.780) Million/y	932,630 t/y	($14.922) Million/y
Production Fixed Cost & Misc. Expense				
Direct Labour	321 Personnel	$30.174 Million/y	321 Personnel	$30.174 Million/y
Annual Maintenance Expense	4.0% CAPEX	$24.880 Million/y	4.0% CAPEX	$24.400 Million/y
Misc. Works Expense		$10.403 Million/y		$10.403 Million/y
Misc. OPEX (incl. environmental cleanup)		$1.300 Million/y		$1.300 Million/y
Total Direct Cost - HM Production	$1,007.3 Million/y		$1,170.1 Million/y	

9. ANNUAL OPERATING COST OF HOT ROLLED COIL PRODUCTION

Table D-24 summarised the components of the annual operating cost (direct cost) of hot rolled coil production when operating at full year production capacity for the REFERENCE steel mill without CO2 capture and steel mill with OBF / MDEA CO_2 Capture.

Table D-24: Hot Rolled Coil Production Cost of the REFERENCE Steel Mill vs Steel Mill with OBF & MDEA CO_2 Capture

Product ID	Hot Rolled Coil		Hot Rolled Coil	
Annual Production (Year 4 - 25)	4,000,000 t/y	1000 kg/t HRC	4,000,000 t/y	1000 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)				
Slab	4,210,526 t/y	$1,474.154 Million/y	4,210,526 t/y	$1,615.004 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	10,526,316 Nm3/y	$0.627 Million/y	10,526,316 Nm3/y	$0.564 Million/y
Scrap (to Steelmaking)	168,421 t/y	($32.588) Million/y	168,421 t/y	($32.588) Million/y
Mill Scales (to Sinter)	59,387 t/y	($1.169) Million/y	59,387 t/y	($1.169) Million/y
Coke Oven Gas (Reheating Furnace)	5,894,737 GJ/y	$57.592 Million/y	5,894,737 GJ/y	$57.592 Million/y
Electricity (Reheating & Rolling Mills)	421,052,632 kWh/y	$52.754 Million/y	421,052,630 kWh/y	$31.719 Million/y
Consumables & Other Utilities				
Works and Back Up Rolls	1 Unit	$9.000 Million/y	1 Unit	$9.000 Million/y
Banding	1 Unit	$0.360 Million/y	1 Unit	$0.360 Million/y
Raw Water	8,000,000 m3/y	$0.908 Million/y	8,000,000 m3/y	$0.908 Million/y
Production Fixed Cost & Misc. Expense				
Direct Labour	480 Personnel	$45.157 Million/y	480 Personnel	$45.157 Million/y
Annual Maintenance Expense	8.0% CAPEX	$36.000 Million/y	8.0% CAPEX	$36.000 Million/y
Misc. Works Expense		$7.747 Million/y		$7.747 Million/y
Misc. OPEX (incl. environmental cleanup)		$1.443 Million/y		$1.443 Million/y
Total Direct Cost - HM Production	$1,652.0 Million/y		$1,771.7 Million/y	

10. ANNUAL OPERATING COST OF THE INTEGRATED STEEL MILL WITH OBF AND MDEA CO_2 CAPTURE TECHNOLOGY

The overall annual operating cost of the "REFERENCE" integrated steel mill without CO_2 capture could be calculated in 2 methods.

- The first method is based on the difference between the overall annual O&M cost (as presented in Table D-15), and the revenues obtained from the sale of by-products (as presented in Table D-16).

- The second method is based on the sum of the annual production cost of the hot rolled coil (which represents the direct cost of the hot rolled coil production as presented in Table D-24), and the indirect cost of the steel mill (which mainly consists of the indirect labour cost as presented in Section 5.1.3).

Table D-23 summarised the results of the calculation of the annual operating cost of the "REFERENCE" Integrated Steel Mill using the two methods for the economic life of the steel mill (i.e. 25 years of operation).

Table D-23: Annual Operating Cost of the Integrated Steel Mill with OBF & MDEA CO_2 Capture

Annual Operating Cost	Operating Period					Cost Reference (Year 4-25)
	1	2	3	4	5 … 25	
Annual HRC Production (t/y)	**2,000,000**	**3,000,000**	**3,600,000**	**4,000,000**	**4,000,000**	
Accounting Method 01						
Annual O&M Cost	1,064.45	1,473.64	1,719.16	1,882.84	1,882.84	Table D-15
Revenues (By-Product Sales)	($17.48)	($26.22)	($31.46)	($34.96)	($34.96)	Table D-16
Annual Operating Cost (US$ Million/y)	**1,046.97**	**1,447.42**	**1,687.70**	**1,847.88**	**1,847.88**	
Accounting Method 02						
Direct Cost of HRC Production	984.46	1,378.10	1,614.28	1,771.74	1,771.74	Table D-24
Indirect Cost of Steel Mill	62.51	69.33	73.41	76.14	76.14	Section 5.1.3
Annual Operating Cost (US$ Million/y)	**1,046.97**	**1,447.42**	**1,687.70**	**1,847.88**	**1,847.88**	

10.1. Cost Base of the Major Plants and Processes (Distribution of Annual O&M Cost and Sale Revenues of By-Products)

Based on Accounting Method 01 (Table D-23), Figures D-5(a) and D5(b) illustrate the breakdown of the annual O&M cost and by-products sales revenues of the different major plants and processes for the steel mill without and with CO_2 capture.

The following should be referred to with regard to the calculation of the cost distribution as presented in Figure D-5(b):

- Energy and Reductants
  - Coking and PCI coal (Table D-7)
  - Natural Gas (Table D-8)

- Raw Materials
  - Iron Ore (Table D-9)
  - Purchased Scrap and Ferroalloys (Table D-9)
  - Fluxes (Table D-10)

- Consumables and Other Utilities (Section D-5.4)

- Direct Labour (Table D-6)

- Maintenance and Other OPEX
  - Annual Maintenance Cost (Table D-5)
  - Miscellaneous Cost (Section D-5.5)
  - Other O&M Cost (Section D-5.6)

- Revenues – Sale of By Products (Section D-6)

It should be noted that the costs presented in the figures do not include the indirect labour cost of the integrated steel mill. The figures demonstrates the cost base of each plant and process by presenting the cost of externally sourced raw materials, energy and reductants, consumables and other utilities used by each business unit.

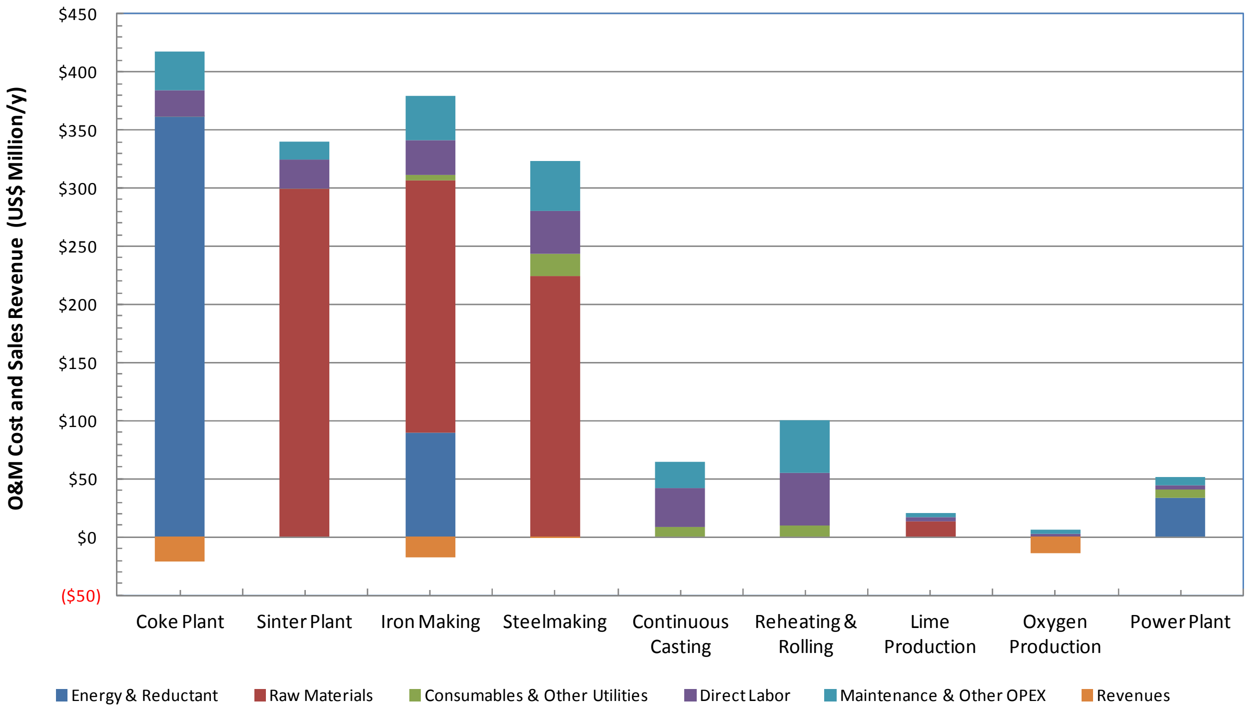

Figure D-5(a): Cost Base of the Major Processes of the "REFERENCE" Steel Mill (excl. Indirect Labour Cost)

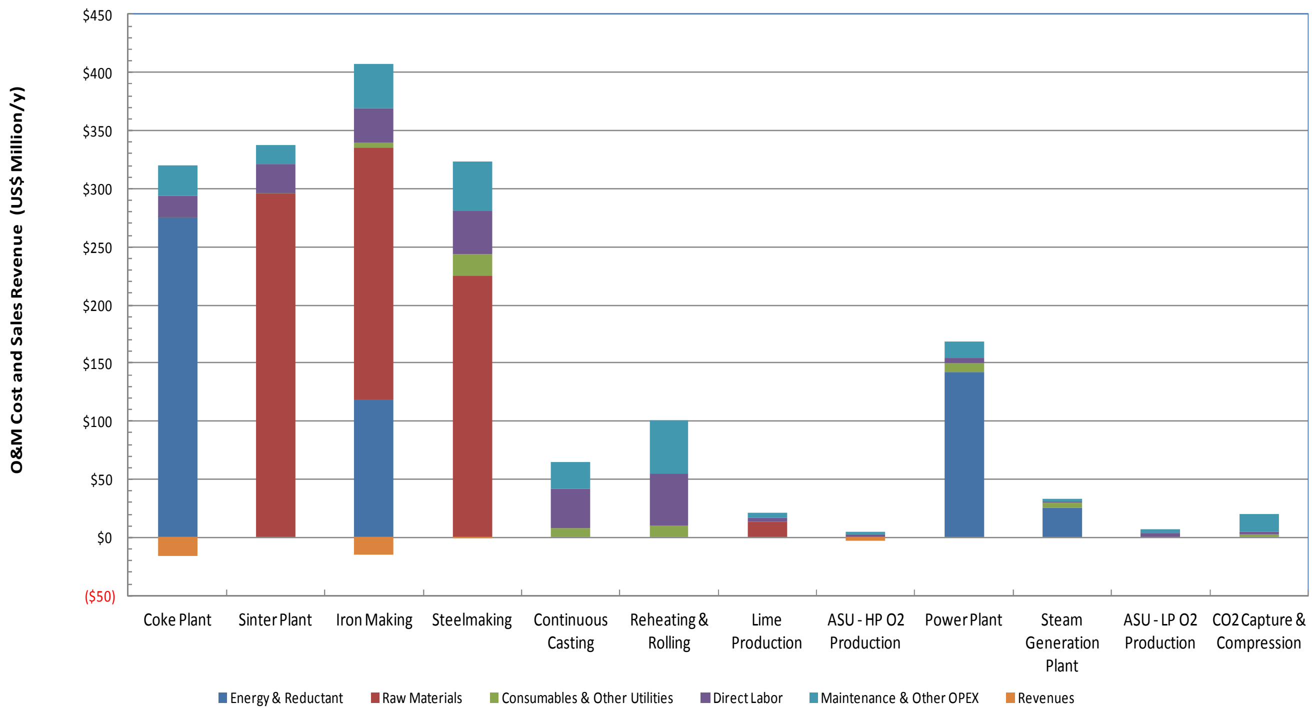

Figure D-5(b): Cost Base of the Major Processes of the Steel Mill with OBF/MDEA CO_2 Capture (excl. Indirect Labour Cost)

11. BREAK EVEN PRICE

The breakeven price (or levelised cost) of the hot rolled coil (ex-works) for the steel mill with CO_2 capture is calculated based on the discounted cash flow presented in Annex 6.

The breakeven price of the hot rolled coil produced from the Integrated Steel Mill with CO_2 capture producing 4 million tonnes per year was estimated at US$ 630.22 per tonne HRC. The breakdown of this price is presented in Figure D-6(b). This an increase of ~US$ 55.00 per tonne HRC as compared to the breakeven price of the HRC produced from REFERENCE Steel Mill without CO_2 Capture (as shown in Figure D-6a)

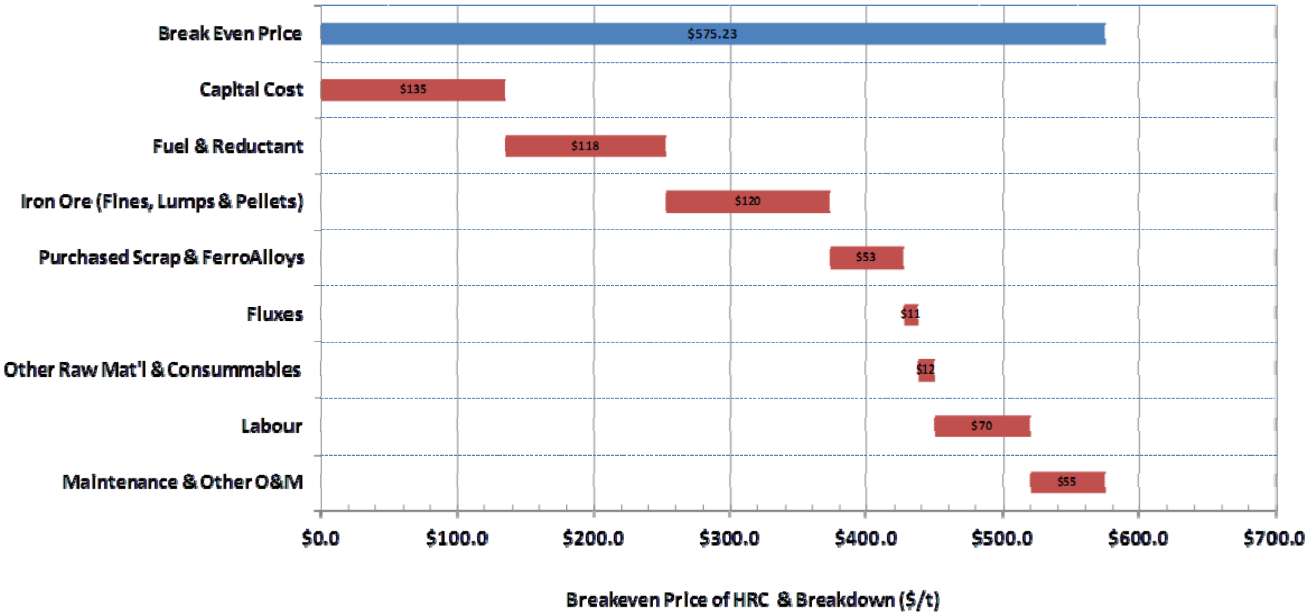

Figure D-6(a): Breakeven Price of Hot Rolled Coil - REFERENCE Steel Mill ($/t HRC) ex-Works

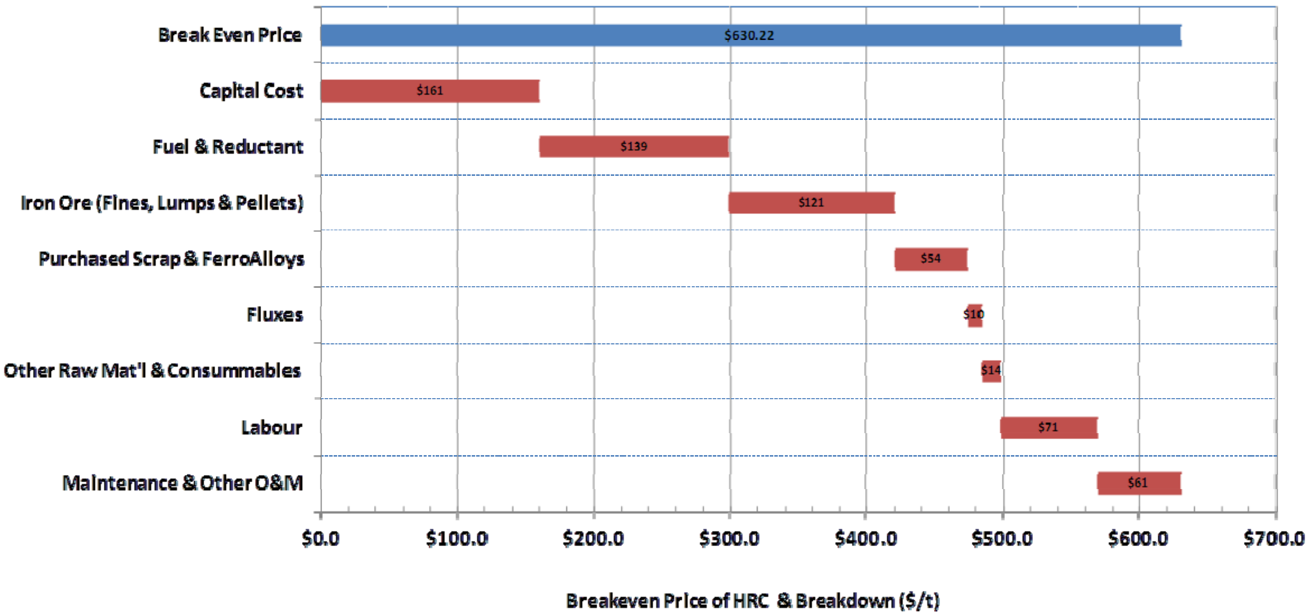

Figure D-6(b): Breakeven Price of Hot Rolled Coil - REFERENCE Steel Mill ($/t HRC) ex-Works

11.1. Simplified Profit and Loss Account

The simplified profit and loss account of the Integrated Steel Mill without and with CO_2 capture at their respective breakeven price of the hot rolled coil (ex-works) is presented in Table D-24. This numbers indicate the minimum annual profit (EBITDA) required to achieve break even of the operation of the integrated steel mill without and with CO_2 capture to cover capital repayment over the 25 years economic life.

Table D-24: Simplified Profit and Loss Account (Operating Years: 4 - 25)
Earnings (EBITDA) of the Steel Mill without & with CO_2 Capture at their Respective Breakeven Price (Ex-Works) Level

Hot Rolled Coil Production (t/y)		4,000,000			
		REFERENCE Base Case ($'000)		OBF with MDEA CO_2 Capture ($'000)	
Breakeven Price ($/t HRC)		$	575.23	$	630.22
Sales Revenues	Unit #				
Hot Rolled Coil	800/900	$	2,300,934.15	$	2,520,889.90
Coke By-Products	100		21,422.91		16,341.15
Granulated Slag	300/400		17,780.03		14,922.08
LD Slag	500/600		449.81		448.21
Argon	1100		14,017.68		3,248.05
		$	2,354,604.57	$	2,555,849.40
Fixed Production Cost					
Annual Maintenance Cost		$	(141,996.10)	$	(163,632.80)
Direct Labour			(204,580.78)		(205,520.78)
Indirect Labour			(76,140.00)		(76,140.00)
		$	(422,716.88)	$	(445,293.58)
Variable Production Cost					
Energy and Reductant		$	(483,937.74)	$	(562,213.60)
Iron Ore Products			(492,053.74)		(492,291.26)
Purchased Scrap & Ferroalloys			(218,228.11)		(218,228.11)
Fluxes			(44,649.89)		(40,091.13)
Consumable & Other Utilities			(49,780.77)		(57,080.00)
Miscellaneous Cost			(62,246.77)		(59,036.06)
Other OPEX			(8,181.34)		(8,601.70)
		$	(1,359,078.36)	$	(1,437,541.86)
NET PROFIT/(LOSS) - EBITDA[1]		$	572,809.34	$	673,013.96

[1] The results showed that for the OBF case would need a profit of 17% more as compared to the profit of the REFERENCE Case to achieve breakeven point.

12. IMPACT OF CO_2 EMISSIONS TRADING SCHEME

12.1. Breakeven Price vs. CO_2 Price

Figure D-8 illustrates the direct CO_2 emissions from the different plants and processes for the integrated steel mills. This shows a reduction of CO_2 emissions from 2090 kg/t HRC for the REFERENCE steel mill to 1115 kg/t HRC for steel mill with OBF / MDEA CO_2 capture.

To illustrate the impact of the price of CO_2 Emissions Trading Scheme, nominal prices of $20, $40, $60, up to $100 per tonne of CO_2 were incorporated in the discounted cash flow and the breakeven prices of the HRC, including the cost of CO_2 emissions, were calculated.

Figure D-9 illustrates the impact of the CO_2 ETS price on the breakeven price of the hot rolled coil for steel mills without and with CO_2 capture. Figures D-10(a) and D-10(b) illustrate how the CO_2 emissions cost would impact the cost base of the different plants and processes within the integrated steel mill.

12.2. Variation to the Calculation of CO_2 Avoidance Cost

In Volume 1 Section F of this study, the sensitivity of breakeven price of the hot rolled coil to the selected power plant configurations was evaluated. Three different step-off cases to the REFERENCE Steel Mill were examined. It could be noted that the breakeven price decreases with increasing efficiency of the power plant.

In this context, the sensitivity of these step-off cases to the calculated avoidance cost were also evaluated, Figure D-10 presents the range of avoidance costs calculated.

This figure shows that cost of CO_2 avoidance could range from $56 when compared to the REFERENCE Steel Mill - Base Case (with 32% power plant efficiency) to a high of $66 when compared to Case 1B (REFERENCE Steel Mill with 40% power plant efficiency).

It can be concluded that interpretation of CO_2 avoidance cost should be made with care as it requires a clear understanding of the assumptions behind the calculations.

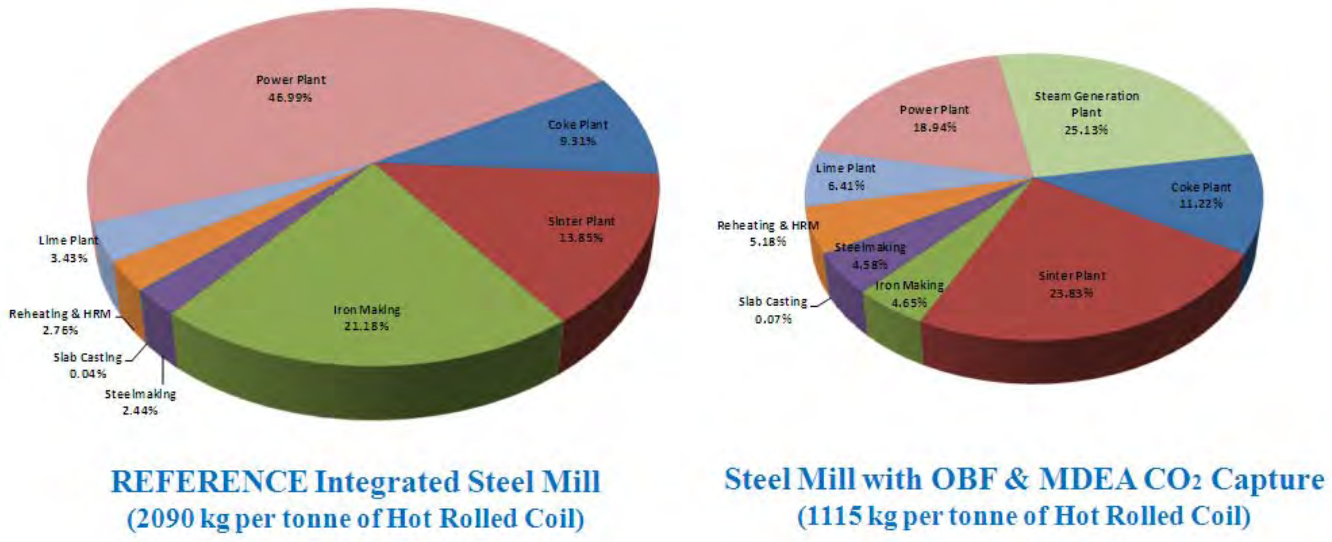

Figure D-8: Direct CO_2 Emissions of the various units from the Integrated Steel Mill without and with CO_2 Capture

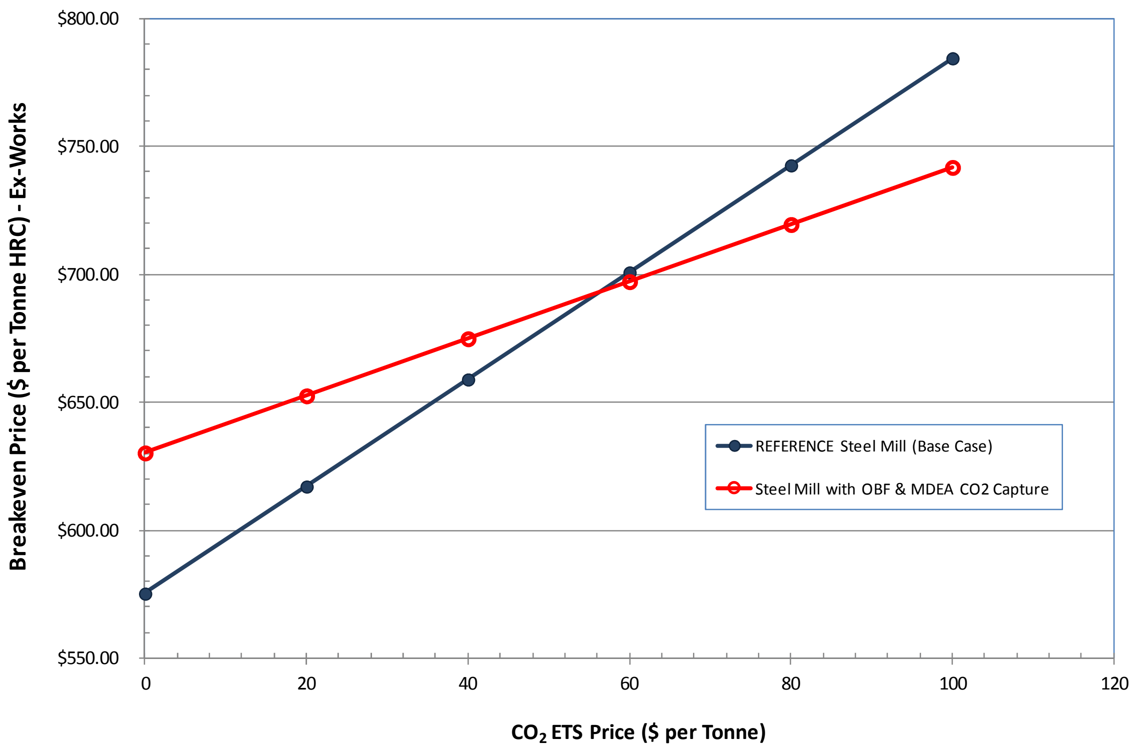

Figure D-8: Impact of the CO_2 ETS Price to Breakeven Price of the Hot Rolled Coil for the Integrated Steel Mill without and with CO_2 Capture

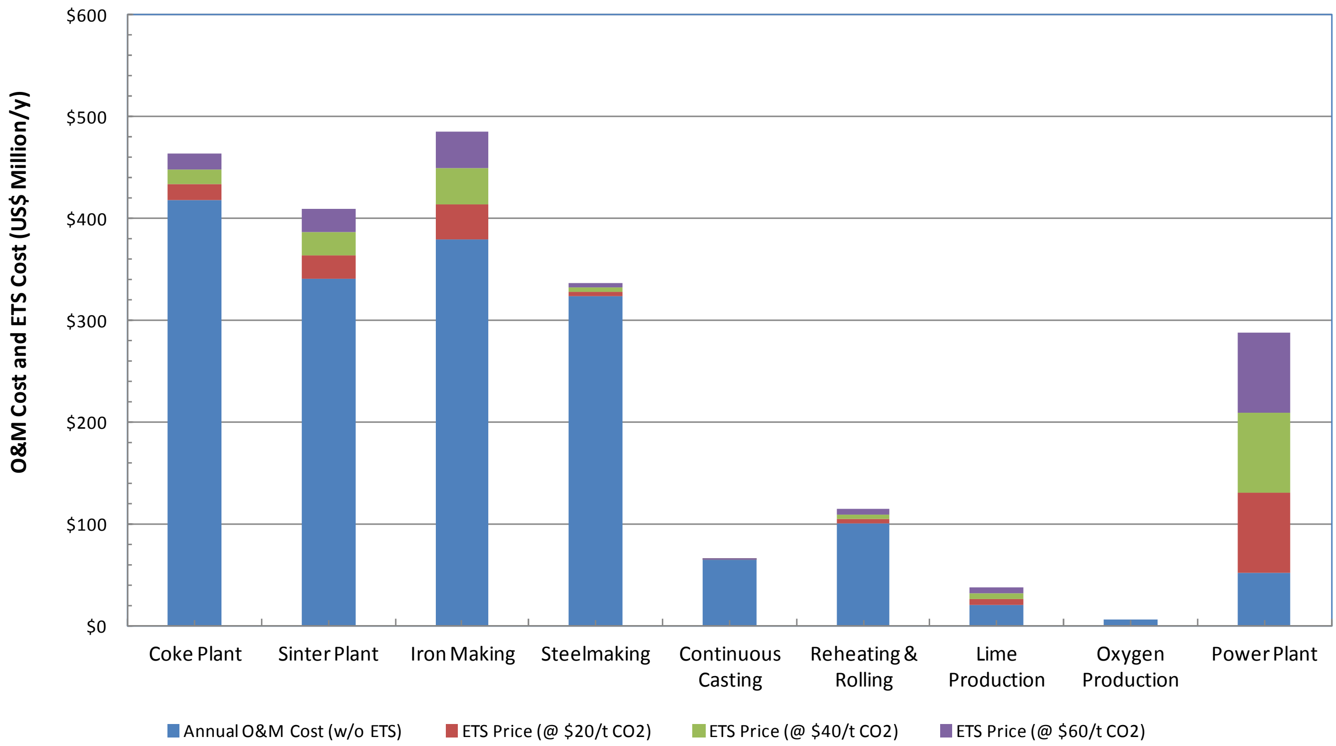

Figure D-9(a): Impact of the CO_2 ETS Price to the Cost Base of the Different Plants and Processes within the "REFERENCE" Integrated Steel Mill

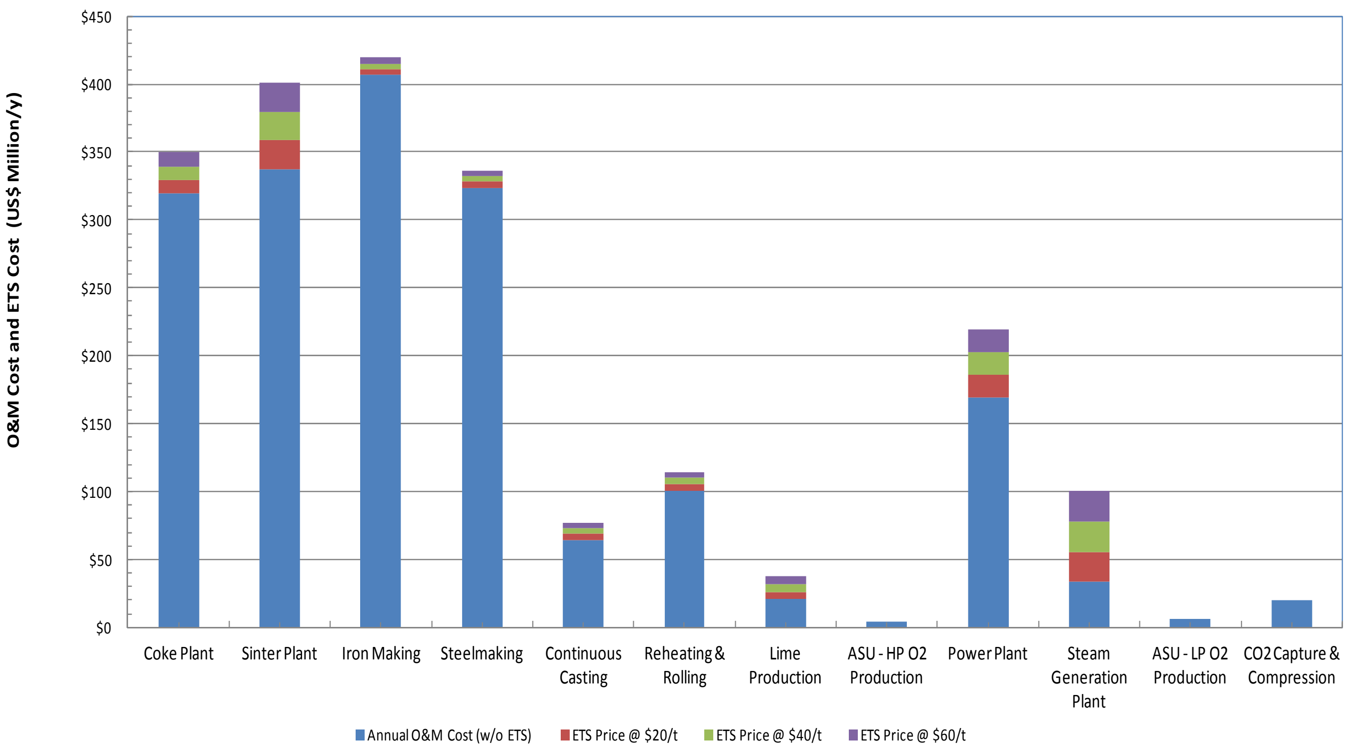

Figure D-9(b): Impact of the CO_2 ETS Price to the Cost Base of the Different Plants and Processes within the Integrated Steel Mill with OBF and MDEA CO_2 Capture Technology

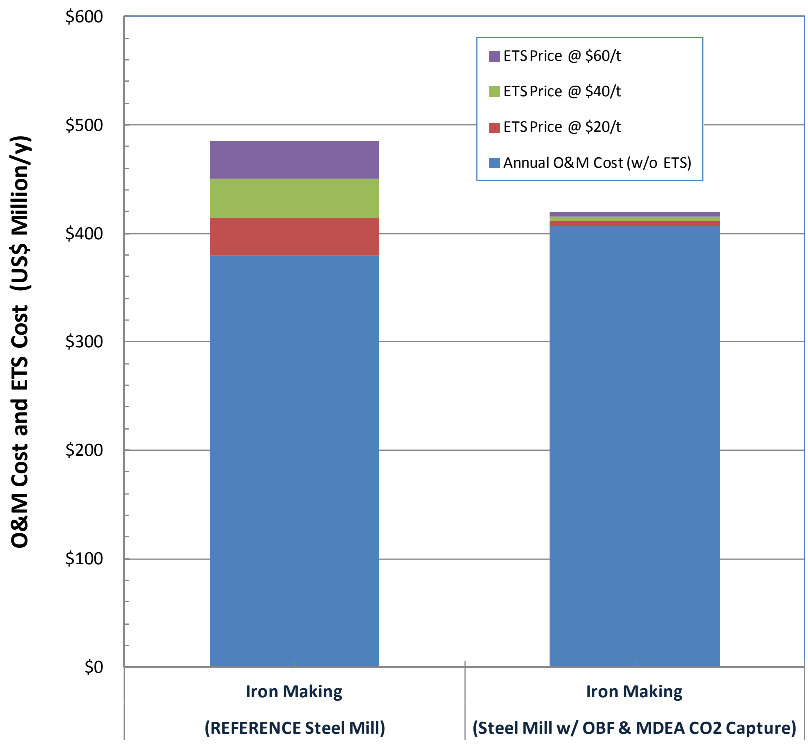

Figure D-9(c): Impact of the CO_2 ETS Price to the Cost Base of the Iron Making Unit of the Integrated Steel Mill without and withCO_2 Capture Technology

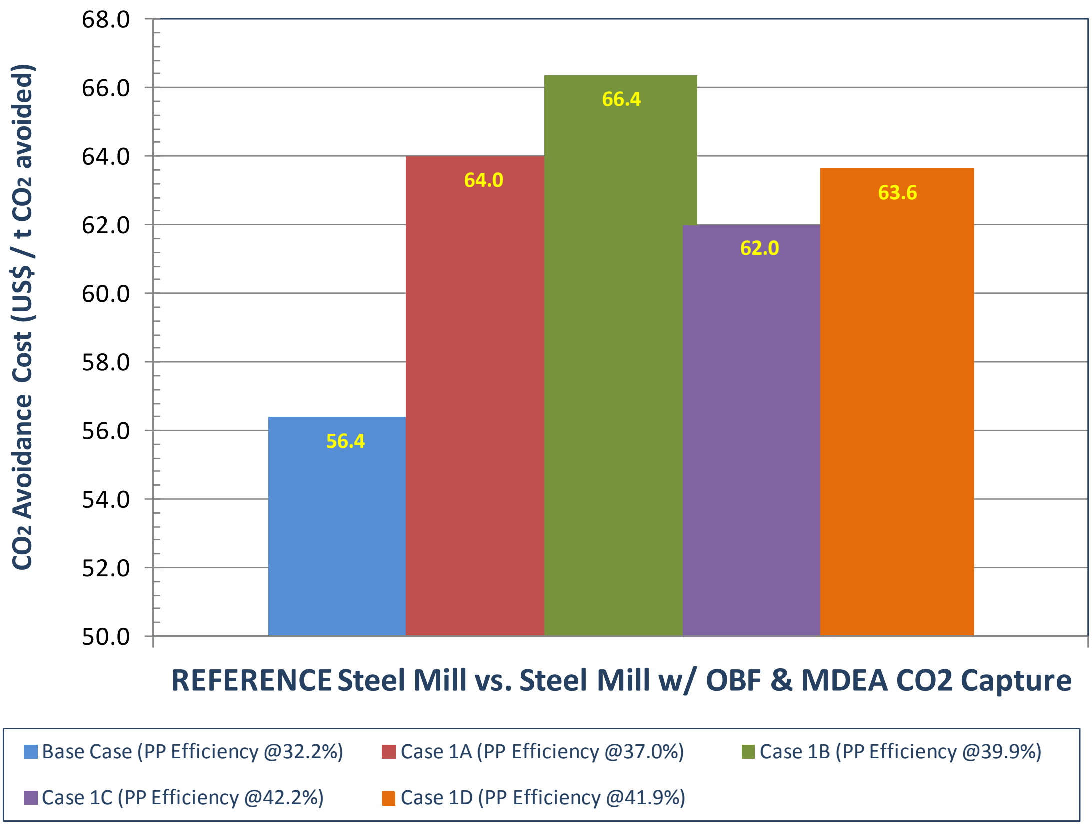

Figure D-10: Variation to the CO_2 Avoidance Cost

13. SENSITIVITY OF THE BREAKEVEN PRICE TO COKING COAL PRICE

Figure D-11 presents the sensitivity of the CO_2 avoidance cost to the coking coal price for the steel mill with post-combustion capture (Case 2A / EOP-L1) and steel mill equipped with OBF and MDEA CO2 Capture (Case 3). This figure shows that the CO_2 avoidance cost for HRC produced from steel mill with Post-Combustion Capture is not sensitive to the coking coal price. However, this is not true to Case 3. It could be observed that an increase in the coking coal price should reduce the CO_2 avoidance cost for the HRC produced from steel mill with OBF and MDEA CO_2 capture.

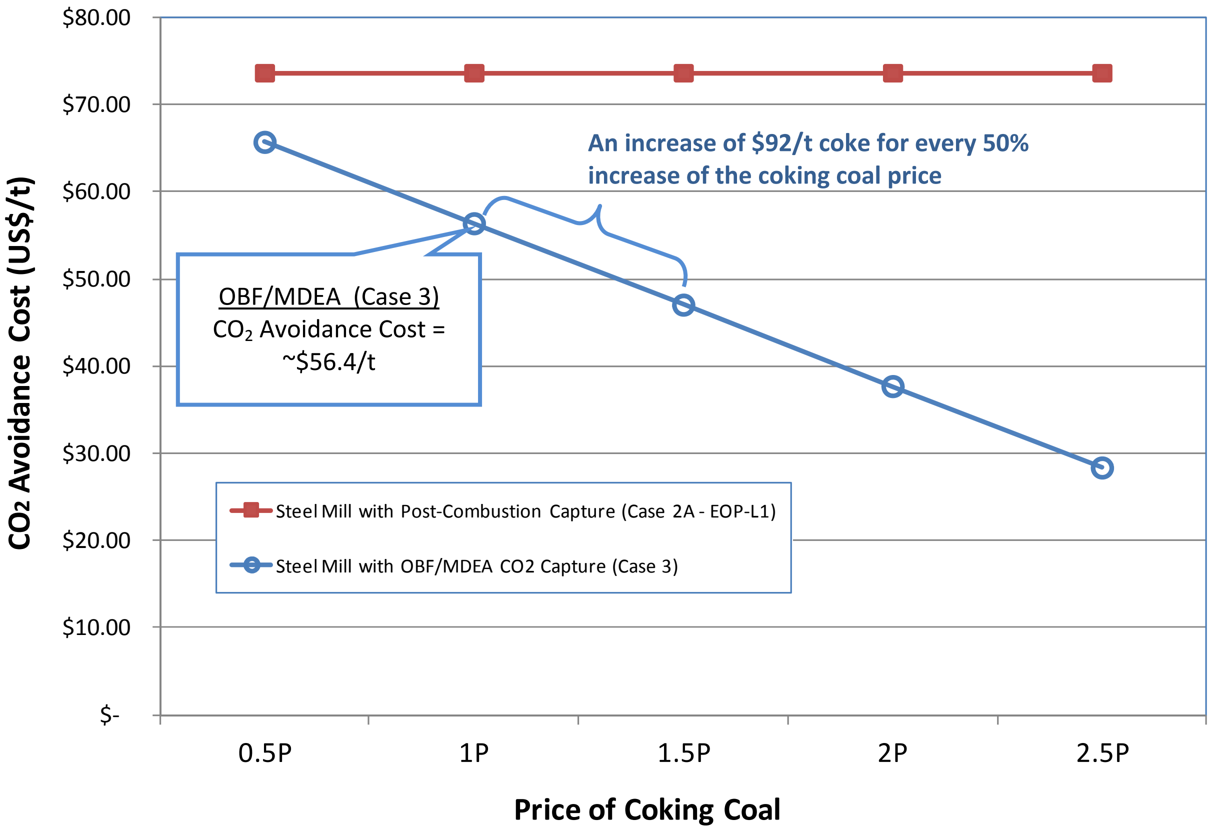

Figure D-11: Sensitivity of the CO_2 Avoidance Cost to Coking Coal Price
(@ 1P → hard coking coal = US$220/t & semi-soft coking coal = US$160/t)

For Case 2A, due to the fact that coke consumption has remained the same compared to the REFERENCE Steel Mill, it should not affect the cost of CO_2 avoidance for the range of coking coal price evaluated in this study. On the other hand, for Case 3, this result could only demonstrate the integrated nature of the steel mill. Due to the reduced coke consumption by the OBF, this should also reduce the coke production required. Consequently, this should also reduce the direct CO_2 emissions of the steel mill. Therefore, a higher coking coal price (which is the main raw material of the coke plant) should only reflect the magnitude of the cost reduction (which represents a cost saving) that could be achieved by the steel mill with OBF as compared to the REFERENCE Case, consequently lowering the CO_2 avoidance cost.

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

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Section E

Sensitivity of the Breakeven Price of the HRC to the Choice of Captive Power and Steam Generation Plants of the Steel Mill with OBF & MDEA CO_2 Capture

INDEX

1. INTRODUCTION

The introduction of CO_2 capture based on chemical absorption technology using MDEA/Pz as solvent to the steel mill increases the demand for steam and electricity. It should be emphasised that addressing these demands is very site specific.

For this study (designated as OBF Base Case), it was assumed that any extra steam required is provided by the steam generation plant (Unit 2000) based on boilers using the off-gases of the steel mill, supplemented by natural gas. The increase in the electricity demand was assumed to be met by the captive power plant (Unit 1200) based on natural gas combined cycle using a single train gas turbine in a single shaft arrangement with the steam turbine and generator.

It should be noted that the option evaluated in the OBF Base Case is not the best available option to address the increase demand for the steam and electricity. However, as it is necessary to make a like for like comparison between steel mills without and with CO_2 capture (REFERENCE Base Case vs. OBF Base Case), the option chosen for a separate steam and electricity generation was considered appropriate.

Having recognised other better options for steam and electricity supply, a re-assessment exercise was undertaken. It could be illustrated that significant cost savings could be potentially achieved by employing a CHP plant fired using off-gases as primary fuel and supplemented by natural gas (providing overall steam and part of the electricity demand of the steel mill). Any deficit to the electricity supply could then be delivered by a smaller NGCC captive power plant as compared to the OBF Base Case.

It should be noted that these re-assessment exercise was evaluated by keeping the same assumptions used in this study (i.e. captive power plant should provide a balanced electricity supply; and there will be no import or export of energy[1]).

2. DEFINITION OF THE CASE STUDY

Two different step-off cases were presented; demonstrating the many options available on how to meet the extra steam and electricity requirements for the steel mill with OBF and MDEA CO_2 capture. These cases are briefly described below.

- <u>OBF Base Case:</u>
    - The extra steam required by the steel mill due to CO_2 capture is provided by low pressure steam boilers (8 trains @ 60 tph each) using off-gas and natural gas as fuel, delivering saturated steam at 9 Bar_a.
    - The captive power plant providing the electricity to steel mill is based on NGCC (1x F-class GT in single shaft arrangement) with nominal net output of 292 MWe having 56.6% net efficiency.

[1] This is an extra-ordinary assumptions not realistic to any steel mill in the world – but was only assumed in this study to simplify the accounting of CO_2 avoidance cost; and to illustrate the real cost of deploying CO_2 capture in an integrated steel mill without the added complexity of importing or exporting energy which normally occur in a steel mill.

- Case 3A:

    - Steam and electricity is provided by a CHP plant based on a gas fired boiler using off-gas and natural gas as fuel with an operating steam parameter of 169 Bar_a and 565^oC (with no steam reheat). The plant has a nominal net output of 75MW_e via HP/IP steam turbine, and delivering steam required by the steel mill at 9 Bar_a and 180^oC extracted just after the HP/IP steam turbine.

    - The captive power plant providing the remaining electricity requirement of the steel mill is based on NGCC (2x E-Class GT in multi-shaft arrangement) with nominal net output of 225 MWe with 53.5% net efficiency.

- Case 3B:

    - Steam and electricity is provided by a CHP plant based on a gas fired boiler using off-gas and natural gas as fuel with an operating steam parameter of 169 Bar_a and 565^oC (with steam reheat at 40 Bar_a and 565^oC). The plant has a nominal net output of 135MW_e via HP and IP steam turbines, and delivering steam required by the steel mill at 9 Bar_a and 180^oC extracted just after the IP steam turbine.

    - The captive power plant providing the remaining electricity requirement of the steel mill is based on NGCC (1x E-Class GT in single-shaft arrangement) with nominal net output of 170 MWe with 51.1% net efficiency.

Figures E-1 and E-3 present the schematic flow diagram of the captive power plant for Cases 3A and 3B respectively. Figures E-2 and E-4 present the captive CHP plant for both cases.

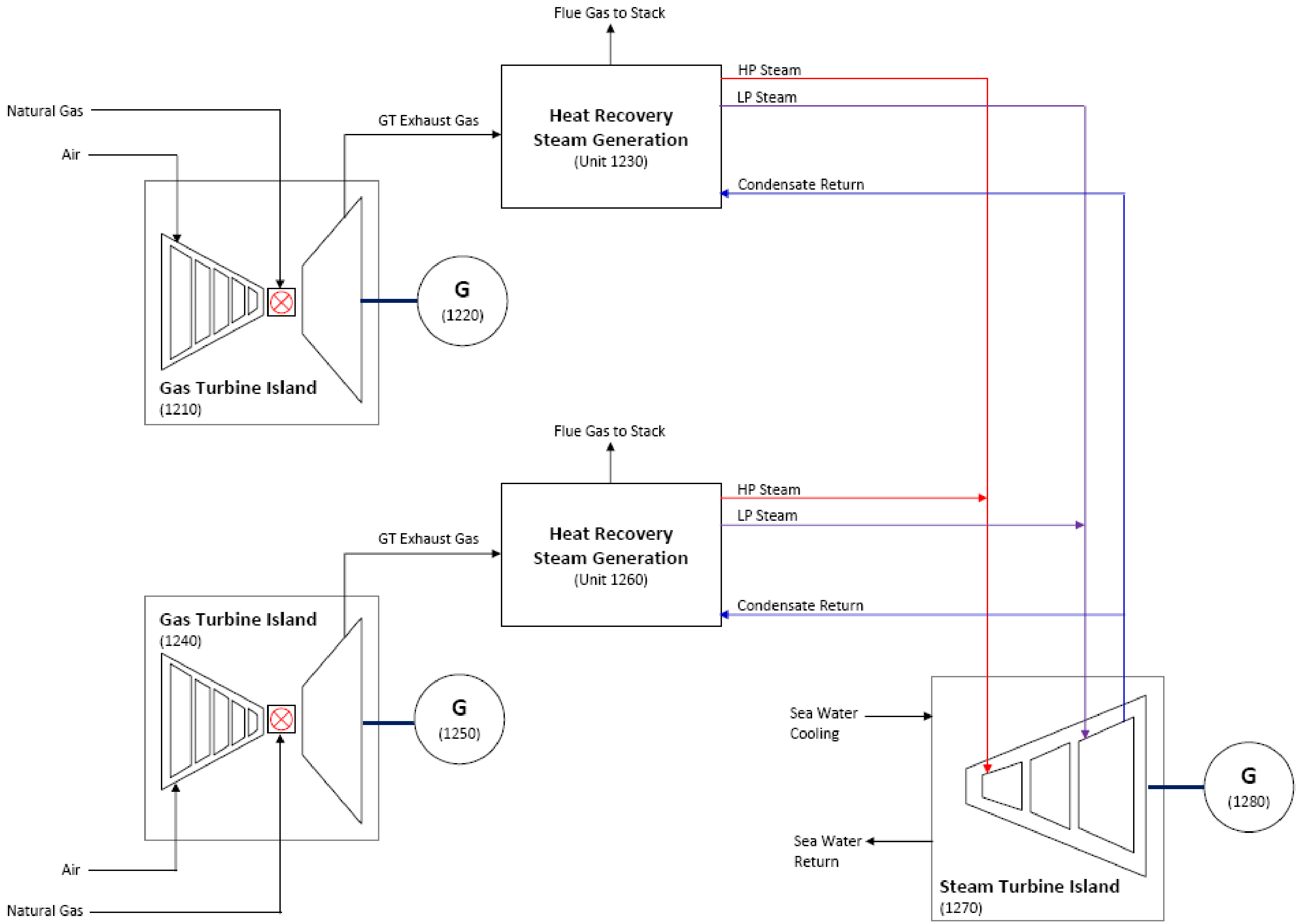

Figure E-1: PFD of the Captive Power Plant (UNIT 1200) for Case 3A
(OBF Base Case vs OBF with Improved Steam & Electricity Supply)

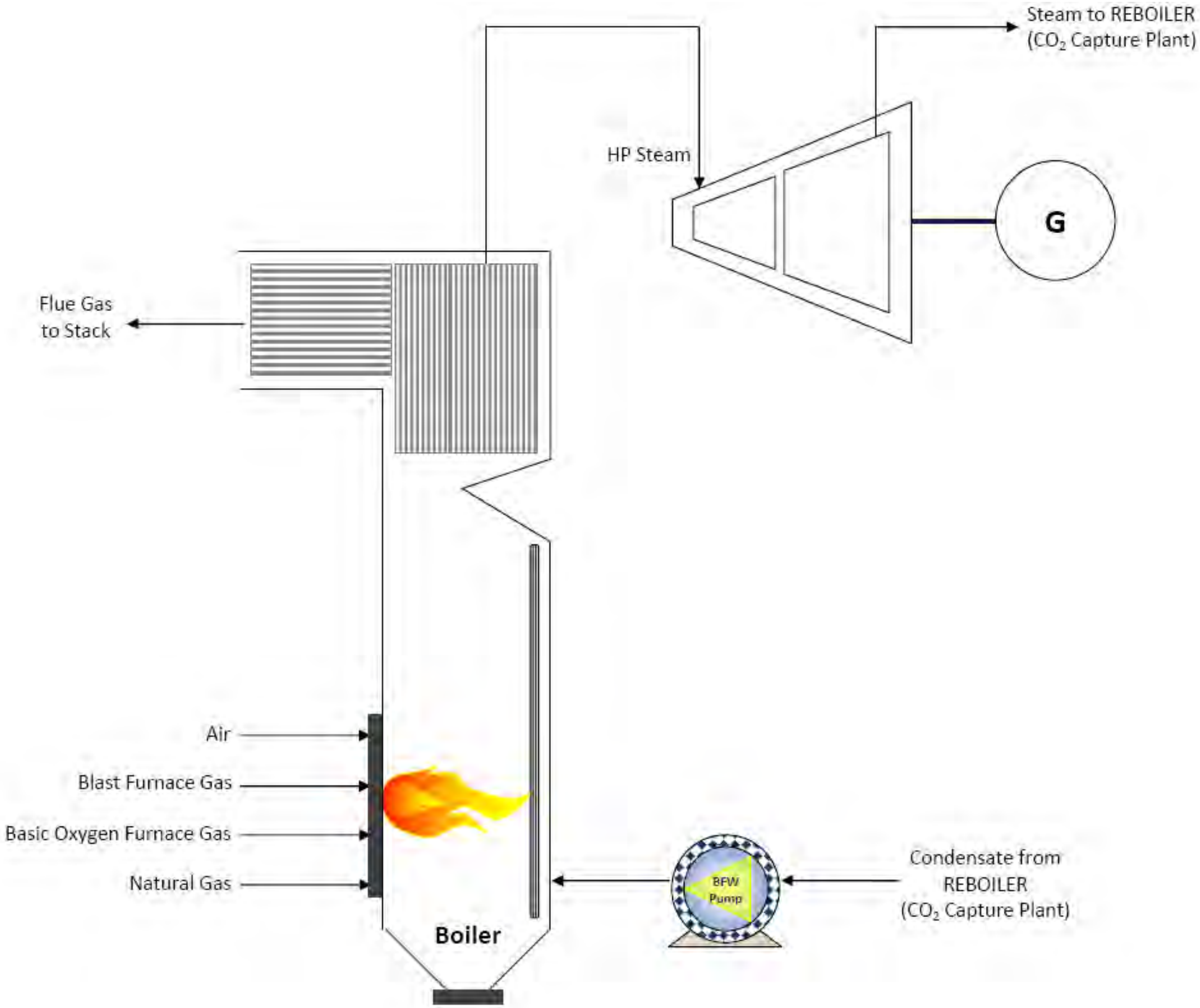

Figure E-2: PFD of the Captive CHP Plant (UNIT 2000) for Case 3A

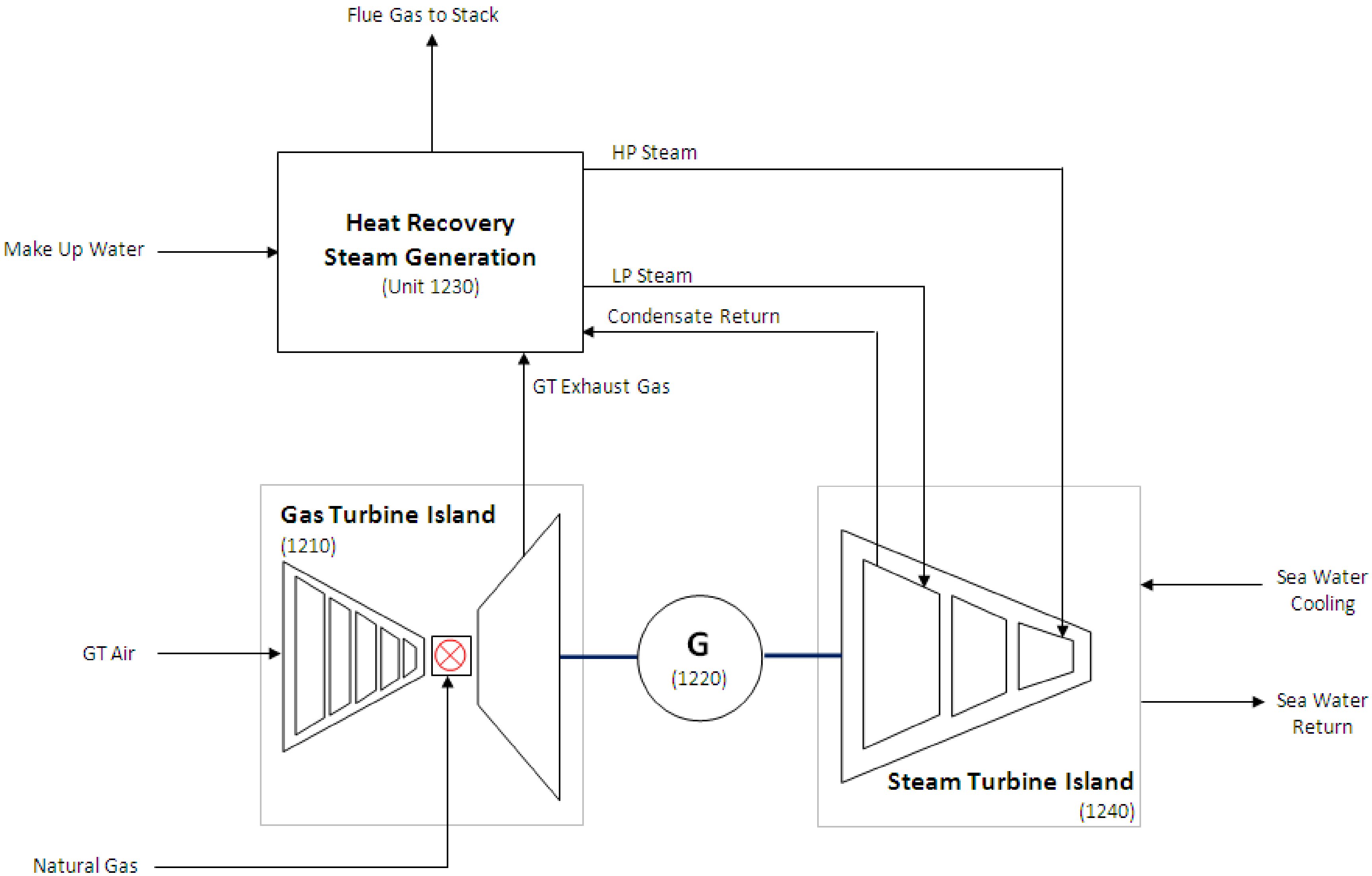

Figure E-3: PFD of the Captive Power Plant (UNIT 1200) for Case 3B

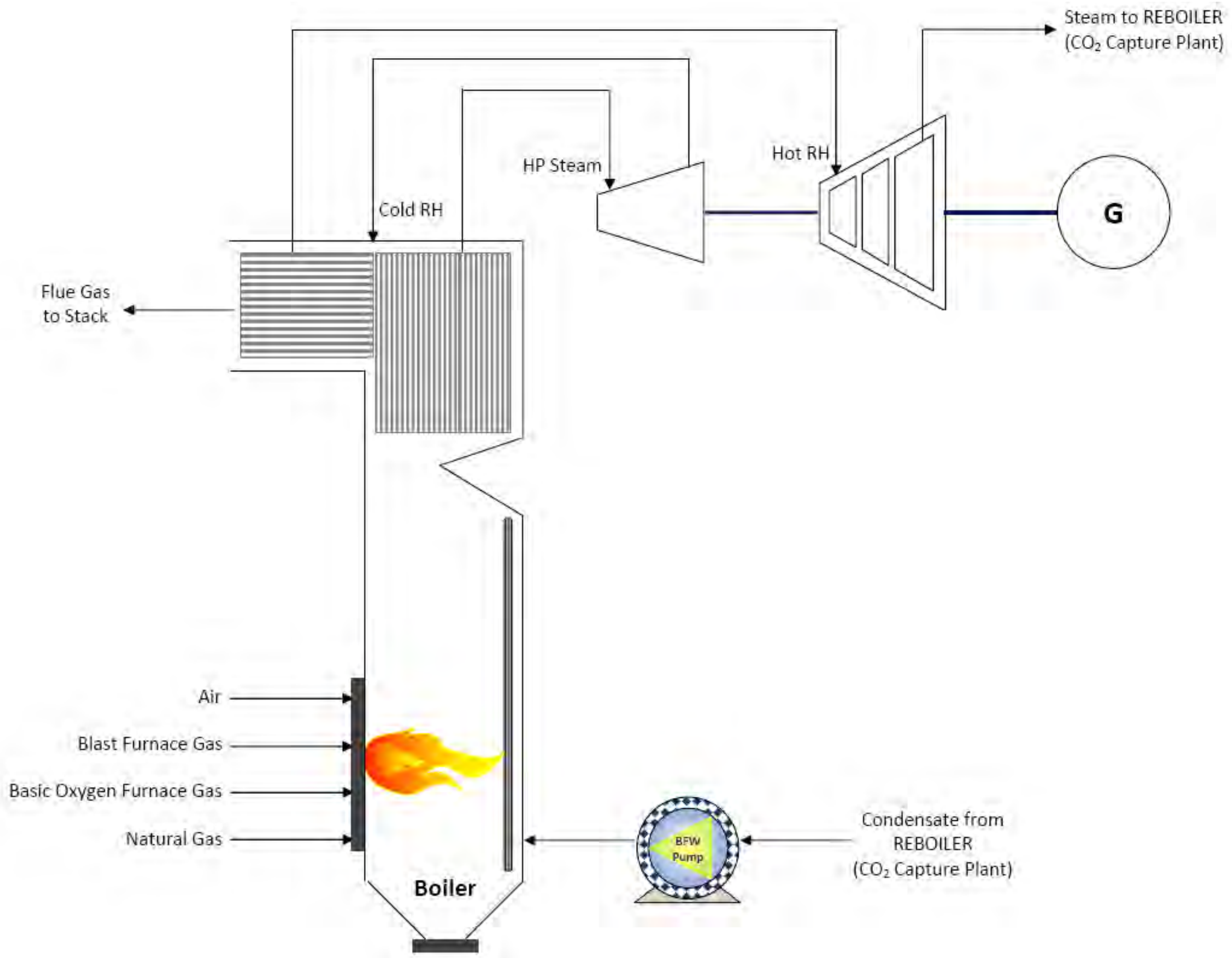

Figure E-4: PFD of the Captive CHP Plant (UNIT 2000) for Case 3B

3. SUMMARY OF RESULTS

Table E-1 summarises the performance of the different steam and power generation plants of the steel mill.

For the purpose of understanding the potential savings that could be delivered by using CHP plant for Cases 3A and 3B, CAPEX and OPEX were evaluated. Table E-5 presents the assumptions used in estimating cost of HRC production. Figure E-2 presents the cost breakdown of the HRC produced from the different cases evaluated for this study.

In summary, the cost savings that could be achieved by using CHP plant was assessed and the following could be concluded:

- Savings in CAPEX of around US$ 31 Million and US$ 69 Million could be achieved for Case 3A and 3B respectively (from US$ 4.876 Billion for the OBF Base Case). Most of the savings are due to the CAPEX reduction of the captive power plant (Unit 1200).

- Savings in OPEX of around US$ 11.5 Million/y and US$ 19.4 Million/y could be achieved for Case 3A and 3B respectively. Most the savings in OPEX were due to the reduction of the annual Natural Gas bill (roughly ~80% of the savings).

This results to breakeven prices (ex-works) of US$ 626.53 and US$ 622.85 per tonne HRC for Case 3A and 3B respectively (as compared to US$ 630.22 per tonne HRC for the OBF Base Case).

Reduction in the annual natural gas consumption of the steel mill also results in a decrease in the direct CO_2 emissions down to 1101.1 and 1092.2 kg/t HRC for Case 3A and 3B respectively (as compared to 1114.8 kg/t HRC for the OBF Base Case).

The cost savings and reduction in direct CO_2 emissions reduces the CO_2 avoidance costs to US$ 51.7 and 47.9 per tonne CO_2 avoided respectively for Case 3A and 3B (down from US$ 56.4/t CO_2 avoided for the OBF Base Case). Figure E-6 illustrates the possible variability of the CO2 avoidance cost (sensitivity to the captive power and steam generation options) as compared to the REFERENCE Steel Mill (without CO_2 capture).

Table E-1: Performance of the Captive Steam and Electricity Generation Plant of the Steel Mill with OBF and CO_2 Capture

	OBF Base Case	Case 3A	Case 3B
Type of Steam Generation Plant	Low Pressure Steam Boilers (Gas Fired)	Combine Heat and Power Plant (Gas Fired)	Combine Heat and Power (Gas Fired)
Nominal Output	8x Steam Boilers Steam at 290 MW_{th}	CHP Plant Steam at 290 MW_{th} Electricity at 75 MWe	CHP Plant Steam at 290 MW_{th} Electricity at 135 MWe
Annual Daily Average Fuel Input (% Thermal Input)	273.8 MJ/s OBF-PG (31%), BOFG (39%) and NG (30%)	346.8 MJ/s OBF-PG (24%), BOFG (31%) and NG (45%)	406.1 MJ/s OBF-PG(21%), BOFG (26%) and NG (53%)
Annual Daily Average Output (Steam)	247.0 MW_{th} (85% Load Factor)	247.0 MW_{th} (85% Load Factor)	247.0 MW_{th} (85% Load Factor)
Annual Daily Average Output (Electricity)	None	63.2 MWe (24.6% of Total Demand)	113.5 MWe (44.2% of Total Demand)
HP Turbine Steam Parameters	None	169 bar, 565°C without steam reheat	169 bar, 565°C with steam reheat
IP Turbine Steam Parameters	None	None	40 bar, 565°C
Steam Parameters to Stripper Reboiler	Saturated Steam at 9 Bar_a	9 Bar_a, 180°C Extracted after the HP/IP Turbine	9 Bar_a, 180°C Extracted after the IP Turbine
Steam Generation Efficiency (Total Fuel Input - LHV Basis)	90.22%	71.2%	60.8%
CHP Efficiency - Steam & Electricity (Total Fuel Input - LHV Basis)	-	89.4%	88.8%
Type of Captive Power Plant	Natural Gas Combine Cycle	Natural Gas Combine Cycle	Natural Gas Combine Cycle
Power Plant Configuration	1x GT, 1x HRSG & 1x Steam Turbine in Single Shaft Arrangement	2x GT, 2x HRSG & 1x Steam Turbine in Multi-Shaft Arrangement	1x GT, 1x HRSG & 1x Steam Turbine in Single Shaft Arrangement
Gas Turbine Type	F Class	E Class	E Class
Nominal Output	292 MWe	224 MWe	169 MWe
Annual Daily Average Fuel Input (% Thermal Input)	462.6 MJ/s (90% Load Factor)	359.2 MJ/s (86% Load Factor)	280.4 MJ/s (85% Load Factor)
Annual Daily Average Output (Electricity)	261.8 MWe (100% of Total Demand)	193.6 MWe (75.4% of Total Demand)	143.3 MWe (63.8% of Total Demand)
Net Efficiency (LHV Basis)	56.6%	53.5%	51.1%
Total Fuel Consumed (Steam and Electricity Generation)	Off-Gas Consumed 190.9 MJ/s NG Consumed 545.5 MJ/s	Off-Gas Consumed 190.9 MJ/s NG Consumed 515.1 MJ/s	Off-Gas Consumed 190.9 MJ/s NG Consumed 495.6 MJ/s
Net Efficiency – Steam & Electricity (Overall Performance - LHV Basis)	69.1%	71.4%	73.4%
Overall Direct CO_2 Emissions	1114.8 kg CO_2/t HRC	1101.1 kg CO_2/t HRC	1091.2 kg CO_2/t HRC

Table E-2: Key Assumptions for the Cost Evaluation of the Steel Mill with OBF and CO_2 Capture

	OBF Base Case	Case 3A	Case 3B
CAPEX – Steam Generation Plant (Unit 2000)	US$ 90 Million	US$ 139 Million	US$ 164 Million
CAPEX – Captive Power Plant (Unit 1200)	US$ 362 Million	US$ 288 Million	US$ 216 Million
Fuel Bill – Natural Gas (Total)	US$ 197.2 Million/y	US$ 187.8 Million/y	US$ 181.8 Million/y
Annual Maintenance Cost (Unit 2000: Steam Generation Plant)	US$ 2.3 Million/y	US$ 3.3 Million/y	US$ 4.2 Million/y
Annual Maintenance Cost (Unit 1200: Power Plant)	US$ 14.5 Million/y	US$ 11.5 Million/y	US$ 8.7 Million/y
Direct Labour (Unit 2000: Steam Generation Plant)	12 Personnel	18 Personnel	27 Personnel
Direct Labour (Unit 1200: Power Plant)	42 Personnel	35 Personnel	29 Personnel
Cost of Steam (Internal Price)	US$ 12.2479 per GJ	US$ 9.3330 per GJ	US$ 6.7442 per GJ
Cost of Electricity (Internal Price)	US$ 75.33 per MWh	US$ 80.52 per MWh	US$ 86.19 per MWh

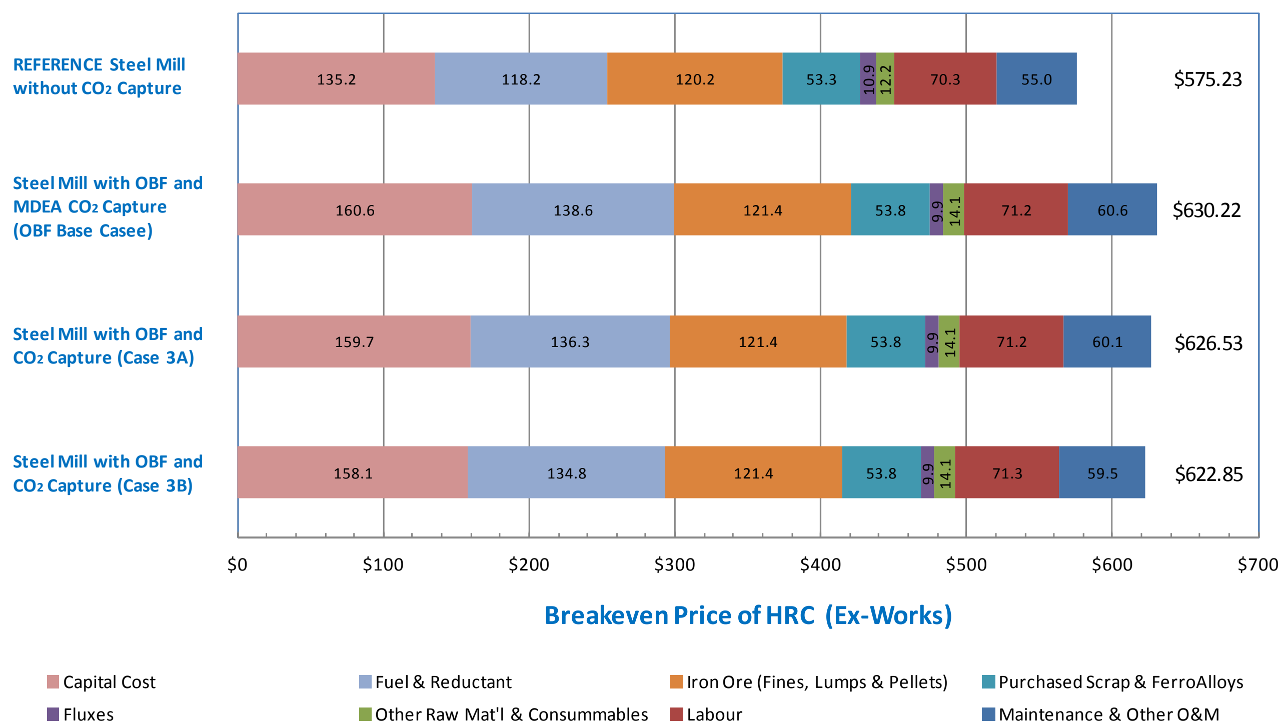

Figure E-5: Breakeven Price of HRC Produced by the REFERENCE Steel Mill and Steel Mills with OBF and CO_2 Capture (OBF Base Case vs OBF with Improved Steam & Electricity Supply)

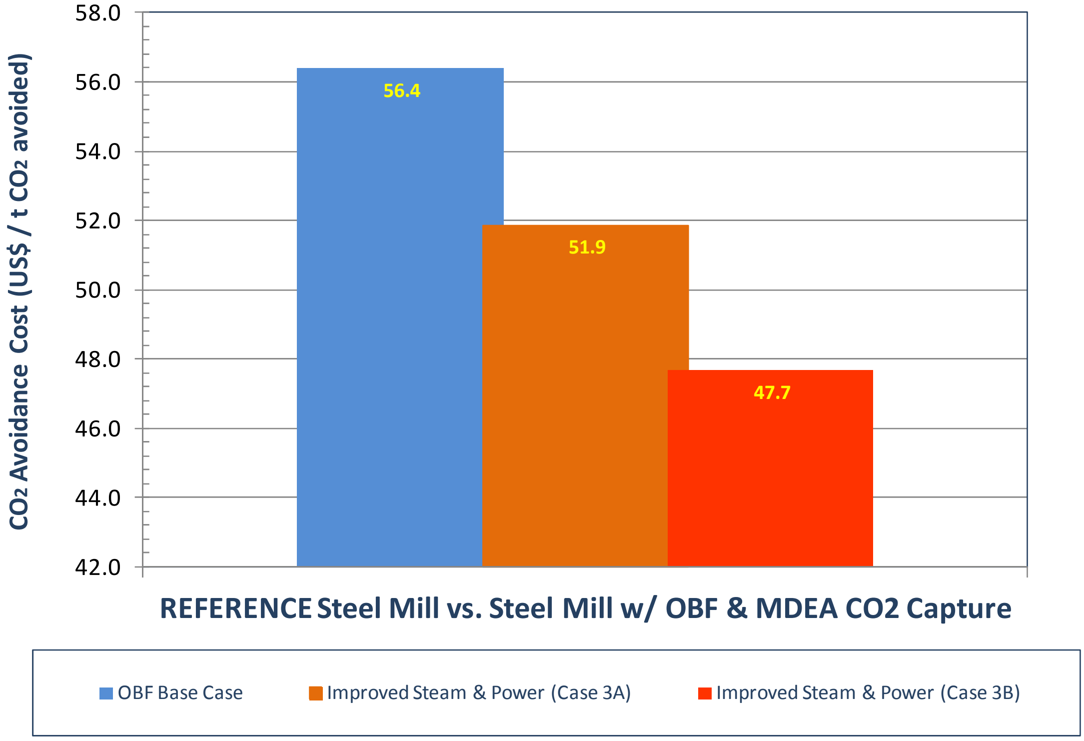

Figure E-6: Sensitivity of CO_2 Avoidance Cost to the internal cost of steam calculated from the REFERENCE Steel Mill (Base Case) vs. 3 different OBF Steel Mill with CO_2 Capture Cases

4. ACKNOWLEDGEMENT

The cost analysis presented in this section of the report was done in-house solely by IEA Greenhouse Gas R&D Programme (IEAGHG).

The objective of this section is to provide information that could help understand the impact of the cost when implementing CO_2 capture in an integrated steel mill. This study has demonstrated that improvements to the demand and supply side of the electricity and steam production of the steel mill are some of the important element of reducing the cost of steel production from steel mill with CO_2 capture.

Finally, it should be noted that significant care and diligence were undertaken in determining the accuracy of the information provided. However, the use of any information or its consequences should not be the responsibility of the authors or the organisation issuing this report.

Synthesis Report:

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume III: Estimating the Cost of Steel Production from an Integrated Steel Mill with OBF and MDEA CO_2 Capture

REPORT ANNEX

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Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume III: Estimating the Cost of Steel Production from an Integrated Steel Mill with OBF and MDEA CO_2 Capture Technology

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Annex I

General Assumptions and Design Basis

I N D E X

1. INTRODUCTION

This section of the report provides the general information and assumptions used in establishing the operating parameters of the Steel Mills with Post-Combustion CO_2 Capture. These include the information regarding:

- General Assumptions
- Design Basis for the Site Specific Conditions

2. GENERAL ASSUMPTIONS

2.1. Extra-Ordinary Assumptions

Some assumptions which are classified as extra-ordinary were used to simplify the accounting of the CO_2 emissions, the energy demand, and the cost of steel produced. It should be noted that these assumptions are only used to provide a clear illustration and to establish a comparable cost basis between steel mills with and without CO_2 capture.

It should be emphasized that these assumptions are very idealized and not intended to represent any actual integrated steel mills in operation. These are only used to simplify the accounting of energy imports and exports and the CO_2 emissions associated with these.

The steering committee agreed to the following extra-ordinary assumptions to be used in the study:

a) Only one type of steel product produced and sold.

   It was assumed in the study that a standard grade hot rolled coil will be the only main product to be sold outside the set boundary limit.

   It should be noted that typical integrated steel mills would produce several grades and forms of steel in a single site; and also have the possibility to sell semi-finished products like slab, beam or billet.

   Annual production of 4 million tonnes of hot rolled coil per year was assumed. This is agreed to represent typical capacity of European Integrated Steel Mills.

b) Plant ownership structure

   The study assumed captive ownership of the lime plant (UNIT 1000), oxygen plant (UNIT 1100), power plant (UNIT 1200) and steam generation plant (UNIT 2000)

   In general, European integrated steel mills, do not own these plants. Electricity, industrial gases (O_2, Ar & N_2) and lime required by the steel mill are generally bought based on long term over the fence contracts and guarantees. CO_2 emissions from these facilities are typically not accounted for in the direct emissions of the integrated steel mill.

   However, directly or indirectly, these plants use the off-gases of the steel mill as their primary energy source. In order to simplify the accounting of the direct CO_2 emissions and cost evaluation without the consideration of the "CO_2 Emission Export", these plants were assumed to be included in the boundary limit and owned by the steel mill.

c) Balanced coke production

The study assumed that coke plant (UNIT 100) will produce lump coke and coke breeze that are sufficient for the demands of the steel mill – i.e. there will be no export or import of coke.

In general – coke is a tradable commodity and any surplus coke produced by an integrated steel mill is sold in the market. Typically, there is no integrated steel mill that will have coke production in balance with the steel mill's requirements.

d) Captive power plant – with balanced electricity production

The captive power plant is assumed to produce electricity that is only enough to supply the requirements of the whole steel mill. There will be no import or export of electricity into or out of the boundary limit. For steel mills with post-combustion CO_2 capture, the study assumed that natural gas is imported into the boundary limit to serve as its primary fuel.

In reality the majority of Western European integrated steel mills do not own their power plant. Any excess off-gases produced from these steel mills are sold as fuel to a power plant or other users outside the steel mill complex. Delivery is via a pipeline based on an off take supply contract. The electricity required by the steel mill is generally bought from a power plant outside their steel mill complex based on a long term over the fence contract or is bought directly from the grid.

e) Other operating considerations

- CO_2 emissions resulting from manufacture of purchased pellets, burnt dolomites and merchant scrap will not be accounted as direct CO_2 emissions of the steel mill.

- Granulated BF Slag will not be given CO_2 emission credit – even if this could be considered as substitute clinker for the cement industry.

2.2. Key Assumptions

Key technical assumptions used to define the boundary conditions in determining the heat and mass balance are summarized below.

a) The steel mill is assumed to have access to natural gas delivered via pipeline.

b) Iron Ore Burden

The iron ore burden composition for the blast furnace was fixed in the study and this consisted of: (1.) Sinter ~70%w; (2.) Pellets ~22%w; and (3.) Lump ore ~8%w. This distribution is maintained constant over the economic life of the integrated steel mill.

The iron ore fines used to produce the sinter are assumed to be imported from Brazil (Hematite), Australia (Hematite & Goethite) and Sweden (Magnetite). The lump ore is from Australia; and the pellets are from Brazil.

In general, there are very wide variations in iron ore burden composition among the operating blast furnaces in Western Europe ranging from 100% pellet to 100% sinter. The burden chosen has been agreed among the members of the Steering Committee and accepted as representative ferrous burden of a typical European Steel Mill equipped with a sinter plant.

c) Coking Coal and Coke By-Products

The study assumed a By-Product Recovery Coking Plant with Coke Oven Gas, Crude Tar, Benzole and Sulphur as the only coking by-products produced by the "Reference" Steel Mill.

Based on industry norms the coke and coke by-products were specified according to the following yields (as %w of the input coking coal):

- Lump Coke 67.2%w
- Coke Breeze 10.6%w
- Coke Oven Gas (wet) 14.2%w
- Crude Tar 3.2%w
- Benzole 0.9%w
- Sulphur 0.2%w

However, it should be noted that the study did not provide a detailed mass balance for the coke by-product plant. Coke demand/coke rate was calculated from the Blast Furnace Model as briefly described in Section B6.3. Coking coal required is defined by the coke demand of the steel mill and typical coke yield reported by the industry.

It should be noted that it is very typical for steel mills to buy their coking coal from various sources and blend both high and low quality coking coal to the coke ovens (type of coking coal used is normally of several varieties unless it is being sourced from a single coal mine).

To represent the typical blends of high and low quality coking coal used in any steel mill, a proportion of 60%w hard coking coal and 40%w semi-soft coking coal was assumed. Both types of coking coal are imported from Australia. This distribution is maintained constant over the economic life of the integrated steel mill.

d) Key Ironmaking Operating Parameters

The following parameters were fixed to determine the overall iron ore requirements, sinter rate and coke rate of the blast furnace.

- PCI Coal Injection rate ~150 kg/thm
- Oxygen enrichment of the blast air 24%
- Slag rate ~280 kg/thm.
- Hot metal temperature set to 1470^{o}C with hot metal Si and C content fixed at 0.5% and 4.7% respectively.

Hot Metal loss was fixed at ~1.9%Fe for the HM Desulphurisation Plant (UNIT 400).

e) Key Steelmaking Operating Parameters

The study assumed liquid steel production based on 2x 220 tonnes BOS Furnaces operating at 45 minutes per cycle, each equipped with waste heat boiler.

The following parameters were fixed to determine the amount of fluxes and additives needed for the steelmaking process.

- Total scrap rate ~190 kg/tls (with purchased scrap at ~116 kg/tls)
- Pellets for cooling ~5 kg/tls
- Burnt dolomite ~11 kg/tls
- Oxygen charged ~52 Nm^3/tls
- Slag rate ~113 kg/tls (with composition of the slag fixed)
- BOF gas recovery set at 75% of carbon recovery using a fixed gas composition.

Other operating considerations

- Continuous casting was assumed to have a slab yield of ~97%.
- Reheating and rolling mills was assumed to have steel recovery of ~95%.

f) Off-Gas Distribution and Utilisation

The composition of off gases obtained from the coke ovens, blast furnaces and basic oxygen furnaces were specified according to industry norms.

The study assumed that all off-gas produced from the coke ovens (UNIT 100), blast furnaces (UNIT 300) and basic oxygen steel furnaces (UNIT 500) are recovered based on industry norms and are used within the steel mill. For steel mills with post-combustion CO_2 capture (i.e. Cases 2A and 2B), any excess off-gases are delivered to the captive steam generation plant (UNIT 2000) as fuel.

In case that any surplus off gases is produced – it will be assumed to be flared. In addition to flared off-gases which are normal in any operating steel mills, all off-gases that are considered lost or not recovered will also be accounted for as “flared”.

For Cases EOP-L1 and EOP-L2, the study assumed the following with regard to the utilisation of the off-gases from the steel mill:

- COG would supply fuel to the following:
    - coke plant (UNIT 100)
    - sinter plant (UNIT 200)
    - hot stoves (UNIT 300)
    - reheating furnace (UNIT 800) and
    - lime plant (UNIT 1000)

- BFG would supply fuel to the following:
    - hot stoves (UNIT 300) and
    - steam generation plant (UNIT 2000)

- BOFG would supply fuel to the steam generation plant (UNIT 2000).

The off-gas distribution will be maintained constant over the economic life of the Steel Mills with Post-Combustion CO_2 Capture.

3. DESIGN BASIS - SITE SPECIFIC CONDITIONS

3.1. Ambient Conditions

The average ambient conditions of the site were assumed as follows:

- Ambient Air Temperature 12°C
- Atmospheric Pressure 1.013 Bar
- Relative Humidity 80%

3.2. Raw Water

Raw water is obtained from the grid. This is normally treated and demineralised to the required standard for process water use and machinery cooling.

For machinery cooling, a maximum of 10°C rise was used during normal operation. It was assumed that a closed loop system was employed with sea water as the medium for cooling the machinery cooling water.

Raw Water

- Source: from grid
- Type : potable water
- Operating pressure at grade: 0.8 barg (min)
- Operating temperature : Ambient

Demineralised Water

- Type: treated water (mixed bed demineralization)
- Operating pressure at grade: 5.0 barg
- Operating temperature: Ambient
- Characteristics:
  - pH 6.5 to 7.0
  - Total dissolved solids (mg/kg) 0.1 max
  - Conductance at 25°C (μS) 0.15 max
  - Iron (mg/kg as Fe) 0.01 max
  - Free CO_2 (mg/kg as CO_2) 0.01 max
  - Silica (mg/kg as SiO_2) 0.015 max

3.3. Sea Water

Seawater used by the steel mill is normally for cooling duty using a once through cooling system. It is generally filtered and chlorinated to remove suspended solids and organic matter.

Sea Water

- Supply temperature:
  - average supply temperature: 12 °C
  - max allowed sea water temperature increase: 7 °C

- Other Data
  - Operating pressure at Users inlet: 0.9 barg
  - Max allowable ΔP for Users: 0.5 barg
  - Design pressure for Users: 4.0 barg
  - Design pressure for sea water line: 4.0 barg

- Design temperature: 55 °C
- Cleanliness Factor (for steam condenser): 0.9
- Fouling Factor: 0.0002 h °C m^2/kcal

3.4. Steam

Steam is available for plant used at 8 Barg and 175^{o}C (saturated).

For the REFERENCE Steel Mill Base Case, it is verified that the steam produced from the basic oxygen steelmaking plant (UNIT 500) should deliver enough steam for the demand of the entire steel mill. Back up steam, if required, could be obtained by extracting low pressure steam from the captive power plant's steam turbine.

It should be noted that the Combined NH_3 cracker and Claus Plant should also produced a small amount of low to medium pressure steam which is not modelled in the study. However, it could be assumed that this will be used by the coke plant and will not be distributed to the works' steam network.

3.5. Electricity

The electricity required for the steel mill is produced from the captive power plant. It was assumed that the steel mill has access to the main grid to provide backup electricity.

Specification of the electricity grid of the steel mill is presented below.

- Voltage: 110kV
- Frequency: 50 Hz
- Fault Duty: 50 kA

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Annex II

Specification: Raw Materials, Intermediate, By-Products and Finished Products

I N D E X

1. INTRODUCTION

This section of the report provides the general information and assumptions used in establishing the operating parameters of the REFERENCE Steel Mill. These include the information regarding:

- Raw materials
- Energy and Reductants
- Products, Intermediate Products and By-Products
- Waste Materials for Disposal or Recycling

It should be noted that specifications reported in this section for all the energy, reductants, raw materials, products, by-products and waste are not the full assay normally required by the steel mill. However, the numbers provided should allow enough details for modelling of the mass and energy balance differences required for techno-economic evaluation.

2. ENERGY AND REDUCTANTS (EXTERNALLY SOURCED)

2.1. Coking Coal

Table A1-1: Specification of the Coking Coal

Dry Basis (%wt.)	Typical Range	Average (used in the study)
C	75 - 85	78.85
H	4 - 6	4.51
Fe	15 - 35	0.33
CaO	-	0.05
MgO	-	0.05
SiO_2	3 - 5	4.68
$Al2O_3$	1 - 3	2.10
Moisture	-	8.00
LHV (MJ/kg) - dry	-	31.10

2.2. PCI Coal

Table A1-2: Specification of the PCI Coal (after drying)

Dry Basis (%wt.)	Average (used in the study)
C	87.00
H	4.03
Fe	0.52
CaO	0.19
MgO	0.04
SiO_2	2.41
Al_2O_3	1.62
Moisture	1.00
LHV (MJ/kg) - dry	33.37

2.3. Natural Gas

Table A1-3: Specification of the Natural Gas

Dry Basis (%vol.)	Average (used in the study)
CH_4	83.90
C_2H_6	9.20
C_3H_8	3.30
C_4H_{10}	1.20
C_5H_{12}	0.20
CO_2	1.80
N_2	0.40
LHV (MJ/Nm^3) - dry	40.64

3. RAW MATERIALS

3.1. Iron Ore – Fines, Lumps and Pellets

Table A1-4: Specification of the Iron Ore Burden

Dry Basis (%wt.)	Iron Ore Fines			Lump Ore (Australia)	Pellets (Brazil)
	Hematite (Australia)	Hematite/Geothite (Brazil)	Magnetite (Sweden)		
Fe (Total)	66.2	57.95	69.77	61.00	65.50
CaO	0.05	0.28	0.42	0.30	1.80
MgO	0.06	0.18	0.45	0.20	1.20
Al_2O_3	0.87	1.91	0.17	2.76	0.60
SiO_2	2.58	5.02	1.15	8.38	2.80
Others[1]	Difference	Difference	Difference	Difference	Difference
Moisture	5.00	5.00	5.00	5.00	2.00

It should be noted that full assay of the iron ore also includes the specification for FeO, Fe_xO_y, Mn, P, S, and other trace elements (i.e. zinc, vanadium, titanium, lead, et. al.). These elements and compounds are all accounted for in the model of the mass balance developed by Swerea MEFOS.

3.2. Purchased Scrap and Ferroalloys

Purchased Scrap

Table A1-5: Specification of the Scrap Steel (External)

Dry Basis (%wt.)	Average (used in the study)
Fe[2]	98.89
C	0.11
Si	0.01
Others[3]	Difference

[1] Others include trace elements such Ti, V, Mn, etc... that comes together with the iron ore.
[2] External scrap comes in various forms and shape. Typically, Fe content should be in the range of 92 to 99%.
[3] Others include P, S, Cr, Nb, Ti, B, Ni, Cu, Pb, Zn, Mg, others trace elements.

Ferroalloys and Aluminium

Table A1-6: Specification of the Ferroalloys

Dry Basis (%wt.)	FeMnC	FeSi-75	Aluminium
Fe	14.58	22.56	0.67
C	6.87	0.03	-
Si	0.11	76.61	1.34
Mn	78.27	0.01	0.23
Al	0.00	0.71	96.30
Others[3]	Difference	Difference	Difference

3.3. Fluxes

Fluxes used in the iron and steelmaking process include:

- Limestone (Lime Production, Sinter Production and Blast Furnace)
- Quartzite (Sinter Production, Blast Furnace)
- Olivine (Sinter Production)
- Burnt Dolomite (Basic Oxygen Steelmaking Furnace)
- Calcium Carbine (Hot Metal Desulphurisation)

Table A1-7: Specification of Different Fluxes Used in Iron and Steelmaking Processes

Dry Basis (%wt.)	Limestone	Quartzite	Olivine	Burnt Dolomite
$CaCO_3$	94.20	-	-	-
CaO	1.20	-	0.20	40.00
$MgCO_3$	2.30	-	-	-
MgO	-	-	47.90	55.00
Al_2O_3	0.50	1.90	0.48	1.00
SiO_2	1.20	98.00	41.60	1.00
Fe (Total)	0.30	-	5.70	0.15
Others[4]	Difference	Difference	Difference	Difference
CO_2 (Total)	42.60	-	-	-
Moisture	1.0	1.0	1.0	1.0

Table A1-8: Specification of Calcium Carbide

Dry Basis (%wt.)	Average (used in the study)
CaC_2	79.00
CaO	15.80
CaS	1.20
Al_2O_3	1.20
SiO_2	1.50
Fe (Total)	0.20
C (Residual)	1.00
Others[4]	Difference
Moisture	0.00

[4] Others include TiO_2, V_2O_5, P_2O_5, MnO, Na_2O, K_2O

4. PRODUCTS, INTERMEDIATE PRODUCTS AND BY-PRODUCTS

4.1. Hot Rolled Coil

Table A1-9: Specification of the Hot Rolled Coil

Dry Basis (%wt.)	Average (used in the study)
Fe	98.73
C	0.12
Others[5]	Difference

The HRC produced from the finishing mill is directly transferred to the product stockyards ready for sale and delivery. Transport of finished goods is generally by rail. Hot Rolled Coil produced could be delivered in several sizes (thickness, width and length) dependent on the setting of the finishing mills. Thickness of the hot rolled coil could be in the range of 1 to 20mm; and width of 0.5 to 1.5m. Table A1-10 presents the typical dimension of the hot rolled coil delivered by the integrated steel mill with CO_2 capture presented in this study.

Table A1-10: Dimension of the Hot Rolled Coil

Hot Rolled Coil	Dimension
Thickness	1.47 mm
Width	700 mm
Hot Rolled Coil (Inside Diameter)	762 mm
Hot Rolled Coil (Outside Diameter)	1000 mm
Tolerance (Inside Diameter)	+0 / -50 mm

4.2. Slab

Typically, slabs are usually rectangular (though sometimes trapezoidal, i.e. a tapered slab), with a dimension in the order of 250 mm thick, 5000 to 12000 mm long, and 300 to 1500 mm wide. The slab should have a similar chemical composition to the hot rolled coil as shown in Table A1-9.

4.3. Liquid Steel

Table A1-11: Specification of the Liquid Steel

Dry Basis (%wt.)	Liquid Steel (after BOF)	Liquid Steel (after Ladle Metallurgy)
Fe	99.91	98.73
C	0.04	0.12
Others[5]	Difference	Difference

[5] Others are alloying materials added and other residual element.

4.4. Hot Metal

Table A1-12: Specification of the Hot Metal

Dry Basis (%wt.)	Hot Metal (Before Desulphurisation)	Hot Metal (After Desulphurisation)
Fe	94.15	94.24
C	4.70	4.65
Si	0.50	0.49
Mn	0.27	0.27
Others	Difference	Difference

For this study, the sulphur content of the hot metal prior to desulphurisation is estimated at 0.032%. After desulphurisation, the sulphur content of the hot metal is reduced to less than 0.01%.

4.5. Sinter

Table A1-13: Specification of Sinter

Dry Basis (%wt.)	Average (used in the study)
Fe (Total)	57.88
CaO	9.40
MgO	1.50
Al_2O_3	1.04
SiO_2	5.23
Others[6]	Difference
Moisture	0.00

4.6. Coke and Coke Breeze

Table A1-14: Chemical Composition of Coke (Lump & Breeze)

Dry Basis (%wt.)	Average (used in the study)
C	88.05
H	0.10
N	1.10
S	0.60
Fe	0.42
CaO	0.06
MgO	0.07
SiO_2	6.27
Al_2O_3	2.82
Alkalis (Na_2O & K_2O)	< 0.30
P	< 0.03
Moisture	4.00
Volatiles Matter	< 2.00
Ash	10.00
LHV (MJ/kg) - dry	29.01

[6] Others include other trace elements that are derived from the iron ore and fluxes.

4.7. Lime

Table A1-15: Specification of Lime

Dry Basis (%wt.)	Average (used in the study)
$CaCO_3$	6.80
CaO	87.40
MgO	1.86
Al_2O_3	0.85
SiO_2	2.03
Fe (Total)	0.51
Others[7]	Difference
CO_2 (Total)	3.00
Moisture	0.00

4.8. Coal Tar, BTX and Sulphur

Coal Tar

For this study, it was assumed that the crude tar sold as by-product has an LHV of 42 MJ/kg (dry) and moisture of 2.0%.

Benzene, Toluene and Xylene (BTX)

The chemical composition (%wt.) of Crude Benzole typically contains the following:

- Benzene 55 - 65%
- Toluene 10 - 20%
- Xylene 5 - 10%
- Others Difference

For this study, Crude Benzole is sold as by-product with an assumed LHV of 38 MJ/kg.

Sulphur

The solid sulphur produced from the Claus unit is estimated to have an LHV of 9.3 MJ/kg. Typically, the sulphur sold as by-product has the following properties:

Table A1-16: Sulphur Qualities

Sulphur	Quality
Status	Solid
Colour	Bright yellow
Purity	99.9% S (min.)
H_2S	< 10 ppm (max.)
Ash Content	< 0.05% (max.)
Carbonaceous Materials	< 0.05% (max)

[7] Others include TiO_2, V_2O_5, P_2O_5, MnO, Na_2O, K_2O

4.9. Steel Mill Slag

The steel mill produce a variety of slag sold as by-products, recycled or discharge as waste. For this study, the following slags were accounted for in the Techno-Economic Evaluation of the Steel Mill with Post-Combustion (End of Pipe) CO_2 capture.

- Granulated BF Slag (GBF Slag)
- Hot Metal Desulphurisation Slag (De-S Slag)
- Basic Oxygen Furnace Slag (BOF Slag also known as LD Slag or BOS Slag)
- Ladle Metallurgy Slag (LM Slag also known as SM Slag)

Table A1-17: Composition of the Steel Mill's Slag

Dry Basis (%wt.)	Granulated BF Slag	De-S Slag	BOF Slag	Ladle Slag (SM Slag)
Fe (Total)	0.30	79.49	20.00	1.08
C (Total)	-	4.16	-	-
CaO	42.21	11.40	50.74	62.46
MgO	7.63	n.r.	5.47	n.r.
Al_2O_3	10.33	n.r.	0.56	28.32
SiO_2	36.71	1.93	9.45	8.03
Others	Difference	Difference	Difference	Difference
Moisture	12.00	1.00	1.00	1.00

4.10. Off-Gases

Coke Oven Gas

For this study, the coke oven gas or COG is a medium CV fuel gases produced from the three coke oven batteries (UNIT 100). The gas from the coke oven is primarily processed to remove the tar, naphthalene, benzene/toluene/xylene (BTX), H_2S, ammonia and particulates as described in Section D. The fuel gas composition is summarized in Table A1-18.

Table A1-18: Specification of the Coke Oven Gas

Wet Basis (%vol.)	COG
CH_4	23.04
H_2	59.53
CO	3.84
CO_2	0.96
N_2	5.76
O_2	0.19
H_2O	3.98
Other HC	2.69
LHV (MJ/Nm^3) - wet	17.33

Blast Furnace Gas

Blast Furnace Gas or BFG is a low CV by-product gas produced by the blast furnaces (UNIT 300). This gas is primarily cleaned to remove the particulates. The specification of the BF gas used in this study is presented below.

Table A1-19: Specification of the Blast Furnace Gas

Wet Basis (%vol.)	BFG to Hot Stove	BFG to Other Users
H_2	3.59	3.63
CO	22.10	22.34
CO_2	21.86	22.10
N_2	48.24	48.77
H_2O	4.21	3.15
LHV (MJ/Nm^3) - wet	3.18	3.21

Basic Oxygen Furnace Gas

Basic Oxygen Furnace Gas or BOFG (also known as BOS Gas, LD Gas or Converter Gas) is a medium CV by-product gas produced by the basic oxygen furnace (UNIT 600). This gas is primarily cleaned to remove the particulates. The specification of the BOF gas used in this study is presented below.

Table A1-20: Specification of the Basic Oxygen Furnace Gas

Wet Basis (%vol.)	BOFG
H_2	2.64
CO	56.92
CO_2	14.44
N_2	13.83
H_2O	12.16
LHV (MJ/Nm^3) - wet	7.47

4.11. Oxygen, Nitrogen and Argon

Oxygen, nitrogen and argon are all produced from the Air Separation Unit (UNIT 1100). All gases will be available in both liquid and gaseous products at required delivery pressure. Table A1-21 summarized the product specification of the oxygen, nitrogen and argon from the ASU.

Table A1-21: Specification of the Oxygen, Nitrogen and Argon

	Oxygen	Nitrogen	Argon
Main Product	Gaseous Oxygen (GOX)	Gaseous Nitrogen (GAN)	Gaseous Argon (GAR) Liquid Argon (LAR)
Purity	99.9%	99.98%	99.99%
Delivery Pressure	7 Bar and 31 Bar	7 Bar and 21 Bar	7 Bar and 31 Bar
Product Sale	-	-	Liquid Argon (LAR)

4.12. Steam

The whole steel mill has an access to steam line at 9 bar_a and 175°C. The steam required by the CO_2 Capture and Compression Plant (Unit 4000) is mainly supplied from the Steam Generation Plant. Whilst the steam required by the whole steel mill is supplied by the steam produced from the waste heat boilers installed at the Basic Oxygen Furnace (UNIT 600).

4.13. Electricity

The electricity required for the steel mill is produced from the captive power plant (UNIT 1200). As backup, it was assumed that electricity could be bought from the grid. For simplicity in CO_2 emissions audit, it is assumed in this study that electricity produced from the captive power plant is balanced.

Specification of the Electricity produced by the captive power plant is presented below.

- Nominal Power Output: 292 MWe
- Voltage: 110 kV
- Frequency: 50 hz
- Fault Duty: 50 Ka

4.14. CARBON DIOXIDE

The Carbon Dioxide characteristics at plant B.L., are the following:

- Status: Supercritical/Dense Phase
- Pressure: 110 bar g
- Temperature: 25°C
- Purity:
  - CO_2: > 99% mol
  - Moisture: < 100 ppmv
  - Oxygen: < 10 ppmv

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Annex III

Process Flow Diagram & Mass Balance

(Integrated Steel Mill with OBF / MDEA CO_2 Capture)

I N D E X

1. UNIT 100: COKE PRODUCTION

1.1. PFD and Mass Balance

Figure A3-1 presents the process flow diagram of the coke production of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-1 presents a summary of the mass balance for the coke production of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

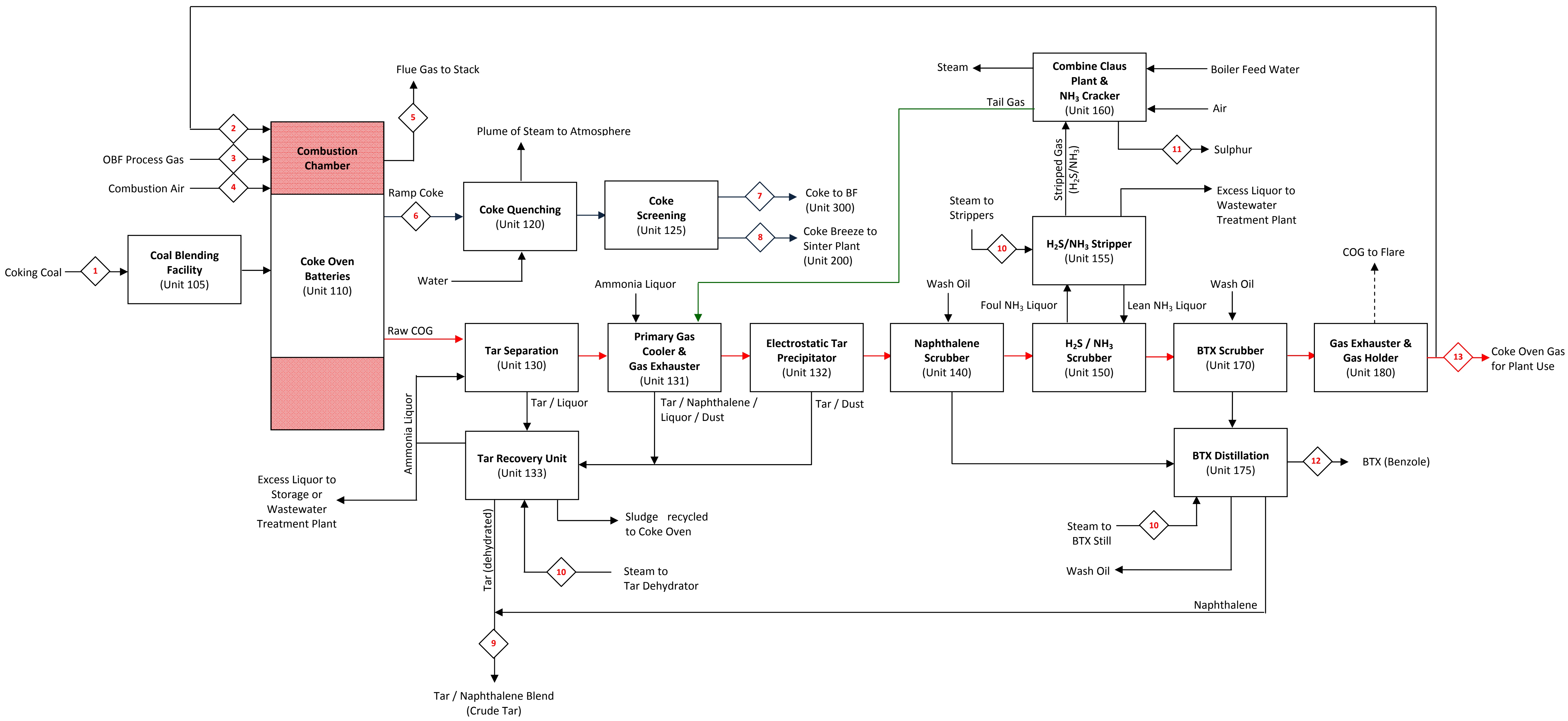

Figure A3-1: PFD of the coke production (Unit 100)

Table A3-1: Mass Balance (Unit 100: Coke Production)

		1	2	3	4	5	6	7	8	9	10	11	12	13
Stream		**Coking Coal**	**COG to Underfire Heating**	**OBF Process Gas**	**Combustion Air**	**Flue Gas**	**Ramp Coke**	**Coke to BF**	**Coke to Sinter**	**Crude Tar & Napthalene**	**Steam to Various Users**	**Sulphur**	**BTX (Benzole)**	**COG to Users**
Total Mass Flow (wet)	**t/y**	**1,737,406**	**22,833**	**459,077**	**2,325,960**	**2,706,198**	**1,295,564**	**1,069,051**	**226,513**	**52,212**	**186,561**	**3,766**	**15,049**	**220,109**
Total Mass Flow (dry)	**t/y**	**1,598,413**	**21,150**	**450,472**	**2,309,762**	**2,528,262**	**1,243,741**	**1,026,289**	**217,452**	**51,168**	**186,561**	**3,766**	**15,049**	**203,888**
Specific Mass Flow (wet)	kg/t coke	1396.9	18.4	369.1	1870.1	2175.9	1041.7	859.5	182.1	42.0	150.0	3.0	12.1	177.0
Specific Mass Flow (dry)	kg/t coke	1285.2	17.0	362.2	1857.1	2032.8	1000.0	825.2	174.8	41.1	150.0	3.0	12.1	163.9
Pressure	Bara	amb.	1.11	1.11	amb.	1.03	amb.	amb.	amb.	amb.	9.01	amb.	amb.	1.11
Temperature	oC	12	29	25	12	250	25	25	25	12	175	12	12	29
Phase		solid	gas	gas	gas	gas	solid	solid	solid	liquid	gas	solid	liquid	gas
Solid Composition (dry basis)														
Fe	%wt.	0.33	-	-	-	-	0.42	0.42	0.42	-	-	-	-	-
C	%wt.	78.85	-	-	-	-	88.05	88.05	88.05	-	-	-	-	-
H	%wt.	4.51	-	-	-	-	0.10	0.10	0.10	-	-	-	-	-
CaO	%wt.	0.05	-	-	-	-	0.06	0.06	0.06	-	-	-	-	-
MgO	%wt.	0.05	-	-	-	-	0.07	0.07	0.07	-	-	-	-	-
SiO2	%wt.	4.68	-	-	-	-	6.27	6.27	6.27	-	-	-	-	-
Al2O3	%wt.	2.10	-	-	-	-	2.82	2.82	2.82	-	-	-	-	-
Moisture (wet basis)	%wt.	8.0	-	-	-	-	4.0	4.0	4.0	2.0	-	-	-	-
Specific Vol. Flow (wet)	Nm3/t coke	-	42.28	273.14	1459.10	1653.26	-	-	-	-	-	-	-	407.62
Average MW			9.7	30.3	28.7	29.5					18.0			9.7
Gas Composition (wet basis)														
CH4	%v.	-	23.04	-	-	-	-	-	-	-	-	-	-	23.04
Other HC (Average MW = C2.5H5)	%v.	-	2.69	-	-	-	-	-	-	-	-	-	-	2.69
H2	%v.	-	59.53	12.50	-	-	-	-	-	-	-	-	-	59.53
CO2	%v.	-	0.96	2.97	-	12.39	-	-	-	-	-	-	-	0.96
CO	%v.	-	3.84	66.69	-	-	-	-	-	-	-	-	-	3.84
O2	%v.	-	0.19	-	20.72	9.50	-	-	-	-	-	-	-	0.19
N2	%v.	-	5.76	14.69	78.17	71.57	-	-	-	-	-	-	-	5.76
H2O	%v.	-	3.98	3.15	1.11	6.54	-	-	-	-	100.00	-	-	3.98

2. UNIT 200: SINTER PRODUCTION

2.1. PFD and Mass Balance

Figure A3-2 presents the process flow diagram of the sinter production of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-2 presents a summary of the mass balance for the sinter production of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

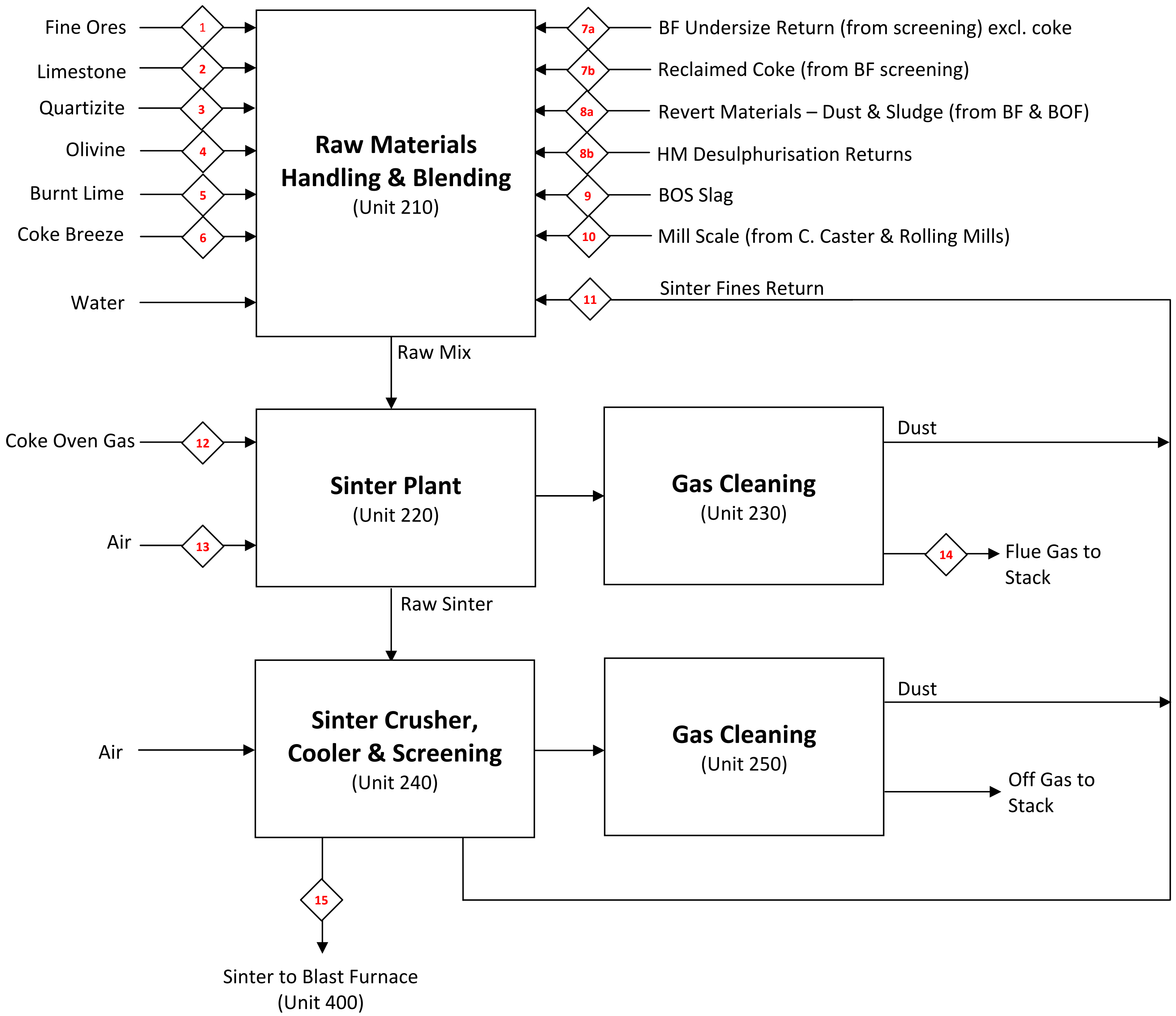

Figure A3-2: PFD of the sinter production (Unit 200)

Table A3-2: Mass Balance (Unit 200: Sinter Production)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stream		**Iron Ore Fines**	**Limestone**	**Quartzite**	**Olivine**	**Lime**	**Coke Breeze**	**BF Undersize**	**Revert Materials**	**BOS Slag**	**Mill Scale**	**Sinter Fines Return**	**COG**	**Combustion Air**	**Flue Gas**	**Sinter to BF**
Total Mass Flow (wet)	**t/y**	**3,706,829**	**394,248**	**35,144**	**91,248**	**43,490**	**226,513**	**84,143**	**255,476**	**137,785**	**97,131**	**1,087,261**	**7,826**	**12,024,295**	**2,215,956**	**4,349,042**
Total Mass Flow (dry)	**t/y**	**3,521,487**	**390,306**	**34,792**	**90,335**	**43,490**	**217,452**	**81,457**	**220,395**	**136,407**	**96,159**	**1,087,261**	**7,366**	**11,940,560**	**2,115,104**	**4,349,042**
Specific Mass Flow (wet)	kg/t sinter	852.3	90.7	8.1	21.0	10.0	52.1	19.3	58.7	31.7	22.3	250.0	1.8	2764.8	509.5	1000.0
Specific Mass Flow (dry)	kg/t sinter	809.7	89.7	8.0	20.8	10.0	50.0	18.7	50.7	31.4	22.1	250.0	1.7	2745.6	486.3	1000.0
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	1.11325	amb.	1.02625	amb.
Temperature	oC	12	12	12	12	12	12	12	12	12	12	80	25	12	120	45
Phase		solid	solid	solid	solid	solid	solid	solid	solid	solid	solid	solid	gas	gas	gas	solid
Solid Composition (dry basis)																
Fe	%wt.	65.62	0.30	-	5.70	0.51	0.42	46.85	54.80	20.00	70.00	59.14	-	-	-	59.14
C	%wt.	-	-	-	-	-	88.05	22.28	14.18	-	-	-	-	-	-	-
H	%wt.	-	-	-	-	-	0.10	-	-	-	-	-	-	-	-	-
CO2 (resiudual)	%wt.	-	42.60	-	-	3.00	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	0.10	54.00	-	0.20	91.26	0.06	1.34	10.22	50.86	0.72	8.00	-	-	-	8.00
MgO	%wt.	0.10	1.10	-	47.90	1.86	0.07	0.60	2.34	5.49	0.07	1.50	-	-	-	1.50
SiO2	%wt.	2.72	1.20	98.00	41.60	2.03	6.27	5.84	2.22	9.47	0.84	4.85	-	-	-	4.85
Al2O3	%wt.	0.93	0.50	1.90	0.48	0.85	2.82	1.81	0.60	0.56	0.16	1.04	-	-	-	1.04
Moisture (wet basis)	%wt.	5.0	1.0	1.0	1.0	-	4.0	3.2	13.7	1.0	1.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/t sinter	-	-	-	-	-	-	-	-	-	-	-	4.18	2157.14	407.62	-
Average MW													9.7	28.7	28.0	
Gas Composition (wet basis)																
CH4	%v.	-	-	-	-	-	-	-	-	-	-	-	23.24	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	-	-	-	-	-	-	-	-	2.71	-	-	-
H2	%v.	-	-	-	-	-	-	-	-	-	-	-	60.05	-	-	-
CO2	%v.	-	-	-	-	-	-	-	-	-	-	-	0.97	-	0.74	-
CO	%v.	-	-	-	-	-	-	-	-	-	-	-	3.87	-	4.62	-
O2	%v.	-	-	-	-	-	-	-	-	-	-	-	0.19	20.72	14.87	-
N2	%v.	-	-	-	-	-	-	-	-	-	-	-	5.81	78.17	72.69	-
H2O	%v.	-	-	-	-	-	-	-	-	-	-	-	3.15	1.11	7.08	-

3. UNIT 300: HOT METAL PRODUCTION

3.1. PFD and Mass Balance

Figure A3-3 presents the process flow diagram of the hot metal production of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-3 presents a summary of the mass balance for the hot metal production of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

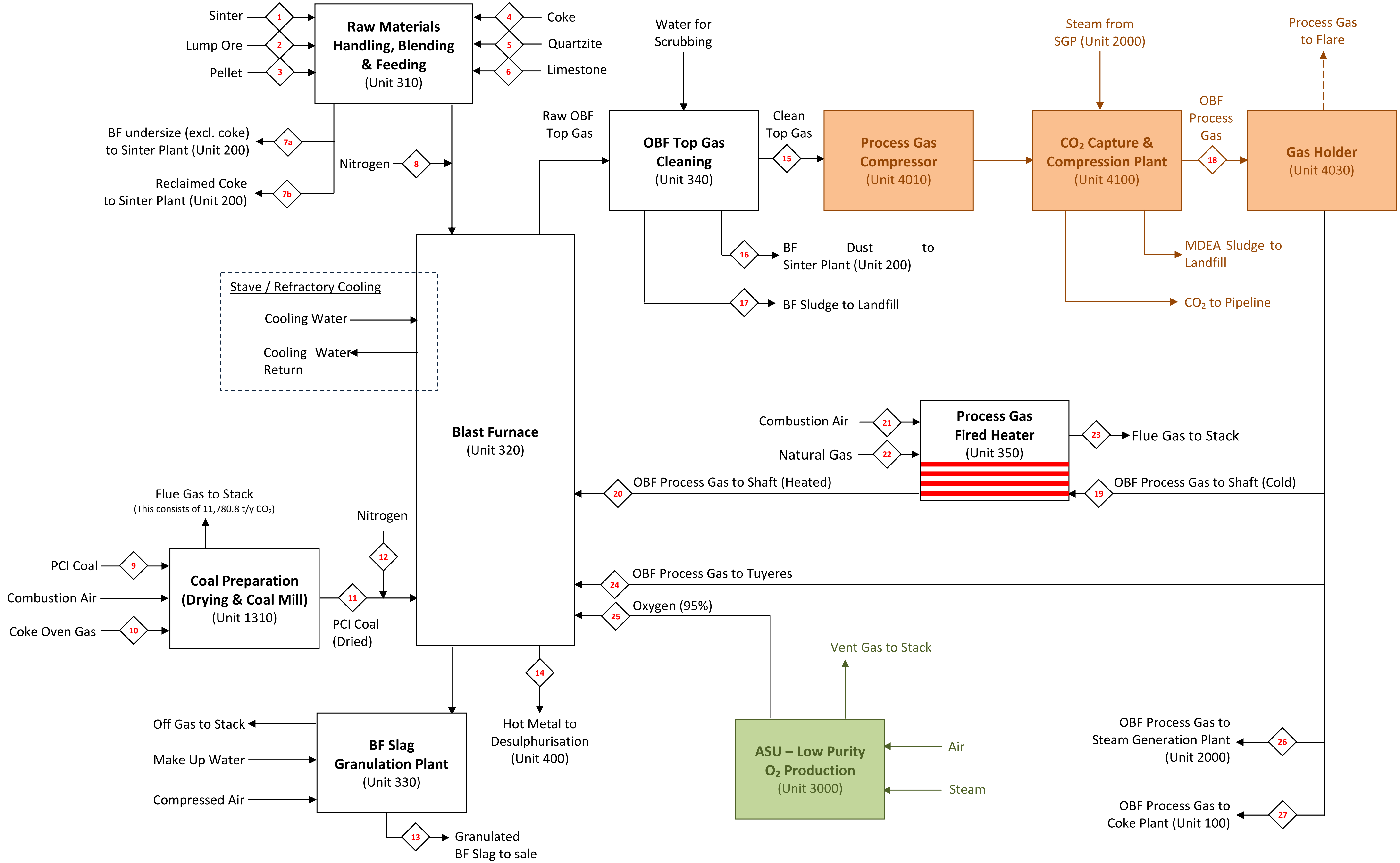

Figure A3-3: PFD of the hot metal production (Unit 300)

Table A3-3: Mass Balance (Unit 300: Hot Metal Production)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Stream		**Sinter**	**Lump Ore**	**Iron Ore Pellets**	**Coke**	**Limestone**	**Quartzite**	**BF Undersize**	**N2 to RM Feeder (Top)**	**PCI Coal to Dryer**	**COG to Dryer**	**PCI Coal (dried)**	**N2 to PCI**	**BF Granulated Slag**	**Hot Metal**
Total Mass Flow (wet)	**t/y**	**4,349,042**	**523,289**	**1,424,437**	**1,069,051**	**23,399**	**13,371**	**84,143**	**19,841**	**655,688**	**4,952**	**609,326**	**19,841**	**1,059,807**	**3,968,639**
Total Mass Flow (dry)	**t/y**	**4,349,042**	**497,124**	**1,399,333**	**1,026,289**	**23,165**	**13,237**	**81,457**	**19,841**	**603,233**	**4,661**	**603,233**	**19,841**	**932,630**	**3,968,639**
Specific Mass Flow (wet)	kg/thm	1095.9	131.9	358.9	269.4	5.9	3.4	21.2	5.0	165.2	1.2	153.5	5.0	267.0	1000.0
Specific Mass Flow (dry)	kg/thm	1095.9	125.3	352.6	258.6	5.8	3.3	20.5	5.0	152.0	1.2	152.0	5.0	235.0	1000.0
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	amb.	6.01	amb.	amb.	amb.	21.01	amb.	amb.
Temperature	oC	45	12	12	25	12	12	12	60	12	25	12	60	12	1470
Phase		solid	solid	solid	solid	solid	solid	solid	gas	solid	gas	solid	gas	solid	liquid
Solid & Liquid Composition (dry basis)															
Fe	%wt.	59.14	61.00	65.50	0.42	0.30	-	46.85	-	0.52	-	0.52	-	0.30	94.15
C	%wt.	-	-	-	88.05	-	-	22.28	-	87.00	-	87.00	-	-	4.70
H	%wt.	-	-	-	0.10	-	-	-	-	4.03	-	4.03	-	-	-
Si	%wt.	-	-	-	-	-	-	-	-	-	-	-	-	-	0.50
CO2 (residual)	%wt.	-	-	-	-	42.60	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	8.00	0.30	1.80	0.06	54.00	-	1.34	-	0.19	-	0.19	-	41.09	-
MgO	%wt.	1.50	0.20	1.20	0.07	1.10	-	0.60	-	0.04	-	0.04	-	8.87	-
SiO2	%wt.	4.85	8.38	2.80	6.27	1.20	98.00	5.84	-	2.41	-	2.41	-	35.73	-
Al2O3	%wt.	1.04	2.76	0.60	2.82	0.50	1.90	1.81	-	1.62	-	1.62	-	11.06	-
Moisture (wet basis)	%wt.	-	5.0	1.8	4.0	1.0	1.0	3.2	-	8.0	-	1.0	-	12.0	-
Specific Vol. Flow (wet)	Nm3/thm	-	-	-	-	-	-	-	4.00	-	2.90	-	4.00	-	-
Average MW									28.0		9.66		28.0		
Gas Composition (wet basis)															
CH4	%v.	-	-	-	-	-	-	-	-		23.24	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	-	-	-	-	-		2.71	-	-	-	-
H2	%v.	-	-	-	-	-	-	-	-		60.05	-	-	-	-
CO2	%v.	-	-	-	-	-	-	-	-		0.97	-	-	-	-
CO	%v.	-	-	-	-	-	-	-	-		3.87	-	-	-	-
O2	%v.	-	-	-	-	-	-	-	0.02		0.19	-	0.02	-	-
N2	%v.	-	-	-	-	-	-	-	99.98		5.81	-	99.98	-	-
Ar	%v.	-	-	-	-	-	-	-	-		-	-	-	-	-
H2O	%v.	-	-	-	-	-	-	-	-		3.15	-	-	-	-

Table A3-3: Mass Balance (Unit 300: Hot Metal Production) – cont'd.

Stream		15 Clean OBF Top Gas (Total)	16 Dust of Sinter Plant	17 Sludge to Landfill	18 OBF PGas after CO2 Capture	19 OBF PGas to Fired Heater	20 OBF PGas to Shaft	21 Combustion Air	22 NG to PGas Fired Heater	23 PGas Fired Heater Flue Gas	24 OBF PGas to Tuyeres	25 Low Purity O2	26 OBF PGas to SGP	27 OBF PGas to Coke Plant
Total Mass Flow (wet)	**t/y**	**7,610,753**	**59,530**	**17,638**	**4,153,254**	**2,490,894**	**2,490,894**	**1,691,133**	**63,501**	**1,752,605**	**905,806**	**1,432,672**	**385,137**	**377,672**
Total Mass Flow (dry)	**t/y**	**7,531,501**	**59,530**	**15,875**	**4,092,203**	**2,454,279**	**2,454,279**	**1,679,357**	**63,501**	**1,620,165**	**892,491**	**1,432,672**	**376,364**	**369,069**
Specific Mass Flow (wet)	kg/thm	1917.7	15.0	4.4	1046.5	627.6	627.6	426.1	16.0	441.6	228.2	361.0	97.0	95.2
Specific Mass Flow (dry)	kg/thm	1897.8	15.0	4.0	1031.1	618.4	618.4	423.2	16.0	408.2	224.9	361.0	94.8	93.0
Pressure	Bara	1.81	amb.	amb.	3.81	3.81	3.81	1.11	1.11	1.02	3.81	9.01	1.11	1.11
Temperature	oC	40	12	12	41	41	900	41	12	150	41	40	25	25
Phase		gas	solid	solid	gas	gas	gas	gas	gas	gas	gas	gas	gas	gas
Solid & Liquid Composition (dry basis)														
Fe	%wt.	-	26.10	37.70	-	-	-	-	-	-	-	-	-	-
C	%wt.	-	47.03	23.69	-	-	-	-	-	-	-	-	-	-
H	%wt.	-	0.43	-	-	-	-	-	-	-	-	-	-	-
Si	%wt.	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2 (residual)	%wt.	-	-	-	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	-	6.00	6.18	-	-	-	-	-	-	-	-	-	-
MgO	%wt.	-	1.23	1.71	-	-	-	-	-	-	-	-	-	-
SiO2	%wt.	-	4.93	4.61	-	-	-	-	-	-	-	-	-	-
Al2O3	%wt.	-	1.98	1.90	-	-	-	-	-	-	-	-	-	-
Moisture (wet basis)	%wt.	-	0.0	10.0	-	-	-	-	-	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/thm	1385.28	-	-	938.21	562.69	562.69	332.47	18.47	351.54	204.62	253.03	87.28	85.59
Average MW		31.0			25.0	25.0	25.0	28.7	19.4	28.2	25.0	32.0	24.9	24.9
Gas Composition (wet basis)														
CH4	%v.	-	-	-	-	-	-	-	83.90	-	-	-	-	-
Other HC (Average MW = C2.6H5.2)	%v.	-	-	-	-	-	-	-	13.90	-	-	-	-	-
H2	%v.	8.56	-	-	12.64	12.64	12.64	-	-	-	12.64	-	12.50	12.50
CO2	%v.	33.89	-	-	3.00	3.00	3.00	-	1.80	6.29	3.00	-	2.97	2.97
CO	%v.	45.69	-	-	67.46	67.46	67.46	-	-	-	67.46	-	66.69	66.69
O2	%v.	-	-	-	-	-	-	20.72	-	7.98	-	95.00	-	-
N2	%v.	10.07	-	-	14.86	14.86	14.86	78.17	0.40	73.93	14.86	3.50	14.69	14.69
Ar	%v.	-	-	-	-	-	-	-	-	-	-	1.50	-	-
H2O	%v.	1.79	-	-	2.04	2.04	2.04	1.11	-	11.81	2.04	-	3.15	3.15

4. UNIT 400: HOT METAL DESULPHURISATION

4.1. PFD and Mass Balance

Figure A3-4 presents the process flow diagram of the hot metal desulphurisation unit of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-4 presents a summary of the mass balance for the hot metal desulphurisation unit of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

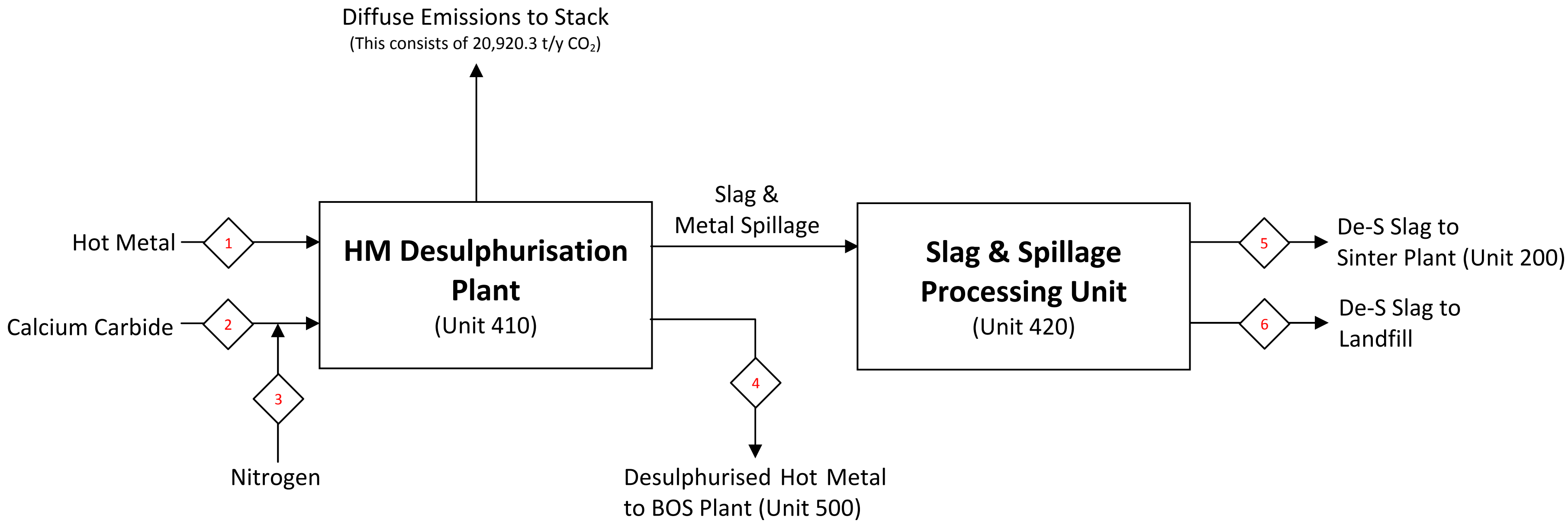

Figure A3-4: PFD of the hot metal desulphurisation (Unit 400)

Table A3-4: Mass Balance (Unit 400: Hot Metal Desulphurisation)

		1	2	3	4	5	6
Stream		**Hot Metal from BF**	**Calcium Carbide**	**N2 to CaC2 Feed**	**De-S Hot Metal**	**De-S Slag to Landfill**	**De-S Slag to Sinter Plant**
Total Mass Flow (wet)	**t/y**	**3,968,639**	**12,708**	**715**	**3,894,147**	**53,602**	**31,481**
Total Mass Flow (dry)	**t/y**	**3,968,639**	**12,708**	**715**	**3,894,147**	**53,066**	**31,166**
Specific Mass Flow (wet)	kg/thm (de-S)	1019.1	3.3	0.2	1000.0	13.8	8.1
Specific Mass Flow (dry)	kg/thm (de-S)	1019.1	3.3	0.2	1000.0	13.6	8.0
Pressure	Bara	amb.	amb.	21.01	amb.	amb.	amb.
Temperature	oC	1470	12	60	1360	12	12
Phase		liquid	solid	gas	liquid	solid	solid
Solid & Liquid Composition (dry basis)							
Fe	%wt.	94.15	0.20	-	94.24	79.49	79.49
C	%wt.	4.70	-	-	4.65	4.16	4.16
Si	%wt.	0.50	-	-	0.49	-	-
CaC2	%wt.	-	79.00	-	-	-	-
CaS	%wt.	-	1.20	-	-	-	-
CaO (incl. carbonates)	%wt.	-	15.80	-	-	11.40	11.40
MgO	%wt.	-	-	-	-	n.r.	n.r.
SiO2	%wt.	-	1.50	-	-	1.93	1.93
Al2O3	%wt.	-	1.20	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	-	1.0	1.0
Specific Vol. Flow (wet)	Nm3/thm (de-S)	-	-	0.15	-	-	-
Average MW				28.0			
Gas Composition (wet basis)							
O2	%v.	-	-	0.02	-	-	-
N2	%v.	-	-	99.98	-	-	-
H2O	%v.	-	-	-	-	-	-

5. UNIT 500: BASIC OXYGEN STEELMAKING PLANT

5.1. PFD and Mass Balance

Figure A3-5 presents the process flow diagram of the primary steelmaking of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-5 presents a summary of the mass balance for the primary steelmaking of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

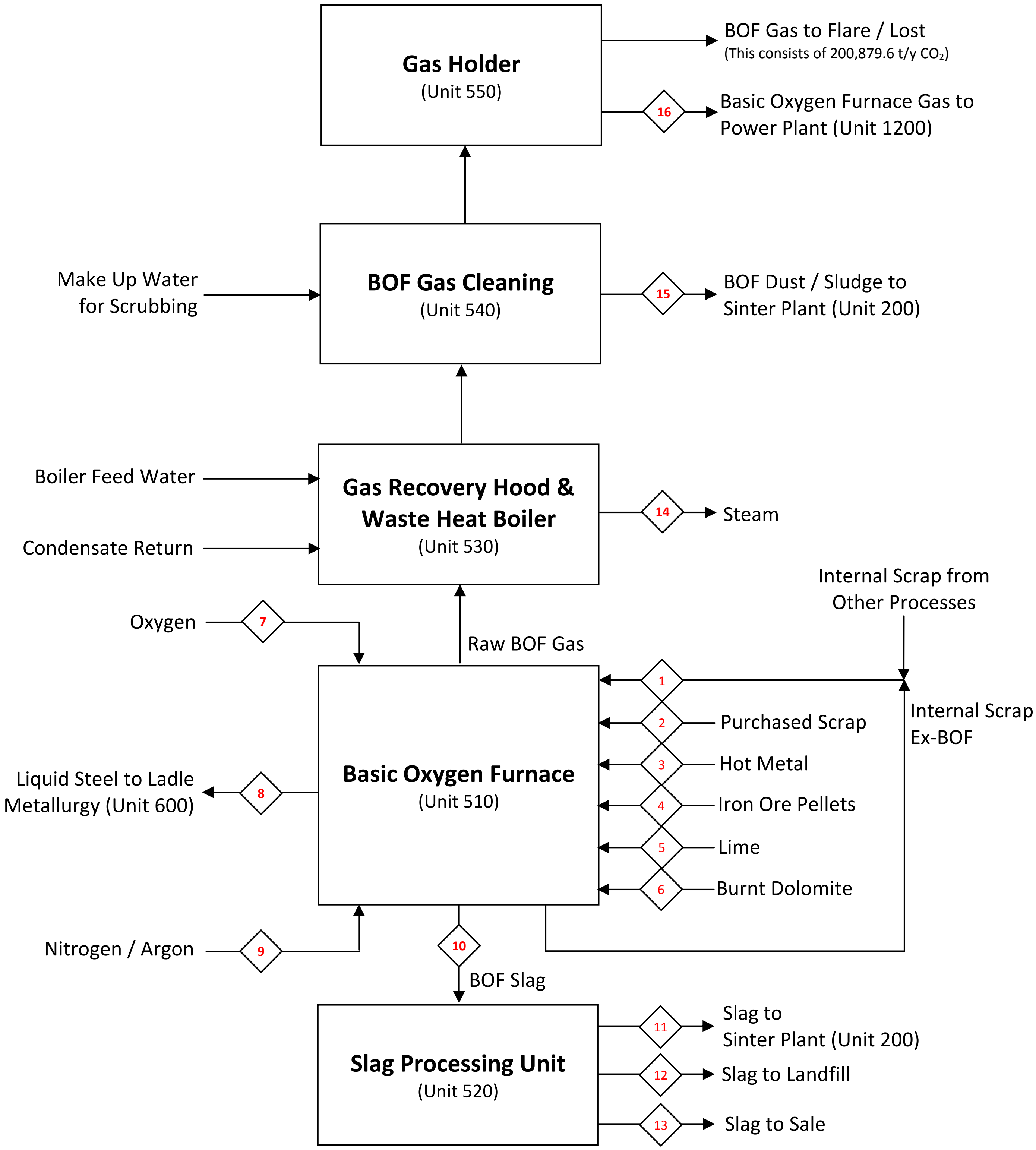

Figure A3-5: PFD of the basic oxygen steelmaking plant (Unit 500)

Table A3-5: Mass Balance (Unit 500: BOS Plant)

		1	2	3	4	5	6	7	8	9a	9b	10	11	12	13	14	15	16
Stream		**Internal Scrap**	**Purchased Scrap**	**De-S Hot Metal**	**Iron Ore Pellets (Cooling)**	**Lime**	**Burnt Dolomite**	**High Purity O2**	**Liquid Steel**	**N2**	**Ar**	**BOF Slag**	**Slag to Sinter Plant**	**Slag to Landfill**	**Slag to Sale**	**Steam to Various Users**	**BOF Dust & Sludge to Sinter Plant**	**BOF Gas to Power Plant**
Total Mass Flow (wet)	**t/y**	**315,940**	**505,492**	**3,894,147**	**21,263**	**280,230**	**47,640**	**318,305**	**4,323,327**	**1,638**	**5,060**	**492,106**	**137,785**	**127,952**	**226,369**	**324,250**	**169,174**	**448,160**
Total Mass Flow (dry)	**t/y**	**315,940**	**505,492**	**3,894,147**	**20,944**	**280,230**	**47,164**	**318,305**	**4,323,327**	**1,638**	**5,060**	**487,185**	**136,407**	**126,673**	**224,105**	**324,250**	**129,700**	**413,607**
Specific Mass Flow (wet)	kg/tls	73.1	116.9	900.7	4.9	64.8	11.0	73.6	1000.0	0.4	1.2	113.8	31.9	29.6	52.4	75.0	39.1	103.7
Specific Mass Flow (dry)	kg/tls	73.1	116.9	900.7	4.8	64.8	10.9	73.6	1000.0	0.4	1.2	112.7	31.6	29.3	51.8	75.0	30.0	95.7
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	31.01	amb.	21.01	21.01	amb.	amb.	amb.	amb.	9.01	amb.	1.11
Temperature	oC	12	12	1360	12	40	12	20	1672	60	60	12	12	12	12	175	12	50
Phase		solid	solid	solid	solid	solid	solid	gas	gas	gas	gas	solid	solid	solid	solid	gas	solid	gas
Solid & Liquid Composition (dry basis)																		
Fe	%wt.	98.89	98.89	94.24	65.50	0.51	0.15	-	99.91	-	-	20.00	20.00	20.00	20.00	-	62.03	-
C	%wt.	0.11	0.11	4.65	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-
Si	%wt.	0.01	0.01	0.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2 (residual)	%wt.	-	-	-	-	3.00	2.00	-	-	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	-	-	-	1.80	91.26	40.00	-	-	-	-	50.86	50.86	50.86	50.86	-	11.09	-
MgO	%wt.	-	-	-	1.20	1.86	55.00	-	-	-	-	5.49	5.49	5.49	5.49	-	3.42	-
SiO2	%wt.	-	-	-	2.80	2.03	-	-	-	-	-	-	-	-	-	-	-	-
Al2O3	%wt.	-	-	-	0.60	0.85	-	-	-	-	-	-	-	-	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	1.5	-	1.0	-	-	-	-	1.0	1.0	1.0	1.0	-	23.3	-
Specific Vol. Flow (wet)	Nm3/tls	-	-	-	-	-	-	51.56	-	0.30	0.43	-	-	-	-	-	-	81.75
Average MW								32.0		28.0	60.4					18.0		28.4
Gas Composition (wet basis)																		
H2	%v.	-	-	-	-	-	-	-	-	-	12.64	-	-	-	-	-	-	2.64
CO2	%v.	-	-	-	-	-	-	-	-	-	3.00	-	-	-	-	-	-	14.44
CO	%v.	-	-	-	-	-	-	-	-	-	67.46	-	-	-	-	-	-	56.92
O2	%v.	-	-	-	-	-	-	99.90	-	0.02	0.01	-	-	-	-	-	-	-
N2	%v.	-	-	-	-	-	-	0.01	-	99.98	-	-	-	-	-	-	-	13.83
Ar	%v.	-	-	-	-	-	-	0.09	-	-	99.99	-	-	-	-	-	-	-
H2O	%v.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.00	-	12.16

6. UNIT 600: LADLE METALLURGY (SECONDARY STEELMAKING)

6.1. PFD and Mass Balance

Figure A3-6 presents the process flow diagram of the secondary steelmaking process of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-6 presents a summary of the mass balance for the secondary steelmaking process of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

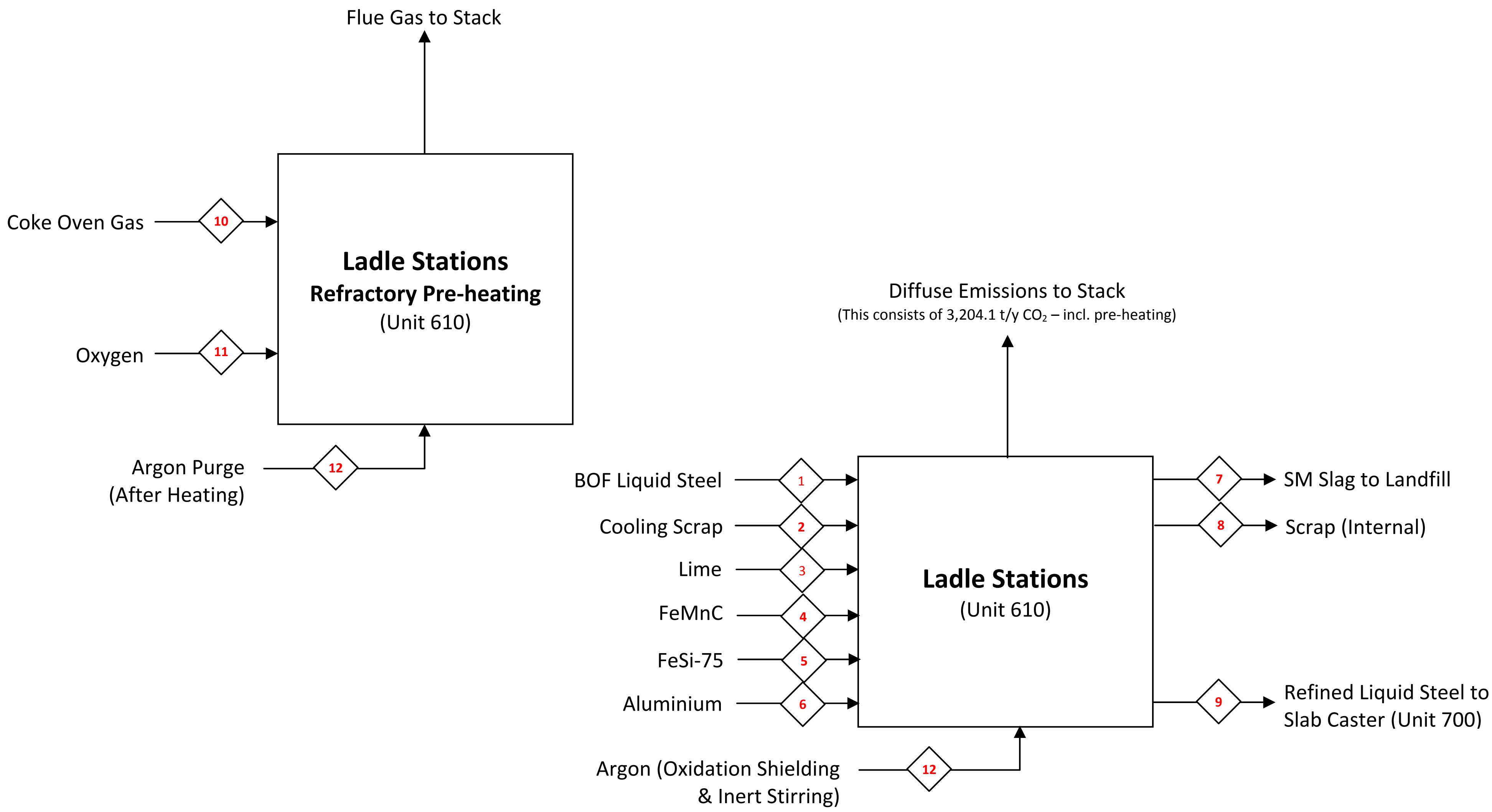

Figure A3-6: PFD of the ladle metallurgy (Unit 600)

Table A3-6: Mass Balance (Unit 600: Ladle Metallurgy)

		1	2	3	4	5	6	7	8	9	10	11	12
Stream		**Liquid Steel from BOF**	**Scrap (Cooling)**	**Lime**	**FeMnC**	**FeSi-75**	**De-Oxidising Aluminium**	**LM Slag to Landfill**	**Scrap to BOF**	**Liquid Steel from LM**	**COG**	**High Purity O2**	**Ar**
Total Mass Flow (wet)	**t/y**	**4,323,327**	**4,345**	**21,726**	**47,798**	**13,036**	**6,518**	**34,412**	**43,233**	**4,345,228**	**1,607**	**13,030**	**2,230**
Total Mass Flow (dry)	**t/y**	**4,323,327**	**4,345**	**21,726**	**47,798**	**13,036**	**6,518**	**34,412**	**43,233**	**4,345,228**	**1,512**	**13,030**	**2,230**
Specific Mass Flow (wet)	kg/tls (ladle)	995.0	1.0	5.0	11.0	3.0	1.5	7.9	9.9	1000.0	0.4	3.0	0.5
Specific Mass Flow (dry)	kg/tls (ladle)	995.0	1.0	5.0	11.0	3.0	1.5	7.9	9.9	1000.0	0.3	3.0	0.5
Pressure	Bara	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	amb.	1.11	31.01	21.01
Temperature	oC	1672	12	40	12	12	12	12	12	1531	25	60	60
Phase		liquid	solid	solid	solid	solid	solid	solid	solid	liquid	gas	gas	gas
Solid & Liquid Composition (dry basis)													
Fe	%wt.	99.91	98.89	0.51	14.58	22.56	0.67	1.08	98.89	98.73	-	-	-
C	%wt.	0.04	0.11	-	6.87	0.03	-	-	0.11	0.12	-	-	-
Si	%wt.	-	0.01	-	0.11	76.61	1.34	-	0.01	-	-	-	-
Mn	%wt.	-	0.10	-	78.27	0.01	0.23	-	0.10	-	-	-	-
Al	%wt.	-	-	-	-	0.71	96.30	-	-	-	-	-	-
CO2 (residual)	%wt.	-	-	3.00	-	-	-	-	-	-	-	-	-
CaO (incl. carbonates)	%wt.	-	-	91.26	-	-	-	62.46	-	-	-	-	-
MgO	%wt.	-	-	1.86	-	-	-	-	-	-	-	-	-
SiO2	%wt.	-	-	2.03	-	-	-	8.02	-	-	-	-	-
Al2O3	%wt.	-	-	0.85	-	-	-	28.32	-	-	-	-	-
Moisture (wet basis)	%wt.	-	-	-	-	-	-	0.0	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/tls (ladle)	-	-	-	-	-	-	-	-	-	0.86	2.10	0.29
Average MW											9.7	32.0	39.9
Gas Composition (wet basis)													
CH4	%v.	-	-	-	-	-	-	-	-	-	23.24	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	-	-	-	-	-	-	-	2.71	-	-
H2	%v.	-	-	-	-	-	-	-	-	-	60.05	-	-
CO2	%v.	-	-	-	-	-	-	-	-	-	0.97	-	-
CO	%v.	-	-	-	-	-	-	-	-	-	3.87	-	-
O2	%v.	-	-	-	-	-	-	-	-	-	0.19	99.90	0.01
N2	%v.	-	-	-	-	-	-	-	-	-	5.81	0.01	-
Ar	%v.	-	-	-	-	-	-	-	-	-	-	0.09	99.99
H2O	%v.	-	-	-	-	-	-	-	-	-	3.15	-	-

7. UNIT 700: CONTINUOUS CASTING

7.1. PFD and Mass Balance

Figure A3-7 presents the process flow diagram of the continuous slab casting of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-7 presents a summary of the mass balance for the slab casting of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

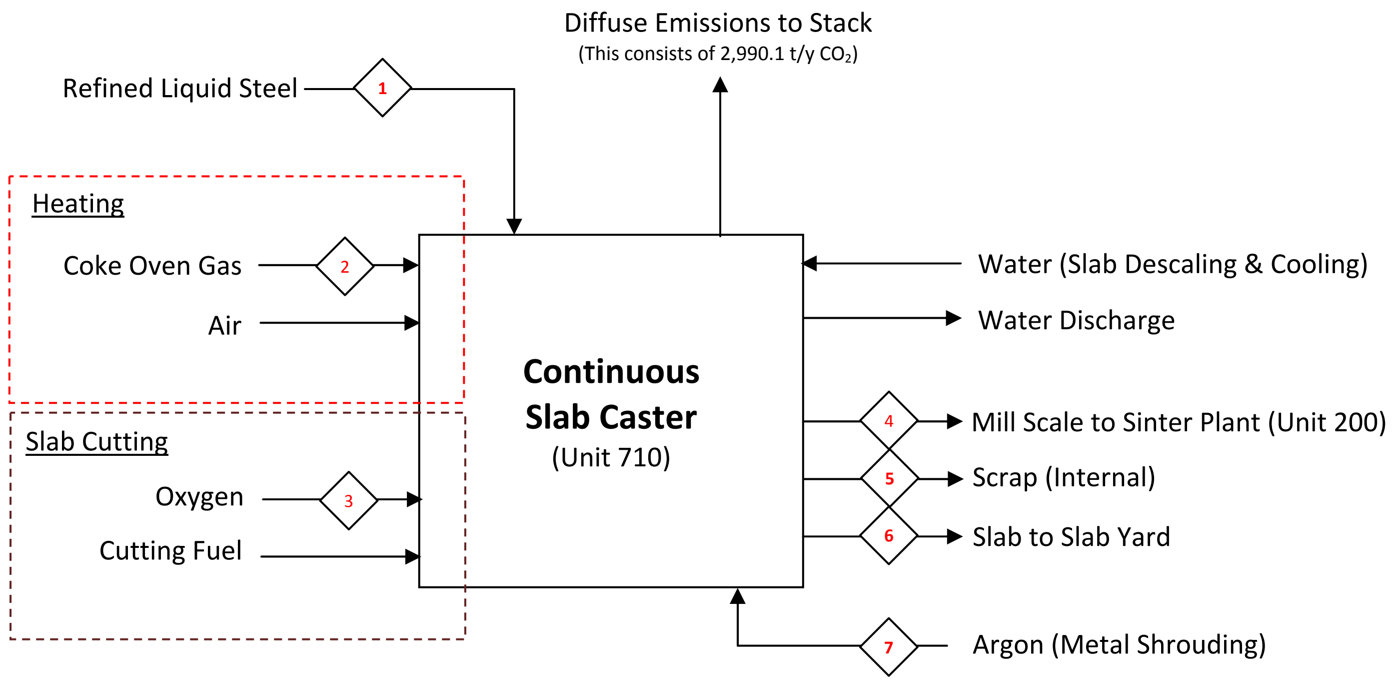

Figure A3-7: PFD of the Continuous Casting (Unit 700)

Table A3-7: Mass Balance (Unit 700: Continuous Casting)

		1	2	3	4	5	6	7
Stream		**Liquid Steel from LM**	**COG**	**High Purity O2**	**Mill Scales to Sinter**	**Scrap to BOF**	**Slab to Reheating Furnace**	**Ar**
Total Mass Flow (wet)	**t/y**	**4,345,228**	**1,934**	**12,409**	**37,144**	**108,631**	**4,210,526**	**774**
Total Mass Flow (dry)	**t/y**	**4,345,228**	**1,820**	**12,409**	**36,772**	**108,631**	**4,210,526**	**774**
Specific Mass Flow (wet)	kg/t slab	1032.0	0.5	2.9	8.8	25.8	1000.0	0.2
Specific Mass Flow (dry)	kg/t slab	1032.0	0.4	2.9	8.7	25.8	1000.0	0.2
Pressure	Bara	amb.	1.11	31.01	amb.	amb.	amb.	21.01
Temperature	oC	1	25	60	12	12	25	60
Phase		liquid	gas	gas	solid	solid	solid	gas
					0.9%	2.6%		
Solid & Liquid Composition (dry basis)								
Fe	%wt.	1530.50	-	-	70.00	98.73	98.73	-
C	%wt.	98.73	-	-	-	0.12	0.12	-
Moisture (wet basis)	%wt.	-	-	-	1.0	-	-	-
Specific Vol. Flow (wet)	Nm3/t slab	-	1.07	2.06	-	-	-	0.10
Average MW			9.7	32.0				39.9
Gas Composition (wet basis)								
CH4	%v.	-	23.24	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	2.71	-	-	-	-	-
H2	%v.	-	60.05	-	-	-	-	-
CO2	%v.	-	0.97	-	-	-	-	-
CO	%v.	-	3.87	-	-	-	-	-
O2	%v.	-	0.19	99.90	-	-	-	0.01
N2	%v.	-	5.81	0.01	-	-	-	-
Ar	%v.	-	-	0.09	-	-	-	99.99
H2O	%v.	-	3.15	-	-	-	-	-

8. UNIT 800 & 900: REHEATING AND HOT ROLLING MILL

8.1. PFD and Mass Balance

Figure A3-8 presents the process flow diagram of the reheating and rolling mills of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-8 presents a summary of the mass balance for the reheating and rolling mills of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

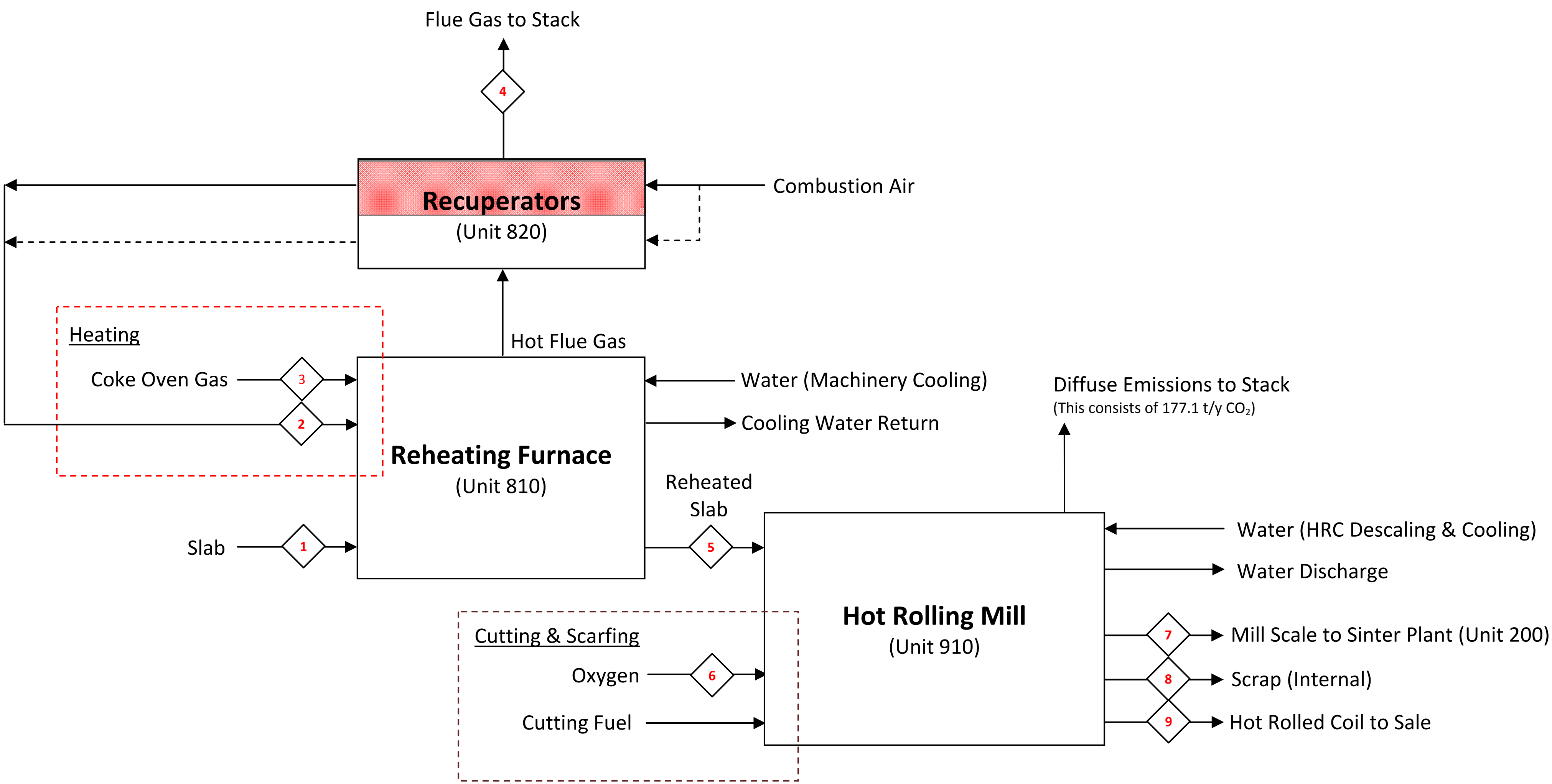

Figure A3-8: PFD of the hot strip mill (Unit 800 & 900)

Table A3-8: Mass Balance (Unit 800 & 900: Reheating and Rolling Mill)

		1	2	3	4	5	6	7	8	9
Stream		**Slab to Reheating Furnace**	**Combustion Air**	**COG (Reheating Furnace)**	**Flue Gas**	**Reheated Slab**	**High Purity O2 to HRM**	**Mill Scale to Sinter**	**Internal Scrap to BOF**	**HRC to Sale**
Total Mass Flow (wet)	**t/y**	**4,210,526**	**2,985,364**	**145,313**	**3,130,752**	**4,210,526**	**24,644**	**59,987**	**168,421**	**4,000,000**
Total Mass Flow (dry)	**t/y**	**4,210,526**	**2,964,574**	**136,772**	**2,794,253**	**4,210,526**	**24,644**	**59,387**	**168,421**	**4,000,000**
Specific Mass Flow (wet)	kg/t HRC	1052.6	746.3	36.3	782.7	1052.6	6.2	15.0	42.1	1000.0
Specific Mass Flow (dry)	kg/t HRC	1052.6	741.1	34.2	698.6	1052.6	6.2	14.8	42.1	1000.0
Pressure	Bara	amb.	1.11	1.11	1.03	amb.	21.01	amb.	amb.	amb.
Temperature	oC	25	400	25	500	1200	60	12	12	12
Phase		solid	gas	gas	gas	solid	gas	solid	solid	solid
Solid & Liquid Composition (dry basis)										
Fe	%wt.	98.73	-	-	-	98.73	-	70.00	98.73	98.73
C	%wt.	0.12	-	-	-	0.12	-	-	0.12	0.12
Moisture (wet basis)	%wt.	-	-	-	-	-	-	1.0	-	-
Specific Vol. Flow (wet)	Nm3/t HRC	-	582.30	84.29	640.23	-	2.63	-	-	-
Average MW			28.7	9.7	27.4		52.5			
Gas Composition (wet basis)										
CH4	%v.	-	-	23.24	-	-	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	2.71	-	-	-	-	-	-
H2	%v.	-	-	60.05	-	-	12.64	-	-	-
CO2	%v.	-	-	0.97	4.59	-	3.00	-	-	-
CO	%v.	-	-	3.87	-	-	67.46	-	-	-
O2	%v.	-	20.72	0.19	7.20	-	99.90	-	-	-
N2	%v.	-	78.17	5.81	71.86	-	0.01	-	-	-
Ar	%v.	-	-	-	-	-	0.09	-	-	-
H2O	%v.	-	1.11	3.15	16.34	-	-	-	-	-

9. UNIT 1000: LIME PRODUCTION

9.1. PFD and Mass Balance

Figure A3-9 presents the process flow diagram of the lime production of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-9 presents a summary of the mass balance for the lime production of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

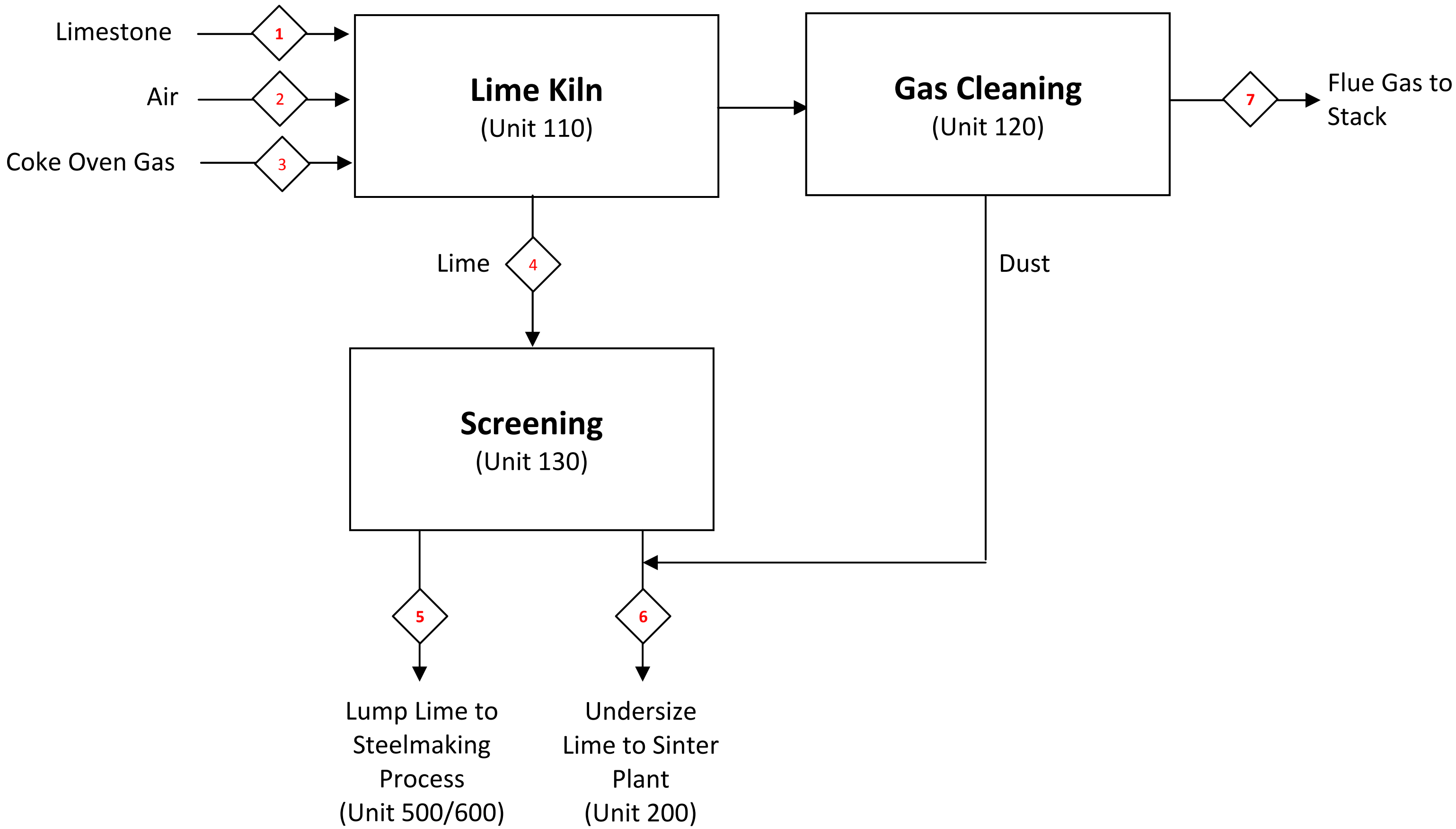

Figure A3-9: PFD of the Lime Production (Unit 1000)

Table A3-9: Mass Balance (Unit 1000: Lime Production)

Stream		1 Limestone	2 Air	3 COG	4 Lime (Total)	5 Lime to BOF & LM	6 Lime to Sinter Plant	7 Flue Gas
Total Mass Flow (wet)	**t/y**	**589,715**	**734,764**	**29,812**	**345,447**	**301,956**	**43,490**	**1,008,970**
Total Mass Flow (dry)	**t/y**	**583,818**	**729,648**	**28,060**	**345,447**	**301,956**	**43,490**	**933,193**
Specific Mass Flow (wet)	kg/t lime	1707.1	2127.0	86.3	1000.0	874.1	125.9	2920.8
Specific Mass Flow (dry)	kg/t lime	1690.0	2112.2	81.2	1000.0	874.1	125.9	2701.4
Pressure	Bara	amb.	1.03	1.11	amb.	amb.	amb.	1.03
Temperature	oC	12	12	25	40	40	40	130
Phase		solid	gas	gas	solid	solid	solid	gas
Solid & Liquid Composition (dry basis)								
Fe	%wt.	0.30	-	-	0.51	0.51	0.51	-
CO2 (residual)	%wt.	42.60	-	-	3.00	3.00	3.00	-
CaO (incl. carbonates)	%wt.	54.00	-	-	91.26	91.26	91.26	-
MgO	%wt.	1.10	-	-	1.86	1.86	1.86	-
SiO2	%wt.	1.20	-	-	2.03	2.03	2.03	-
Al2O3	%wt.	0.50	-	-	0.85	0.85	0.85	-
Moisture (wet basis)	%wt.	1.0	-	-	-	-	-	-
Specific Vol. Flow (wet)	Nm3/t lime	-	1659.51	200.25	-	-	-	2169.76
Average MW			28.7	9.7				30.2
Gas Composition (wet basis)								
CH4	%v.	-	-	23.24	-	-	-	-
Other HC (Average MW = C2.5H5)	%v.	-	-	2.71	-	-	-	-
H2	%v.	-	-	60.05	-	-	-	-
CO2	%v.	-	-	0.97	-	-	-	19.41
CO	%v.	-	-	3.87	-	-	-	-
O2	%v.	-	20.72	0.19	-	-	-	7.77
N2	%v.	-	78.17	5.81	-	-	-	60.24
H2O	%v.	-	1.11	3.15	-	-	-	12.58

10. UNIT 1100: ASU – HIGH PURITY O_2 PRODUCTION

10.1. PFD and Mass Balance

Figure A3-10 presents the process flow diagram of the ASU for the high purity oxygen production of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-10 presents a summary of the mass balance for the high purity oxygen production of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

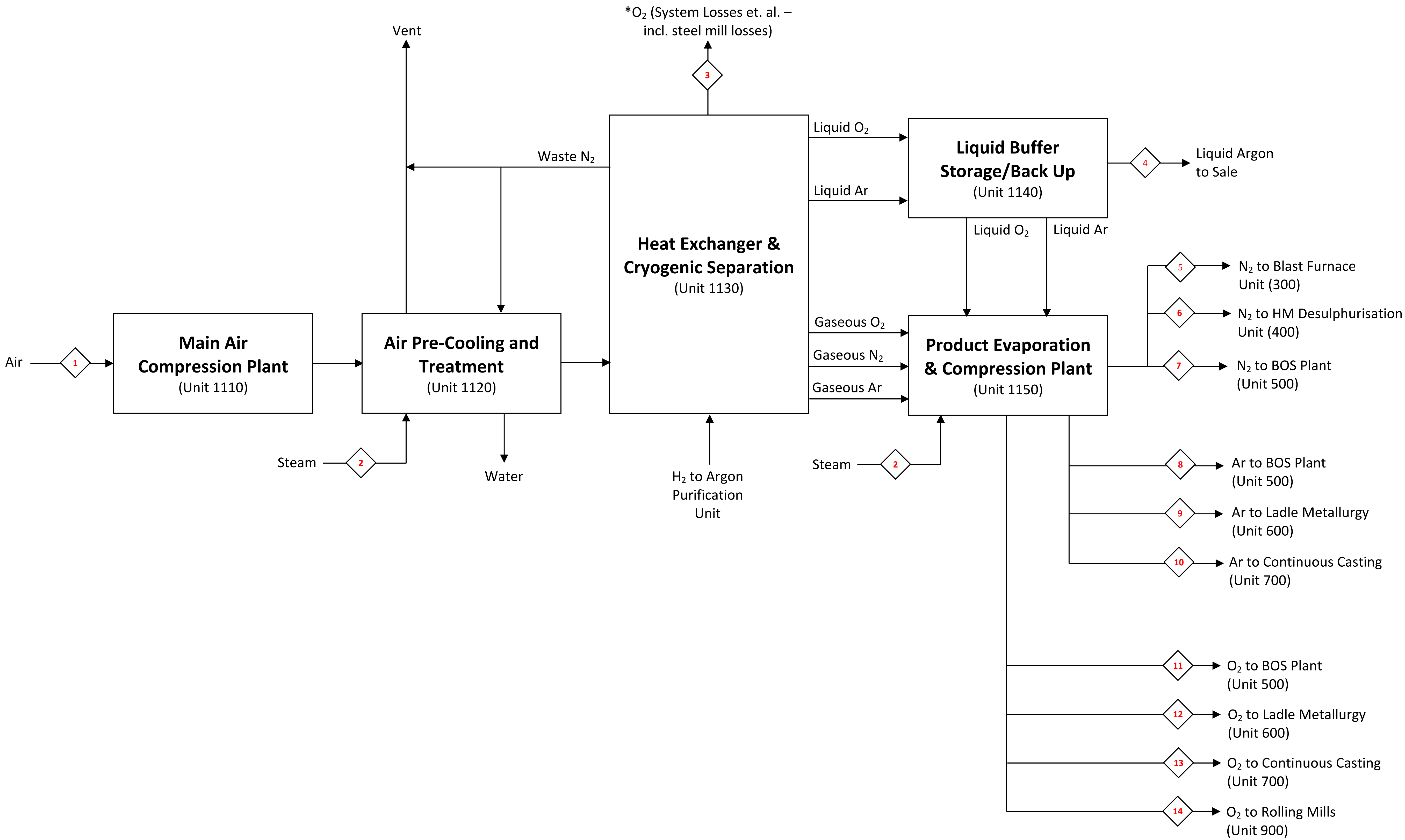

Figure A3-10: PFD of ASU – high purity O_2 production (Unit 1100)

Table A3-10: Mass Balance (Unit 1100: ASU – High Purity O_2 Production)

		1	2	3	4	5a	5b	6	7
Stream		**Air**	**Steam**	**O2 (Lost or Flared)**	**Ar to Sale**	**N2 to BF (RM Feeder)**	**N2 to BF (PCI Coal Feeder)**	**N2 to HM Desulph.**	**N2 to BOF**
Total Mass Flow (wet)	**t/y**	**1,928,317**	**16,583**	**31,415**	**6,219**	**19,841**	**19,841**	**715**	**1,638**
Total Mass Flow (dry)	**t/y**	**1,915,912**	**16,583**	**31,415**	**6,219**	**19,841**	**19,841**	**715**	**1,638**
Specific Mass Flow (wet)	kg/Nm3 O2	6.977	0.060	0.114	0.023	0.072	0.072	0.003	0.006
Specific Mass Flow (dry)	kg/Nm3 O2	6.932	0.060	0.114	0.023	0.072	0.072	0.003	0.006
Pressure	Bara	1.03	9.01	1.03	1.01	7.01	25.01	25.01	25.01
Temperature	oC	12	175	60	-	60	60	60	60
Phase		gas	gas	gas	liquid	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/Nm3 O2	5.0298	-	0.0909	0.0126	0.0574	0.0574	0.0021	0.0047
Average MW		31.1	18.0	28.0	39.9	28.0	28.0	28.0	28.0
Gas Composition (wet basis)									
O2	%v.	77.26	-	0.01	0.01	0.02	0.02	0.02	0.02
N2	%v.	20.71	-	99.90	-	99.98	99.98	99.98	99.98
Ar	%v.	0.92	-	0.09	99.90	-	-	-	-
H2O	%v.	1.11	100.00	-	-	-	-	-	-

		8	9	10	11	12	13	14
Stream		**Ar to BOF**	**Ar to Ladle Metallurgy**	**Ar to Slab Casting**	**O2 to BOF**	**O2 to Ladle Metallurgy**	**O2 to Slab Casting**	**O2 to HRM**
Total Mass Flow (wet)	**t/y**	**3,346**	**2,230**	**774**	**318,305**	**13,030**	**12,409**	**15,031**
Total Mass Flow (dry)	**t/y**	**3,346**	**2,230**	**774**	**318,305**	**13,030**	**12,409**	**15,031**
Specific Mass Flow (wet)	kg/Nm3 O2	0.012	0.008	0.003	1.152	0.047	0.045	0.054
Specific Mass Flow (dry)	kg/Nm3 O2	0.012	0.008	0.003	1.152	0.047	0.045	0.054
Pressure	Bara	25.01	25.01	25.01	31.01	37.01	37.01	25.01
Temperature	oC	60	60	60	60	60	60	60
Phase		gas	gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/Nm3 O2	0.0068	0.0045	0.0016	0.8065	0.0330	0.0314	0.0381
Average MW		39.9	39.9	39.9	32.0	32.0	32.0	32.0
Gas Composition (wet basis)								
O2	%v.	0.01	0.01	0.01	99.90	99.90	99.90	99.90
N2	%v.	-	-	-	0.01	0.01	0.01	0.01
Ar	%v.	99.99	99.99	99.99	0.09	0.09	0.09	0.09
H2O	%v.	-	-	-	-	-	-	-

11. UNIT 1200: CAPTIVE POWER PLANT

11.1. PFD and Mass Balance

Figure A3-11 presents the process flow diagram of the captive power plant of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-11 presents a summary of the mass balance for the captive power plant of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

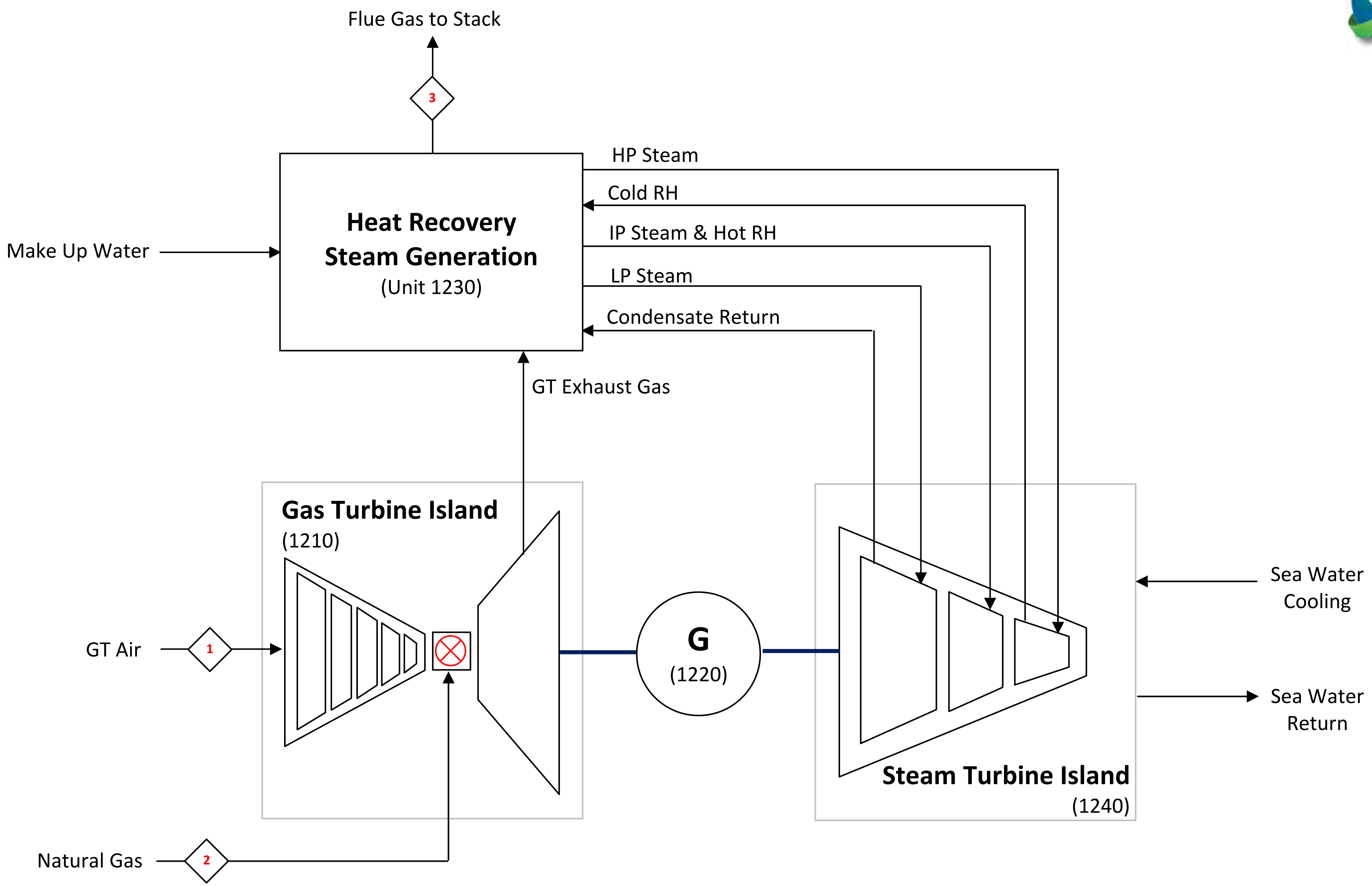

Figure A3-11: PFD of the captive power plant (Unit 1200)

Table A3-11: Mass Balance (Unit 1200: Power Plant)

		1	2	3
Stream		**Gas Turbine Air**	**NG**	**Flue Gas**
Total Mass Flow (wet)	**t/y**	**15,067,725**	**311,157**	**15,379,034**
Total Mass Flow (dry)	**t/y**	**14,962,795**	**311,157**	**14,651,304**
Specific Mass Flow (wet)	kg/kWh	6.57	0.14	6.71
Specific Mass Flow (dry)	kg/kWh	6.52	0.14	6.39
Pressure	Bara	1.03	1.01	1.01
Temperature	oC	12	12	150
Phase		gas	gas	gas
Specific Vol. Flow (wet)	Nm3/kWh	5.1255	0.1565	5.2978
Average MW		28.7	19.4	28.4
Gas Composition (wet basis)				
CH4	%v.	-	83.90	-
C2H6	%v.	-	9.20	-
C3H8	%v.	-	3.30	-
C4H10	%v.	-	1.20	-
C5H12	%v.	-	0.20	-
H2	%v.	-	-	-
CO2	%v.	-	1.80	3.54
CO	%v.	-	-	-
O2	%v.	20.72	-	13.37
N2	%v.	78.17	0.40	75.64
H2O	%v.	1.11	-	7.45

12. UNIT 2000: STEAM GENERATION PLANT

12.1. PFD and Mass Balance

Figure A3-12 presents the process flow diagram of the captive steam generation plant of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-12 presents a summary of the mass balance for the captive steam generation plant of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

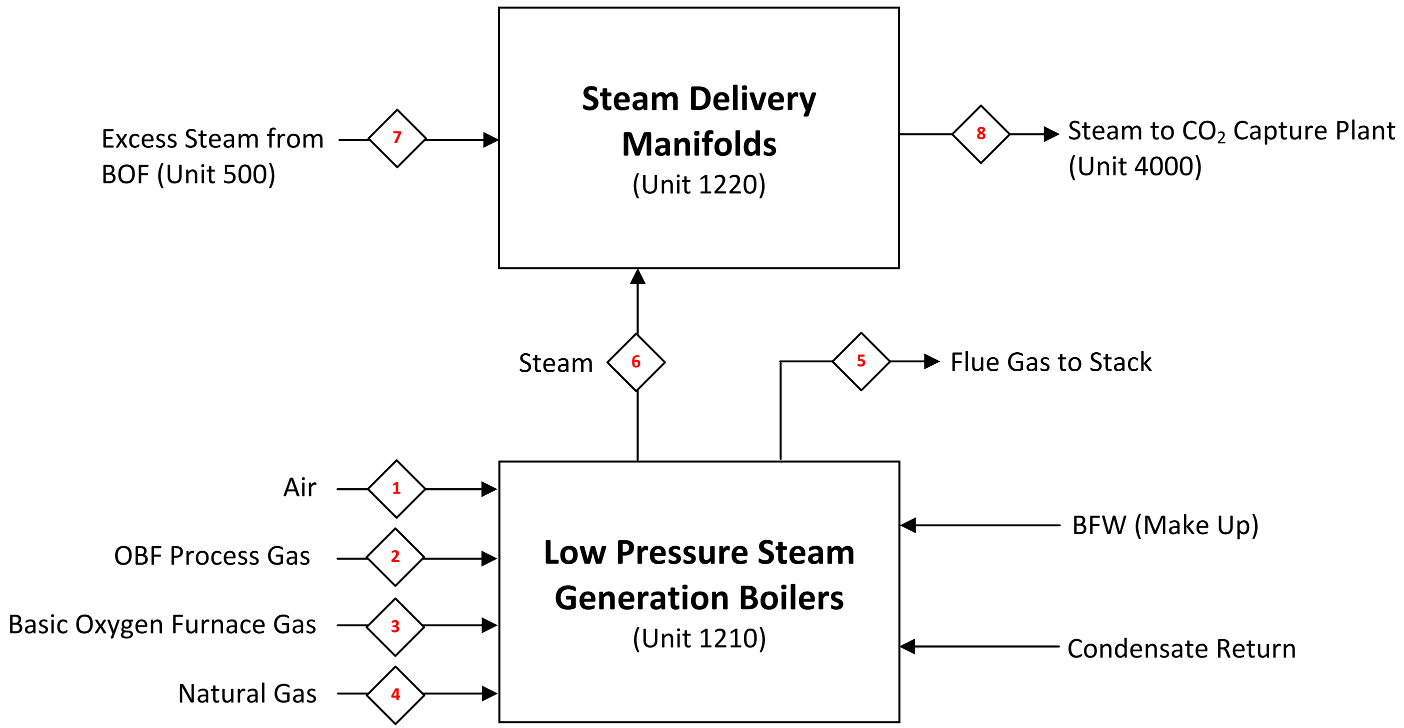

Figure A3-11: PFD of the steam generation plant (Unit 2000)

Table A3-11: Mass Balance (Unit 2000: Steam Generation Plant)

		1	2	3	4	5	6	7	8
Stream		**Combustion Air**	**OBF PGas**	**BOFG**	**NG**	**Flue Gas**	**Steam from Boilers**	**Steam from BOF**	**Steam to CO2 Capture Plant**
Total Mass Flow (wet)	**t/y**	**2,505,759**	**385,188**	**448,310**	**55,714**	**3,395,002**	**3,405,077**	**105,742**	**3,510,819**
Total Mass Flow (dry)	**t/y**	**2,488,309**	**376,414**	**413,733**	**55,714**	**3,180,388**	**3,405,077**	**105,742**	**3,510,819**
Specific Mass Flow (wet)	kg/MJ	0.3217	0.0495	0.0576	0.0072	0.4359	0.4372	0.0136	0.4508
Specific Mass Flow (dry)	kg/MJ	0.3195	0.0483	0.0531	0.0072	0.4083	0.4372	0.0136	0.4508
Pressure	Bara	1.03	1.11	1.11	1.11	1.03	9.01	9.01	9.01
Temperature	oC	12	25	50	12	150	175	175	175
Phase		gas	gas	gas	gas	gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/MJ	0.2510	0.0445	0.0454	0.0083	0.3188	-	-	-
Average MW		28.7	24.9	28.4	19.4	30.6	18.0	18.0	18.0
Gas Composition (wet basis)									
CH4	%v.	-	-	-	83.90	-	-	-	-
C2H6	%v.	-	-	-	9.20	-	-	-	-
C3H8	%v.	-	-	-	3.30	-	-	-	-
C4H10	%v.	-	-	-	1.20	-	-	-	-
C5H12	%v.	-	-	-	0.20	-	-	-	-
H2	%v.	-	12.50	2.64	-	-	-	-	-
CO2	%v.	-	2.97	14.44	1.80	22.98	-	-	-
CO	%v.	-	66.69	56.92	-	-	-	-	-
O2	%v.	20.72	-	-	-	0.70	-	-	-
N2	%v.	78.17	14.69	13.83	0.40	65.57	-	-	-
H2O	%v.	1.11	3.15	12.16	-	10.75	100.00	100.00	100.00

13. UNIT 3000: ASU – LOW PURITY O_2 PRODUCTION

13.1. PFD and Mass Balance

Figure A3-12 presents the process flow diagram of the ASU for low purity oxygen production of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-12 presents a summary of the mass balance for the low purity oxygen production of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

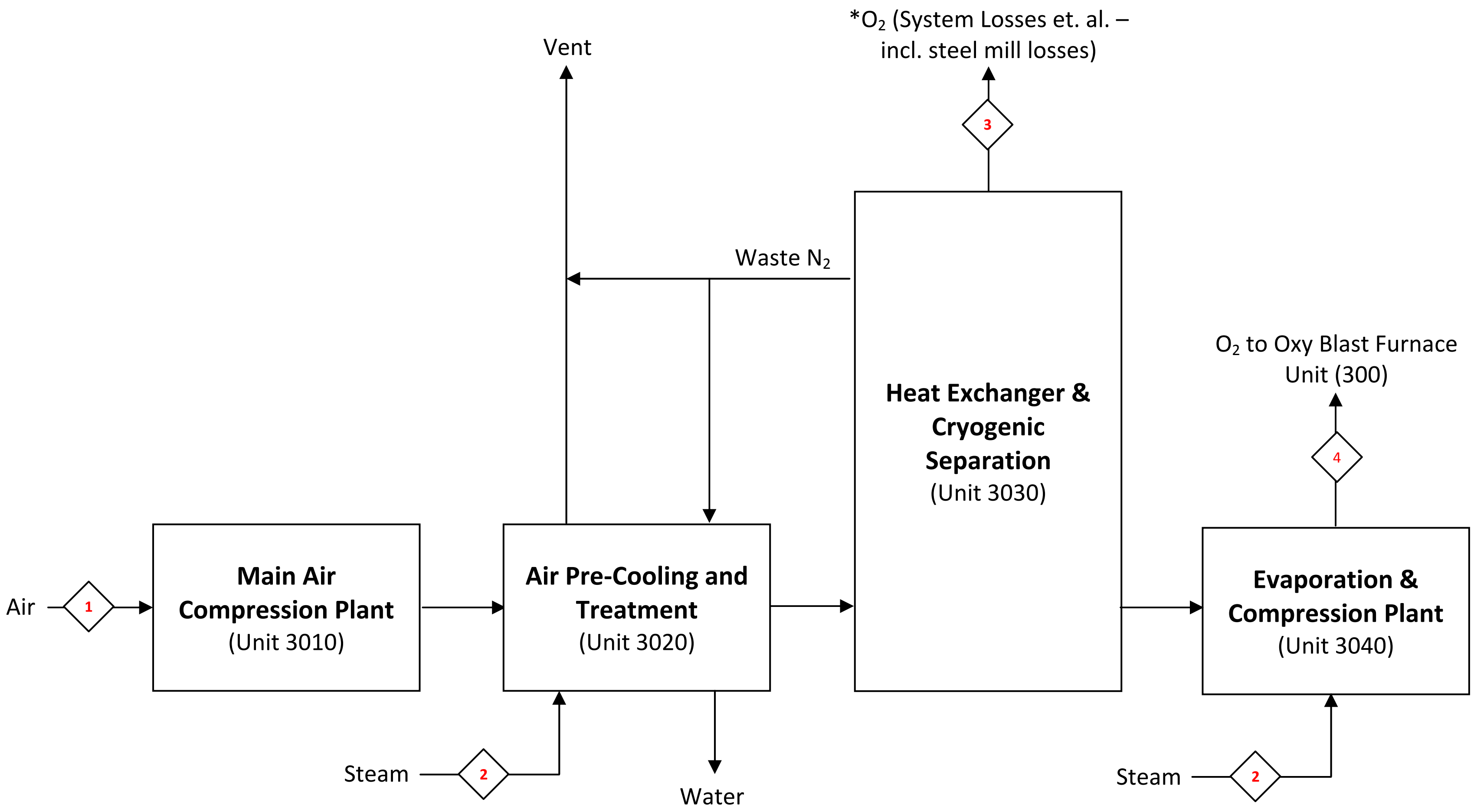

Figure A3-12: PFD of the ASU – low purity O_2 production (Unit 3000)

Table A3-12: Mass Balance (Unit 3000: ASU – Low Purity O_2 Production)

		1	2	3	4
Stream		**Air**	**Steam**	**Low Purity O2 (Lost or Flared)**	**Low Purity O2 to OBF**
Total Mass Flow (wet)	**t/y**	**6,294,538**	**20,485**	**28,653**	**1,432,672**
Total Mass Flow (dry)	**t/y**	**6,250,878**	**20,485**	**28,653**	**1,432,672**
Specific Mass Flow (wet)	kg/Nm3 O2	6.145	0.020	0.028	1.399
Specific Mass Flow (dry)	kg/Nm3 O2	6.103	0.020	0.028	1.399
Pressure	Bara	1.03	9.01	1.03	10.01
Temperature	oC	12	175	40	40
Phase		gas	gas	gas	gas
Specific Vol. Flow (wet)	Nm3/Nm3 O2	4.7766	0.0187	0.0196	0.9804
Average MW		28.8	18.0	32.0	32.0
Gas Composition (wet basis)					
O2	%v.	20.71	-	95.00	95.00
N2	%v.	77.26	-	3.50	3.50
Ar	%v.	0.92	-	1.50	1.50
H2O	%v.	1.11	100.00	-	-

14. UNIT 4000: CO_2 CAPTURE AND COMPRESSION PLANT

14.1. PFD and Mass Balance

Figure A3-12 presents the process flow diagram of the CO_2 capture and compression plant of the integrated steel mill (OBF / MDEA CO_2 Capture Case). Table A3-12 presents a summary of the mass balance for the CO_2 capture and compression plant of the integrated steel mill – OBF / MDEA CO_2 Capture Case.

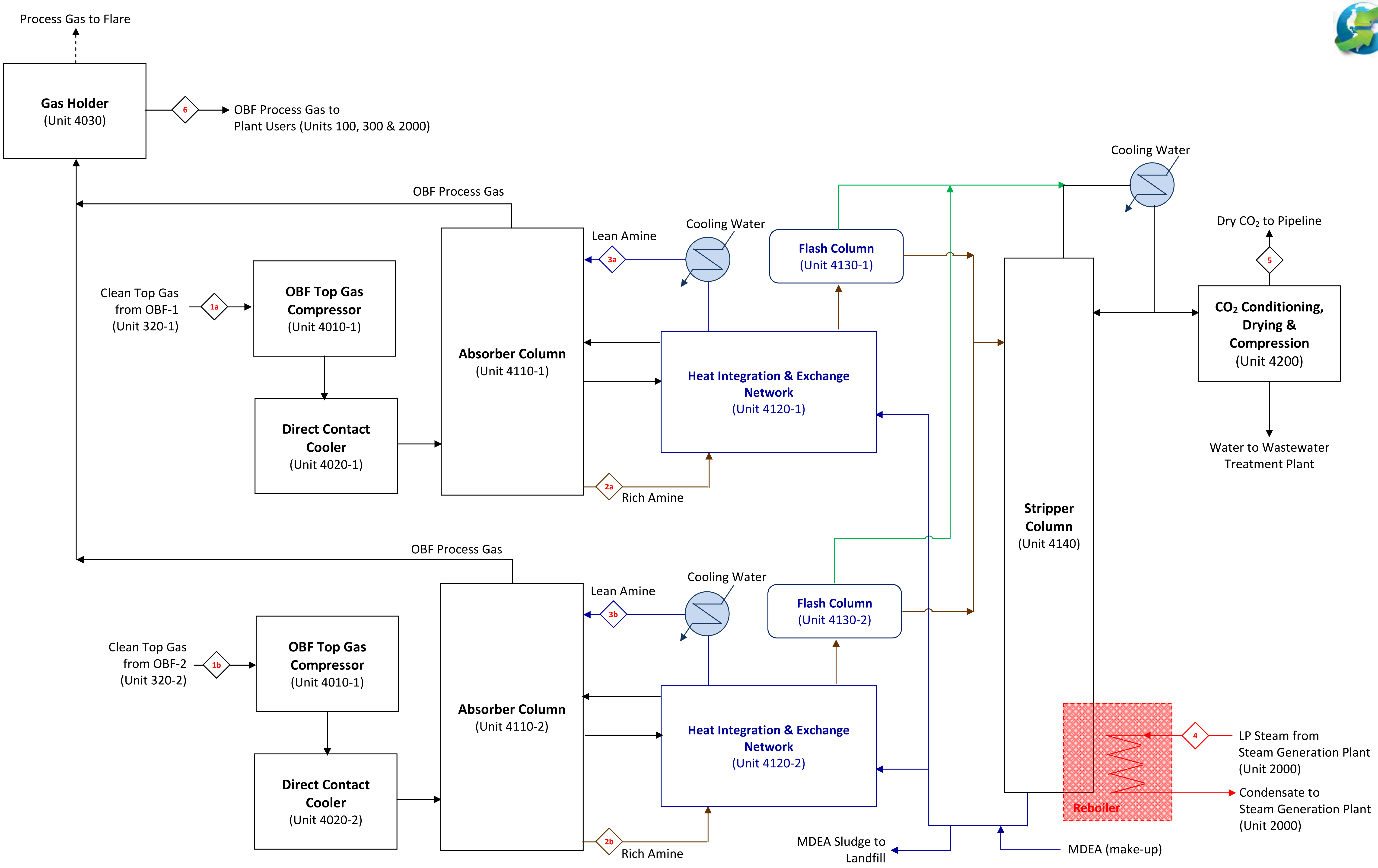

Figure A3-11: PFD of the CO_2 capture and compression plant (Unit 4000)

Table A3-11: Mass Balance (Unit 4000: CO_2 Capture and Compression Plant)

		1	2	3	4	5	6
Stream		**Clean OBF Top Gas (Total)**	**Rich MDEA Solution**	**Lean MDEA Solution**	**LP Steam from SGP**	**CO2 to Pipeline**	**OBF PGas after CO2 Capture to Steel Mill**
Total Mass Flow (wet)	**t/y**	**7,610,753**	**46,981,652**	**43,542,293**	**3,510,819**	**3,439,360**	**4,153,254**
Total Mass Flow (dry)	**t/y**	**7,531,501**	**-**	**-**	**3,510,819**	**3,439,360**	**4,092,203**
Specific Mass Flow (wet)	kg/t CO2 captured	2212.8	13660.0	12660.0	1020.8	1000.0	1207.6
Specific Mass Flow (dry)	kg/t CO2 captured	2189.8	-	-	1020.8	1000.0	1189.8
Pressure	Bara	1.81	-	-	9.01	110.00	3.81
Temperature	oC	40	-	-	175	25	41
Phase		gas	-	-	gas	liquid	gas
Specific Vol. Flow (wet)	Nm3/t CO2 Captured	1598.46	-	-	-	-	1082.59
Average MW		31.0	-	-	18.0	44.0	25.0
Gas Composition (wet basis)							
H2	%v.	8.56	-	-	-	-	12.64
CO2	%v.	33.89	-	-	-	99.99	3.00
CO	%v.	45.69	-	-	-	-	67.46
O2	%v.	-	-	-	-	-	-
N2	%v.	10.07	-	-	-	-	14.86
Ar	%v.	-	-	-	-	-	-
H2O	%v.	1.79	-	-	100.00	-	2.04

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume II: Estimating the Cost of Steel Production from an Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

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<u>Annex IV</u>

FINANCIAL ASSUMPTIONS

Integrated Steel Mill with Post-Combustion (End of Pipe) CO_2 Capture Technology

<u>**I N D E X**</u>

1 Plant Location

The Integrated Steel Mill with Post-Combustion CO_2 Capture is located along the Coastal Region of Western Europe. The plant location has been described in Volume 2 (Section B) of the report.

- Site should have no special civil works required to add onto the construction cost.
- The study assumed that the site is accessible to the Port of Rotterdam with no extra additional cost needed to deliver raw materials and goods from Rotterdam to the plant site.
- Adequate site and facility services should be accessible to the integrated steel mill to make it self sufficient.
- The breakeven price reported in this study should represent the gate price (i.e. excluding cost for delivery to customers)

2 Plant Life

The integrated steel mill is assumed to have an economic life of 25 years as the basis for appraisal.

3 Design and Construction Period

Plant design and construction will be completed within 60 months starting from issue of "Notice to Proceed" to the EPC contractor. Operations would start after three years of construction with the completion of one blast furnace and full production achieved at the end of second year of operation.

The curve of capital expenditure during construction is assumed to be:

Year	Capital Expenditure (% investment cost)
-3	10
-2	35
-1	30
1	20
2	5

4 Commissioning

The study assumed the start up of steel mill producing 50% of the plant capacity on year 1 and achieving the full capacity on year 4. The commissioning of the plant involves the following schedule of production for the period between 1st and 3rd year as shown below:

Year	Iron and Steel Production (% Capacity)	Power Plant (% Load Factor)
1	50%	42.5%
2	75%	63.8%
3	90%	76.5%
4 and onward	100%	85.0%

5 Decommissioning

Decommissioning and remediation of the land by the end of the steel mill's life is excluded in the cash flow analysis.

6 Capital Charges

- The discounted cash flow analysis is used to evaluate the breakeven price per tonne of hot rolled coil produced. A discount rate of 10% was assumed.

- All capital requirements will be available according to the schedule of capital expenditure as described in Section E2.3. The capital infusion could be assumed as cash available for the construction of the steel mill based on combined equity and debt. However, the level of debt is not considered or accounted for in this study. The Cost of Capital will also use the same discount rate of 10%, which represents the weighted average of capital charges (WACC).

- No interest during construction is applied but the timing of capital expenditure is taken into account in the discounted cash flow analysis (using end of the year as basis).

7 Recurring Capital Expenditure

The steel mill requires the refractory relining of the blast furnaces for every 10-15 years of continuous operation. The study assumed a relining to be done on the 15th year with steel production assumed to maintain at 100% full capacity during this period[1].

8 Working Capital

The storage time for materials and balance of trade were taken according to normal industry practice:

- Stocks - Raw Materials: 63 days
- Stocks - Slabs: 5 days
- HRC: 15 days
- Trade debtors: 15 days
- Trade creditors (excl. raw materials): 30 days

Working capital comprises the value of raw materials (coking coal, iron ores, fluxes, purchased scrap and ferroalloys), slabs and hot rolled coils stored in the stockyard and the balance of the trade between debtors and creditors.

The trade debtors only considered the sale value of the hot rolled coil, whilst the trade creditors only account for the value of goods used by the steel mill excluding the value of raw materials.

[1] Note: This is a simplifying assumption to reduce the complexity in the calculation of the breakeven price of the HRC

9 Currency

The cost evaluation was developed in US$ (2010). Where necessary, the conversion was based on the following exchange rates:

- € 1.00 = US$ 1.34
- £ 1.00 = US$ 1.55

10 Inflation

Inflation assumptions were not included. No allowance has been made for escalation of fuel, reductant, raw materials, labour and other cost relative to each other.

11 Depreciation

Although the study assumed that depreciation of the integrated steel mill is to follow a straight line at 4% rate, this is not included in the calculation of the breakeven price of the Hot Rolled Coil as calculation of HRC breakeven price is based on EBITDA cash flow analysis.

12 Estimate Accuracy

The estimate accuracy is within the range +/- 30%.

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume III: Estimating the Cost of Steel Production from an Integrated Steel Mill with OBF and MDEA CO_2 Capture Technology

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Annex V

TECHNO-ECONOMICS - COST BREAKDOWN (OPEX)

(Integrated Steel Mill with OBF / MDEA CO_2 Capture)

INDEX

Product ID	Coke & Coke Breeze	
Annual Production (Year 4 - 25)	1,243,741 t/y	310.94 kg/t HRC
Cost Items	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Hard Coking Coal	959,048 t/y	$182.428 Million/y
Soft Coking Coal	639,365 t/y	$93.125 Million/y
Raw Materials & Energy (Internally Sourced)		
Coke Oven Gas (Export)	8,786,744 GJ/y	($85.846) Million/y
OBF Process Gas	3,315,590 GJ/y	$32.393 Million/y
Electricity	43,530,946 kWh/y	$3.279 Million/y
Steam (9 Bar_a sat.)	1,435,261 GJ/y	$6.338 Million/y
Consumables & Other Utilities		
Raw Water	2,236,247 m^3/y	$0.254 Million/y
By-Product Sales		
Coal Tar	51,168 t/y	($9.005) Million/y
Benzole	15,049 t/y	($7.016) Million/y
Sulphur	3,766 t/y	($0.320) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	191 Operation Staff	$17.954 Million/y
Annual Maintenance Expense	5.0% CAPEX	$15.500 Million/y
Misc. Works Expense		$7.476 Million/y
Misc. OPEX (incl. environmental cleanup)		$2.824 Million/y
Total Operating Cost (Direct Cost of Coke Production)		$259.383 Million/y
Specific Cost (Internal Price of Coke)	**$ 208.55 per tonne coke**	**$ 64.85 per tonne HRC**

Product ID	Sinter	
Annual Production (Year 4 - 25)	4,349,045 t/y	1,087.26 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Iron Ore Fines (Brazil)	2,922,836 t/y	$234.452 Million/y
Iron Ore Fines (Australia)	352,149 t/y	$29.145 Million/y
Iron Ore Fines (Sweden)	246,504 t/y	$20.942 Million/y
Limestone	390,306 t/y	$9.074 Million/y
Quartzite	34,792 t/y	$0.626 Million/y
Olivine	90,335 t/y	$1.536 Million/y
Raw Materials & Energy (Internally Sourced)		
Lime	43,490 t/y	$4.184 Million/y
BF Undersize (excl. Reclaimed Coke)	60,932 t/y	$1.828 Million/y
BF Dust	59,530 t/y	$1.786 Million/y
HM Spillage & de-S Slag	31,166 t/y	$0.935 Million/y
BOS Dust & Sludge	129,700 t/y	$3.891 Million/y
BOS Slag (LD Slag)	136,407 t/y	$4.092 Million/y
Mill Scales	96,159 t/y	$1.923 Million/y
Coke Breeze	217,452 t/y	$45.350 Million/y
Reclaimed Coke (ex BF Screens)	20,526 t/y	$0.616 Million/y
Coke Oven Gas	317,480 GJ/y	$3.102 Million/y
Electricity	139,169,437 kWh/y	$10.484 Million/y
Consumables & Other Utilities		
Raw Water	1,296,015 m^3/y	$0.147 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	270 Operation Staff	$25.380 Million/y
Annual Maintenance Expense	5.0% CAPEX	$11.000 Million/y
Misc. Works Expense		$3.206 Million/y
Misc. OPEX (incl. environmental cleanup)		$1.603 Million/y
Total Operating Cost (Direct Cost of Sinter Production)		$415.301 Million/y
Specific Cost (Internal Price of Sinter)	**$ 95.49 per tonne sinter**	**$ 103.83 per tonne HRC**

Product ID	Hot Metal (Desulphurised)	
Annual Production (Year 4 - 25)	3,894,147 t/y	973.54 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
PCI Coal	603,233 t/y	$89.488 Million/y
Natural Gas	2,978,899 GJ/y	$29.104 Million/y
Lump Ore (Australian)	497,124 t/y	$51.067 Million/y
Pellets (Brazil)	1,399,333 t/y	$154.374 Million/y
Limestone	23,164 t/y	$0.539 Million/y
Quartzite	13,237 t/y	$0.238 Million/y
Calcium Carbide Powder	12,708 t/y	$10.167 Million/y
Raw Materials & Energy (Internally Sourced)		
Sinter	4,349,045 t/y	$415.301 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	1,004,170,271 Nm^3/y	$43.427 Million/y
BF Undersize (excl. reclaimed coke)	60,932 t/y	($1.809) Million/y
BF Dust (Recycled)	59,530 t/y	($1.767) Million/y
HM Spillage & De-Slag (Recycled)	31,166 t/y	($0.925) Million/y
Lump Coke	1,026,289 t/y	$214.033 Million/y
Reclaimed Coke (ex BF Screens)	20,526 t/y	($0.609) Million/y
Coke Oven Gas (for Ancillary Users)	358,719 GJ/y	$3.505 Million/y
OBF Process Gas (Export)	6,696,713 GJ/y	($65.427) Million/y
Electricity (Iron Making incl. HM Desulph.)	119,061,489 kWh/y	$8.969 Million/y
Electricity (Ancillary Users)	19,272,000 kWh/y	$1.452 Million/y
Consumables & Other Utilities		
Refractories (Torpedo car, HM Desulf, etc...)	5,062 t/y	$4.151 Million/y
Raw Water	2,923,682 m^3/y	$0.332 Million/y
Other Variable O&M Cost		
Slag Processing Fee (De-S Slag)	84,232 t/y	$0.496 Million/y
BF Sludge Disposal Fee	15,875 t/y	$0.317 Million/y
Slag Disposal Fee (De-S Slag)	53,066 t/y	$0.288 Million/y
Other Variable O&M Cost (Internally Sourced)		
CO_2 Capture and Compression Charge	3,439,360 t/y	$161.989 Million/y
By-Product Sales		
Granulated BF Slag	932,630 t/y	($14.922) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	321 Operation Staff	$30.174 Million/y
Annual Maintenance Expense	4.0% CAPEX	$24.400 Million/y
Misc. Works Expense		$10.403 Million/y
Misc. OPEX (incl. environmental cleanup)		$1.300 Million/y
Total Operating Cost (Direct Cost of Hot Metal Production)		$1,170.055 Million/y
Specific Cost (Internal Price of Hot Metal)	**$ 300.47 per tonne Hot Metal**	**$ 292.51 per tonne HRC**

Product ID	Liquid Steel	
Annual Production (Year 4 - 25)	4,345,228 t/y	1,086.31 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Pellets	20,944 t/y	$2.311 Million/y
Purchased Scrap	505,492 t/y	$115.252 Million/y
FeMnC	47,798 t/y	$67.068 Million/y
FeSi-75	13,036 t/y	$21.513 Million/y
DeOx Aluminium	6,518 t/y	$14.395 Million/y
Burnt Dolomite	47,164 t/y	$4.339 Million/y
Raw Materials & Energy (Internally Sourced)		
Hot Metal	3,894,147 t/y	$1,170.055 Million/y
Lime	301,956 t/y	$29.046 Million/y
Oxygen (Nm^3/y @ 273K)	232,039,177 Nm^3/y	$12.436 Million/y
Scrap (Internal)	320,285 t/y	$53.706 Million/y
LD Slag to Sinter Plant	136,407 t/y	($4.050) Million/y
LD Dust & Sludge	129,700 t/y	($3.851) Million/y
Coke Oven Gas (Ladle Metallurgy)	928,613 GJ/y	$9.073 Million/y
Basic Oxygen Furnace Gas (Export)	2,638,774 GJ/y	($25.781) Million/y
Electricity (Steel Making incl. Ladle Metallurgy)	195,097,243 kWh/y	$14.697 Million/y
Steam (9 Bar_a sat.)	2,494,531 GJ/y	($11.015) Million/y
Consumables & Other Utilities		
Refractories (BOS furnace, Ladle vessels)	15,208 t/y	$12.881 Million/y
Electrodes	1,304 t/y	$5.289 Million/y
Raw Water	1,673,679 m^3/y	$0.190 Million/y
Other Variable O&M Cost		
Slag Processing Fee (LD Slag)	487,185 t/y	$2.869 Million/y
Slag Processing Fee (Ladle Slag)	34,412 t/y	$0.203 Million/y
Disposal Fee (LD Slag)	126,673 t/y	$0.687 Million/y
Disposal Fee (Ladle Slag)	34,412 t/y	$3.040 Million/y
By-Product Sales		
LD Slag	224,105 t/y	($0.448) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	396 Operation Staff	$37.224 Million/y
Annual Maintenance Expense	5.0% CAPEX	$22.950 Million/y
Misc. Works Expense		$10.738 Million/y
Misc. OPEX (incl. environmental cleanup)		$2.844 Million/y
Total Operating Cost (Direct Cost of Liquid Steel Production)		$1,567.660 Million/y
Specific Cost (Internal Price of Liquid Steel)	**$ 360.78 per tonne Liquid Steel**	**$ 391.92 per tonne HRC**

Product ID	Slab	
Annual Production (Year 4 - 25)	**4,210,526 t/y**	**1,052.63 kg/t HRC**
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)		
Liquid Steel	4,345,228 t/y	$1,567.660 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	8,690,457 Nm^3/y	$0.466 Million/y
Scrap (to BOS furnace)	108,631 t/y	($21.019) Million/y
Scale (to Sinter)	36,772 t/y	($0.724) Million/y
Coke Oven Gas	78,437 GJ/y	$0.766 Million/y
Electricity	43,452,284 kWh/y	$3.273 Million/y
Consumables & Other Utilities		
Refractories (Casters)	8,842 t/y	$5.571 Million/y
Casting Powder	3,368,421 t/y	$2.257 Million/y
Raw Water	3,655,576 m^3/y	$0.415 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	360 Operation Staff	$33.840 Million/y
Annual Maintenance Expense	8.0% CAPEX	$15.636 Million/y
Misc. Works Expense		$5.905 Million/y
Misc. OPEX (incl. environmental cleanup)		$0.956 Million/y
Total Operating Cost (Direct Cost of Slab Production)		$1,615.003 Million/y
Specific Cost (Internal Price of Slab)	**$ 383.56 per tonne Slab**	**$ 403.75 per tonne HRC**

Product ID	Lime	
Annual Production (Year 4 - 25)	345,447 t/y	86.36 kg/t HRC
Cost Components	Annual Consumption	Annual Cost (US $)
Raw Materials & Energy (Externally Sourced)		
Limestone	583,818 t/y	$13.573 Million/y
Raw Materials & Energy (Internally Sourced)		
Coke Oven Gas (Lime Kiln)	1,208,759 GJ/y	$11.810 Million/y
Electricity	10,363,403 kWh/y	$0.781 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	34 Operation Staff	$3.196 Million/y
Annual Maintenance Expense	8.0% CAPEX	$1.280 Million/y
Misc. Works Expense		$2.591 Million/y
Total Operating Cost (Direct Cost of Lime Production)		$33.230 Million/y
Specific Cost (Internal Price of Lime)	$ 96.19 per tonne Lime	$ 8.31 per tonne HRC

Product ID	Oxygen (99.9%)	
Annual Production (Year 4 - 25)	276,381,545 Nm3/y	69.10 Nm3/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)		
Electricity	152,009,850 kWh/y	$11.451 Million/y
Steam (9 Bar_a sat.)	127,300 GJ/y	$0.562 Million/y
By-Product Sales		
Argon (Nm^3/y @ 273K and 1 Bar)	3,492,790 Nm^3/y	($3.248) Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	25 Operation Staff	$2.350 Million/y
Annual Maintenance Expense	2.5% CAPEX	$2.350 Million/y
Total Operating Cost (Direct Cost of Oxygen Production)		$13.465 Million/y
Specific Cost	**$ 0.04872 per Nm3 Oxygen**	**$ 3.37 per tonne HRC**
Adjustment Factor	**1.10000**	
Adjusted Internal Price of Oxygen	**$ 0.05359 per Nm3 Oxygen**	

Product ID	Electricity	
Annual Production (Year 4 - 25)	2,293,670 MWh/y	573.42 MWh/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Natural Gas	14,588,712 GJ/y	$142.532 Million/y
Consumables & Other Utilities		
Chemicals and Consumables	3.436 $/MWh	$7.880 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	42 Operation Staff	$3.948 Million/y
Annual Maintenance Expense	4.0% CAPEX	$14.469 Million/y
Total Operating Cost (Direct Cost of Electricity Production)		$168.829 Million/y
Specific Cost (Internal Price of Electricity)	**$ 0.0736 per kWh Electricity**	**$ 42.21 per tonne HRC**
Adjustment Factor	**1.02345**	
Adjusted Internal Price of Oxygen	**$ 0.0753 per kWh Electricity**	

Product ID	Steam (9 Bar_a, Sat.)	
Annual Production (Year 4 - 25)	7,789,168 GJ/y	1.95 GJ/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Externally Sourced)		
Natural Gas	2,613,836 GJ/y	$25.537 Million/y
Raw Materials & Energy (Internally Sourced)		
OBF Process Gas	3,381,123 GJ/y	$33.034 Million/y
Basic Oxygen Furnace Gas	2,638,774 GJ/y	$25.781 Million/y
Electricity	44,079,016 kWh/y	$3.321 Million/y
Consumables & Other Utilities		
Chemicals and Consumables	0.558 $/GJ Steam	$4.350 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	12 Operation Staff	$1.128 Million/y
Annual Maintenance Expense	2.5% CAPEX	$2.250 Million/y
Total Operating Cost (Direct Cost of Steam Production)		$95.400 Million/y
Specific Cost (Internal Price of Steam)	**$ 12.2478 per GJ Steam**	**$ 23.85 per tonne HRC**
Specific Cost (Internal Price of Steam)	**$ 33.97 per tonne Steam**	

Product ID	Oxygen (95%)	
Annual Production (Year 4 - 25)	1,024,253,677 Nm3/y	256.06 Nm3/t HRC
Cost Components	Annual Consumption	Annual Cost (US $)
Raw Materials & Energy (Internally Sourced)		
Electricity	481,399,228 kWh/y	$36.265 Million/y
Steam (9 Bar_a sat.)	42,614 GJ/y	$0.522 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	35 Operation Staff	$3.290 Million/y
Annual Maintenance Expense	2.5% CAPEX	$3.350 Million/y
Total Operating Cost (Direct Cost of Oxygen Production)		$43.427 Million/y
Specific Cost	$ 0.04240 per Nm3 Oxygen	$ 10.86 per tonne HRC
Adjustment Factor	1.02000	
Adjusted Internal Price of Oxygen	$ 0.04325 per Nm3 Oxygen	

Product ID	Carbon Dioxide	
Annual Production (Year 4 - 25)	3,439,360 t/y	859.84 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)		
Electricity	572,622,619 kWh/y	$43.137 Million/y
Steam (9 Bar_a sat.)	8,082,495 GJ/y	$98.993 Million/y
Consumables & Other Utilities		
MDEA (Make Up)	688 t/y	$1.896 Million/y
Raw Water	10,557,185 m^3/y	$1.199 Million/y
Other Variable O&M Cost		
Disposal Fee (MDEA Sludge)	688 t/y	$0.436 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	20 Operation Staff	$1.880 Million/y
Annual Maintenance Expense	2.5% CAPEX	$14.448 Million/y
Total Operating Cost (Direct Cost of CO2 Capture & Compression)		$161.989 Million/y
Specific Cost (Internal Price of CO2 Capture)	**$ 47.10 per tonne CO2 captured**	**$ 40.50 per tonne HRC**

Product ID	Hot Rolled Coil	
Annual Production (Year 4 - 25)	4,000,000 t/y	1,000.00 kg/t HRC
Cost Components	**Annual Consumption**	**Annual Cost (US $)**
Raw Materials & Energy (Internally Sourced)		
Slab	4,210,526 t/y	$1,615.003 Million/y
Oxygen (Nm^3/y @ 273K and 1 Bar)	10,526,316 Nm^3/y	$0.564 Million/y
Scrap (to Steelmaking)	168,421 t/y	($32.588) Million/y
Mill Scales (to Sinter)	59,387 t/y	($1.169) Million/y
Coke Oven Gas (Reheating Furnace)	5,894,737 GJ/y	$57.592 Million/y
Electricity (Reheating & Rolling Mills)	421,052,630 kWh/y	$31.719 Million/y
Consumables & Other Utilities		
Works and Back Up Rolls	1 Unit	$9.000 Million/y
Banding	1 Unit	$0.360 Million/y
Raw Water	8,000,000 m^3/y	$0.908 Million/y
Production Fixed Cost & Misc. Expense		
Direct Labour	480 personnel	$45.157 Million/y
Annual Maintenance Expense	8.0% CAPEX	$36.000 Million/y
Misc. Works Expense		$7.747 Million/y
Other OPEX (incl. environmental cleanup)		$1.443 Million/y
Total Operating Cost (Direct Cost of Hot Rolled Coil Production)		$1,771.735 Million/y
Specific Cost (Internal Price of Hot Rolled Coil)	**$ 442.93 per tonne Hot Rolled Coil**	

Understanding the Economics of Deploying CO_2 Capture Technology in an Integrated Steel Mill

Volume III: Estimating the Cost of Steel Production from an Integrated Steel Mill with OBF and MDEA CO_2 Capture Technology

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<u>Annex VI</u>

Discounted Cash Flow for Each Major Processes

(Integrated Steel Mill with OBF / MDEA CO_2 Capture)

<u>I N D E X</u>

APPENDIX 1-A: ANNUAL CASH FLOW (COKE PRODUCTION)

COKE PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Coke	To: Blast Furnace	tonnes		513,145	769,717	923,660	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289
Coke Breeze	To: Sinter Plant	tonnes		108,726	163,089	195,707	217,452	217,452	217,452	217,452	217,452	217,452	217,452	217,452	217,452	217,452
			Total	621,871	932,806	1,119,367	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741

			Period	14	15	16	17	18	19	20	21	22	23	24	25
Coke	To: Blast Furnace	tonnes		1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289	1,026,289
Coke Breeze	To: Sinter Plant	tonnes		217,452	217,452	217,452	217,452	217,452	217,452	217,452	217,452	217,452	217,452	217,452	217,452
			Total	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741	1,243,741

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Hard Coking Coal			$91,214	$136,821	$164,185	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428
Semi-soft Coking Coal			$46,562	$69,844	$83,812	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125
		Sub-Total	**$137,776**	**$206,664**	**$247,997**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**
Consummables and Other Utilities (US$ '000)															
Raw Water			$127	$190	$229	$254	$254	$254	$254	$254	$254	$254	$254	$254	$254
		Sub-Total	**$127**	**$190**	**$229**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Coke Oven Gas	(for Export)		($42,923)	($64,385)	($77,262)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)
OBF Process Gas	(for Oven Underfire Heating)		$16,197	$24,295	$29,154	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393
Electricity			$1,819	$2,549	$2,987	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279
Steam			$3,293	$4,815	$5,729	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338
		Sub-Total	**($21,615)**	**($32,726)**	**($39,392)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS															
By-Products (US$ '000)															
Crude Tar			($4,503)	($6,754)	($8,105)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)
Benzole (BTX)			($3,508)	($5,262)	($6,314)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)
Sulphur			($160)	($240)	($288)	($320)	($320)	($320)	($320)	($320)	($320)	($320)	($320)	($320)	($320)
		Sub-Total	**($8,171)**	**($12,256)**	**($14,707)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**
FIXED O&M COST & MISC. OPEX															
Fixed O&M (US$ '000)															
Labour			$10,199	$14,077	$16,403	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954
Maintenance & Spares			$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500
		Sub-Total	**$25,699**	**$29,577**	**$31,903**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**
Misc. O&M (US$ '000)															
Misc. Works Expenses			$3,738	$5,607	$6,728	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476
Misc. Operational Expenses			$1,412	$2,118	$2,542	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824
		Sub-Total	**$5,150**	**$7,725**	**$9,270**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**
ANNUAL OPERATING COST (COKE PRODUCTION) - $'000			**$138,967**	**$199,175**	**$235,300**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**

		Period	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Hard Coking Coal			$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428	$182,428
Semi-soft Coking Coal			$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125	$93,125
		Sub-Total	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**	**$275,553**
Consummables and Other Utilities (US$ '000)														
Raw Water			$254	$254	$254	$254	$254	$254	$254	$254	$254	$254	$254	$254
		Sub-Total	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**	**$254**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Coke Oven Gas	(for Export)		($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)	($85,846)
OBF Process Gas	(for Oven Underfire Heating)		$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393	$32,393
Electricity			$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279	$3,279
Steam			$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338	$6,338
		Sub-Total	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**	**($43,836)**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS														
By-Products (US$ '000)														
Crude Tar			($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)	($9,005)
Benzole (BTX)			($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)	($7,016)
Sulphur			($320)	($320)	($320)	($320)	($320)	($320)	($320)	($320)	($320)	($320)	($320)	($320)
		Sub-Total	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**	**($16,341)**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour			$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954	$17,954
Maintenance & Spares			$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500	$15,500
		Sub-Total	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**	**$33,454**
Misc. O&M (US$ '000)														
Misc. Works Expenses			$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476	$7,476
Misc. Operational Expenses			$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824	$2,824
		Sub-Total	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**	**$10,300**
ANNUAL OPERATING COST (COKE PRODUCTION) - $'000			**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**	**$259,383**

APPENDIX 1-B: ANNUAL CASH FLOW (SINTER PRODUCTION)

SINTER PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Sinter	To: Blast Furnace	Tonnes		2,174,522	3,261,784	3,914,140	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045
			Total	2,174,522	3,261,784	3,914,140	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045	4,349,045

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Raw Materials (US$ '000)																											
Sinter Fines (Brazil)			$117,226	$175,839	$211,007	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452	$234,452
Sinter Fines (Australia)			$14,572	$21,859	$26,230	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145	$29,145
Sinter Fines (Sweden)			$10,471	$15,707	$18,848	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942	$20,942
Limestone			$4,537	$6,805	$8,167	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074	$9,074
Quartzite			$313	$470	$564	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626	$626
Olivine			$768	$1,152	$1,382	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536	$1,536
		Sub-Total	**$147,888**	**$221,831**	**$266,198**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**	**$295,775**
Consummables and Other Utilities (US$ '000)																											
Raw Water			$74	$110	$132	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147	$147
		Sub-Total	**$74**	**$110**	**$132**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**	**$147**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Breeze	(ex Coke Plant)		$24,297	$34,823	$41,139	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350	$45,350
Reclaimed Coke	(ex BF Screens)		$308	$462	$554	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616	$616
Coke Oven Gas	(for Sinter Plant Ignition Fuel)		$1,551	$2,326	$2,792	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102	$3,102
Electricity			$5,814	$8,149	$9,550	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484	$10,484
		Sub-Total	**$31,969**	**$45,760**	**$54,035**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**	**$59,551**
Raw Materials and Recycled Materials (US$ '000)																											
Lime	(ex Lime Plant)		$2,201	$3,192	$3,787	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184	$4,184
Screenings (excl. Coke)	(ex BF Screens)		$914	$1,371	$1,645	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828	$1,828
BF Dust	(ex Blast Furnace)		$893	$1,339	$1,607	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786	$1,786
HM Losses + Desulph. Slag	(ex HM Desulphurisation)		$467	$701	$841	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935	$935
LD Slag	(ex BOF)		$2,046	$3,069	$3,683	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092	$4,092
LD Dust & Sludge	(ex BOF)		$1,945	$2,918	$3,502	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891	$3,891
Mill Scale	(ex Continuous Caster)		$368	$552	$662	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735	$735
Mill Scale	(ex HRM)		$594	$891	$1,069	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188	$1,188
		Sub-Total	**$9,429**	**$14,034**	**$16,797**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**	**$18,639**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$14,335	$19,858	$23,171	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380	$25,380
Maintenance & Spares			$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000
		Sub-Total	**$25,335**	**$30,858**	**$34,171**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**	**$36,380**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$1,603	$2,404	$2,885	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206	$3,206
Misc. Operational Expenses			$801	$1,202	$1,443	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603	$1,603
		Sub-Total	**$2,404**	**$3,606**	**$4,328**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**	**$4,809**
ANNUAL OPERATING COST (SINTER PRODUCTION) - $'000			**$217,099**	**$316,200**	**$375,661**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**	**$415,301**

APPENDIX 1-C: ANNUAL CASH FLOW (HOT METAL PRODUCTION)

HOT METAL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
ANNUAL PRODUCTION:																											
Hot Metal	To: Steelmaking	Tonnes	1,947,074	2,920,610	3,504,732	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147
		Total	1,947,074	2,920,610	3,504,732	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147	3,894,147

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coal (PCI)			$44,744	$67,116	$80,539	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488	$89,488
Natural Gas	(for OBF Process Gas Heater)		$14,552	$21,828	$26,193	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104	$29,104
		Sub-Total	**$59,296**	**$88,944**	**$106,733**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**	**$118,592**
Raw Materials (US$ '000)																											
Lump Ore (Australia)			$25,534	$38,300	$45,960	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067	$51,067
Pellets (Brazil)			$77,187	$115,781	$138,937	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374	$154,374
Limestone			$269	$404	$485	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539	$539
Quartzite			$119	$179	$214	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238	$238
Calcium Carbide Powder			$5,083	$7,625	$9,150	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167	$10,167
		Sub-Total	**$108,192**	**$162,289**	**$194,746**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**	**$216,385**
Consummables and Other Utilities (US$ '000)																											
Refractories (excl. Blast Furnace)			$2,076	$3,113	$3,736	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151	$4,151
Raw Water			$166	$249	$299	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332	$332
		Sub-Total	**$2,242**	**$3,362**	**$4,035**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**	**$4,483**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Lump Coke	(ex Coke Plant)		$114,670	$164,352	$194,161	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033	$214,033
Reclaimed Coke	(to Sinter Plant)		($305)	($457)	($548)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)	($609)
Coke Oven Gas	(for Ancilliary Users)		$1,752	$2,629	$3,154	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505	$3,505
OBF Process Gas	(for Export)		($32,713)	($49,070)	($58,884)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)	($65,427)
Electricity	(for Iron Making incl. HM Desulphurisation & Slag Granulation)		$4,974	$6,972	$8,170	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969	$8,969
Electricity	(for Ancilliary Users)		$805	$1,128	$1,322	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452	$1,452
		Sub-Total	**$89,183**	**$125,553**	**$147,375**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**	**$161,923**
Raw Materials and Recycled Materials (US$ '000)																											
Sinter	(ex Sinter Plant)		$217,099	$316,200	$375,661	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301	$415,301
Oxygen	(ex ASU - LP Oxygen Production)		$25,612	$34,519	$39,864	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427	$43,427
Screenings (excl. Coke)	(to Sinter Plant)		($905)	($1,357)	($1,628)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)	($1,809)
BF Dust	(to Sinter Plant)		($884)	($1,326)	($1,591)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)	($1,767)
HM Losses + Desulph. Slag	(to Sinter Plant)		($463)	($694)	($833)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)	($925)
		Sub-Total	**$240,460**	**$347,343**	**$411,473**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**	**$454,226**
Waste Processing and Disposal Cost																											
Waste Processing Fee (US$ '000)																											
Slag Processing Fee (De-S Slag)			$248	$372	$446	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496	$496
BF Sludge Disposal Fee			$159	$238	$286	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317	$317
De-S Slag Disposal Fee			$144	$216	$259	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288	$288
		Sub-Total	**$551**	**$826**	**$991**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**	**$1,101**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																											
By-Products (US$ '000)																											
Granulated BF Slag			($7,461)	($11,192)	($13,430)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)	($14,922)
		Sub-Total	**($7,461)**	**($11,192)**	**($13,430)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**	**($14,922)**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$17,155	$23,665	$27,570	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174	$30,174
Maintenance & Spares			$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400	$24,400
		Sub-Total	**$41,555**	**$48,065**	**$51,970**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**	**$54,574**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$5,202	$7,802	$9,363	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403	$10,403
Misc. Operational Expenses			$650	$975	$1,170	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300	$1,300
CO2 Capture & Compression Expenses			$93,452	$127,721	$148,282	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990	$161,990
		Sub-Total	**$99,304**	**$136,498**	**$158,815**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**	**$173,693**
ANNUAL OPERATING COST (HOT METAL PRODUCTION) - $'000			**$633,321**	**$901,689**	**$1,062,709**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**	**$1,170,056**

APPENDIX 1-D: ANNUAL CASH FLOW (LIQUID STEEL PRODUCTION)

LIQUID STEEL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Liquid Steel	To: Casting	Tonnes		2,172,614	3,258,921	3,910,706	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228
			Total	2,172,614	3,258,921	3,910,706	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228	4,345,228

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Raw Materials (US$ '000)																											
Pellets			$1,155	$1,733	$2,079	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311	$2,311
Merchant Scrap (Rotterdam - Mixed)			$57,626	$86,439	$103,727	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252	$115,252
FeMnC			$33,534	$50,301	$60,361	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068	$67,068
FeSi75			$10,756	$16,134	$19,361	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513	$21,513
Desox Al			$7,198	$10,796	$12,956	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395	$14,395
Burnt Dolomite			$2,170	$3,254	$3,905	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339	$4,339
		Sub-Total	**$112,439**	**$168,658**	**$202,390**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**	**$224,878**
Consummables and Other Utilities (US$ '000)																											
Refractories (Steelmaking)			$6,441	$9,661	$11,593	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881	$12,881
Electrodes (Ladle Metallurgy)			$2,644	$3,966	$4,760	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289	$5,289
Raw Water			$95	$143	$171	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190	$190
		Sub-Total	**$9,180**	**$13,770**	**$16,524**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**	**$18,360**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																											
Energy and Reductants (US$ '000)																											
Coke Oven Gas	(for Ladle Metallurgy)		$4,536	$6,804	$8,165	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073	$9,073
Basic Oxygen Furnace Gas	(for Export)		($12,890)	($19,336)	($23,203)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)	($25,781)
Electricity	(for Steelmaking incl. Ladle Metallurgy)		$8,150	$11,424	$13,388	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697	$14,697
Steam	(for Export)		($5,724)	($8,369)	($9,957)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)	($11,015)
		Sub-Total	**($5,927)**	**($9,477)**	**($11,607)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**	**($13,026)**
Raw Materials and Recycled Materials (US$ '000)																											
Hotmetal	(ex Iron Making)		$633,321	$901,689	$1,062,709	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056	$1,170,056
Lime	(ex Lime Plant)		$15,284	$22,165	$26,294	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046	$29,046
Oxygen	(ex ASU - HP Oxygen Production)		$8,020	$10,228	$11,552	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436	$12,436
Scrap (Internal)	(ex Ladle Metallurgy, Caster, HRM)		$26,853	$40,280	$48,335	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706	$53,706
LD Dust & Sludge	(to Sinter Plant)		($1,925)	($2,888)	($3,466)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)	($3,851)
LD Slag	(to Sinter Plant)		($2,025)	($3,037)	($3,645)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)	($4,050)
		Sub-Total	**$679,528**	**$968,436**	**$1,141,780**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**	**$1,257,343**
Waste Processing and Disposal Cost																											
Waste Processing Fee (US$ '000)																											
Slag Processing Fee (LD Slag)			$1,435	$2,152	$2,582	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869	$2,869
Slag Processing Fee (Ladle Slag)			$101	$152	$182	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203	$203
LD Slag Disposal Fee			$344	$515	$618	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687	$687
Ladle Slag Disposal Fee			$1,520	$2,280	$2,736	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040	$3,040
		Sub-Total	**$3,400**	**$5,099**	**$6,119**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**	**$6,799**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																											
By-Products (US$ '000)																											
LD Slag			($224)	($336)	($403)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)	($448)
		Sub-Total	**($224)**	**($336)**	**($403)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**	**($448)**
FIXED O&M COST & MISC. OPEX																											
Fixed O&M (US$ '000)																											
Labour			$20,727	$28,976	$33,925	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224	$37,224
Maintenance & Spares			$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950	$22,950
		Sub-Total	**$43,677**	**$51,926**	**$56,875**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**	**$60,174**
Misc. O&M (US$ '000)																											
Misc. Works Expenses			$5,369	$8,053	$9,664	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738	$10,738
Misc. Operational Expenses			$1,422	$2,133	$2,560	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844	$2,844
		Sub-Total	**$6,791**	**$10,186**	**$12,223**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**	**$13,582**
ANNUAL OPERATING COST (LIQUID STEEL PRODUCTION) - $'000			**$848,863**	**$1,208,262**	**$1,423,901**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**	**$1,567,661**

APPENDIX 1-E: ANNUAL CASH FLOW (SLAB CASTING)

CONTINUOUS CASTING

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12
Slab	To: Reheat Furnaces	Tonnes		0	0	0	2,105,263	3,157,895	3,789,474	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526
			Total	0	0	0	2,105,263	3,157,895	3,789,474	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526

			Period	13	14	15	16	17	18	19	20	21	22	23	24	25
Slab	To: Reheat Furnaces	Tonnes		4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526
			Total	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526	4,210,526

		Period	1	2	3	4	5	6	7	8	9	10	11	12
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Consummables and Other Utilities (US$ '000)														
Refractories (Casters)			$2,785	$4,178	$5,013	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571
Casting Powder			$1,128	$1,693	$2,031	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257
Raw Water			$208	$311	$374	$415	$415	$415	$415	$415	$415	$415	$415	$415
		Sub-Total	**$4,121**	**$6,182**	**$7,418**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Coke Oven Gas	(for Tundish Heating etc...)		$383	$575	$690	$766	$766	$766	$766	$766	$766	$766	$766	$766
Electricity			$1,815	$2,544	$2,982	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273
		Sub-Total	**$2,198**	**$3,119**	**$3,671**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**
Raw Materials and Recycled Materials (US$ '000)														
Liquid Steel	(ex Steelmaking)		$848,863	$1,208,262	$1,423,901	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661
Oxygen	(ex ASU)		$300	$383	$433	$466	$466	$466	$466	$466	$466	$466	$466	$466
Scrap (Internal)	(to BOS Furnace)		($10,509)	($15,764)	($18,917)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)
Mill Scales	(to Sinter Plant)		($362)	($543)	($652)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)
		Sub-Total	**$838,292**	**$1,192,338**	**$1,404,765**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour			$19,646	$26,743	$31,001	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840
Maintenance & Spares			$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636
		Sub-Total	**$35,282**	**$42,379**	**$46,637**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**
Misc. O&M (US$ '000)														
Misc. Works Expenses			$2,953	$4,429	$5,315	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905
Misc. Operational Expenses			$478	$717	$860	$956	$956	$956	$956	$956	$956	$956	$956	$956
		Sub-Total	**$3,431**	**$5,146**	**$6,175**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**
ANNUAL OPERATING COST (CONTINUOUS CASTING) - $'000			**$883,324**	**$1,249,164**	**$1,468,668**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**

		Period	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Consummables and Other Utilities (US$ '000)															
Refractories (Casters)			$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571	$5,571
Casting Powder			$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257	$2,257
Raw Water			$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415	$415
		Sub-Total	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**	**$8,242**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Coke Oven Gas	(for Tundish Heating etc...)		$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766	$766
Electricity			$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273	$3,273
		Sub-Total	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**	**$4,040**
Raw Materials and Recycled Materials (US$ '000)															
Liquid Steel	(ex Steelmaking)		$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661	$1,567,661
Oxygen	(ex ASU)		$466	$466	$466	$466	$466	$466	$466	$466	$466	$466	$466	$466	$466
Scrap (Internal)	(to BOS Furnace)		($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)	($21,019)
Mill Scales	(to Sinter Plant)		($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)	($724)
		Sub-Total	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**	**$1,546,384**
FIXED O&M COST & MISC. OPEX															
Fixed O&M (US$ '000)															
Labour			$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840	$33,840
Maintenance & Spares			$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636	$15,636
		Sub-Total	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**	**$49,476**
Misc. O&M (US$ '000)															
Misc. Works Expenses			$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905	$5,905
Misc. Operational Expenses			$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956	$956
		Sub-Total	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**	**$6,861**
ANNUAL OPERATING COST (CONTINUOUS CASTING) - $'000			**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**	**$1,615,004**

LIME PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Lime	To: Steelmaking	Tonnes		150,978	226,467	271,761	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956
	To: Sinter Plant	Tonnes		21,745	32,618	39,141	43,490	43,490	43,490	43,490	43,490	43,490	43,490	43,490	43,490	43,490
			Total	172,723	259,085	310,902	345,447	345,447	345,447	345,447	345,447	345,447	345,447	345,447	345,447	345,447

			Period	14	15	16	17	18	19	20	21	22	23	24	25
Lime	To: Steelmaking	Tonnes		301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956	301,956
	To: Sinter Plant	Tonnes		43,490	43,490	43,490	43,490	43,490	43,490	43,490	43,490	43,490	43,490	43,490	43,490
			Total	345,447	345,447	345,447	345,447	345,447	345,447	345,447	345,447	345,447	345,447	345,447	345,447

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Raw Materials (US$ '000)															
Limestone			$6,786	$10,180	$12,215	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573
		Sub-Total	**$6,786**	**$10,180**	**$12,215**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Coke Oven Gas	(for Lime Kiln)		$5,905	$8,857	$10,629	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810
Electricity			$433	$607	$711	$781	$781	$781	$781	$781	$781	$781	$781	$781	$781
		Sub-Total	**$6,338**	**$9,464**	**$11,340**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**
FIXED O&M COST & MISC. OPEX															
Fixed O&M (US$ '000)															
Labour			$1,295	$1,943	$2,332	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591
Maintenance & Spares			$1,786	$2,491	$2,914	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196
		Sub-Total	**$3,081**	**$4,434**	**$5,246**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**
Misc. O&M (US$ '000)															
Misc. Works Expenses			$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280
		Sub-Total	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**
ANNUAL OPERATING COST (LIME PRODUCTION) - $'000			**$17,486**	**$25,358**	**$30,081**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**

		Period	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Raw Materials (US$ '000)														
Limestone			$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573	$13,573
		Sub-Total	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**	**$13,573**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Coke Oven Gas	(for Lime Kiln)		$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810	$11,810
Electricity			$781	$781	$781	$781	$781	$781	$781	$781	$781	$781	$781	$781
		Sub-Total	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**	**$12,590**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour			$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591	$2,591
Maintenance & Spares			$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196	$3,196
		Sub-Total	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**	**$5,787**
Misc. O&M (US$ '000)														
Misc. Works Expenses			$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280	$1,280
		Sub-Total	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**	**$1,280**
ANNUAL OPERATING COST (LIME PRODUCTION) - $'000			**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**	**$33,230**

APPENDIX 1-G: ANNUAL CASH FLOW (AIR SEPARATION UNIT - HP O_2)

ASU - HIGH PURITY OXYGEN PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Oxygen	To: Steelmaking	nm^3		116,019,589	174,029,383	208,835,260	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177	232,039,177
	To: Continuous Caster	nm^3		4,345,228	6,517,843	7,821,411	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457	8,690,457
	To: HRM	nm^3		5,263,158	7,894,737	9,473,684	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316	10,526,316
	Buffer Requirements	nm^3		12,562,797	18,844,196	22,613,035	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595	25,125,595
			Total	138,190,772	207,286,159	248,743,390	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545	276,381,545

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																										
Energy and Reductants (US$ '000)																										
Electricity		$6,350	$8,901	$10,431	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451	$11,451
Steam		$292	$427	$508	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562	$562
	Sub-Total	**$6,642**	**$9,328**	**$10,939**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**	**$12,013**
EXTERNAL REVENUES - SALE OF BY-PRODUCTS																										
By-Products (US$ '000)																										
Liquid Argon		($1,624)	($2,436)	($2,923)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)	($3,248)
	Sub-Total	**($1,624)**	**($2,436)**	**($2,923)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**	**($3,248)**
FIXED O&M COST & MISC. OPEX																										
Fixed O&M (US$ '000)																										
Labour		$1,316	$1,833	$2,143	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350
Maintenance & Spares		$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350
	Sub-Total	**$3,666**	**$4,183**	**$4,493**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**	**$4,700**
ANNUAL OPERATING COST (ASU - HIGH PURITY OXYGEN PRODUCTION) - $'000		**$8,684**	**$11,075**	**$12,509**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**	**$13,465**

ELECTRICITY PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Electricity	To: Coke Plant	MWh		21,765	32,648	39,178	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531	43,531
	To: Sinter Plant	MWh		69,585	104,377	125,252	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169	139,169
	To: Iron Making & Ancilliary	MWh		69,167	103,750	124,500	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333	138,333
	To: Steelmaking	MWh		97,549	146,323	175,588	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097	195,097
	To: Continuous Casting	MWh		21,726	32,589	39,107	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452	43,452
	To: Reheat Furnaces & HRM	MWh		210,526	315,789	378,947	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053	421,053
	To: Lime Plant	MWh		5,182	7,773	9,327	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363	10,363
	To: ASU High Purity O2 Prod.	MWh		76,005	114,007	136,809	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010	152,010
	To: Steam Generation Plant	MWh		22,039	33,059	39,671	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079	44,079
	To: ASU Low Purity O2 Prod.	MWh		240,700	361,049	433,259	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399	481,399
	To: CO2 Capture Plant	MWh		286,311	429,467	515,360	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623	572,623
	To: Off-Sites & Losses	MWh		26,280	39,420	47,304	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560	52,560
			Total	1,146,835	1,720,252	2,064,303	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670	2,293,670

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																										
Energy and Reductants (US$ '000)																										
Natural Gas		$71,266	$106,899	$128,279	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532	$142,532
	Sub-Total	**$71,266**	**$106,899**	**$128,279**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**	**$142,532**
Consummables and Other Utilities (US$ '000)																										
Chemicals & Consummables		$3,940	$5,910	$7,092	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880	$7,880
	Sub-Total	**$3,940**	**$5,910**	**$7,092**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**	**$7,880**
FIXED O&M COST & MISC. OPEX																										
Fixed O&M (US$ '000)																										
Labour		$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948	$3,948
Maintenance & Spares		$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469	$14,469
	Sub-Total	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**	**$18,417**
ANNUAL OPERATING COST (ELECTRICITY PRODUCTION) - $'000		**$93,623**	**$131,226**	**$153,788**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**	**$168,829**

APPENDIX 1-I: ANNUAL CASH FLOW (STEAM GENERATION PLANT)

LOW PRESSURE STEAM PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Low Pressure Steam	To: CO2 Capture Plant	GJ		4,041,248	6,061,871	7,274,246	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495
	From: Steelmaking	GJ		146,696	220,044	264,053	293,392	293,392	293,392	293,392	293,392	293,392	293,392	293,392	293,392	293,392
			Total	3,894,552	5,841,827	7,010,193	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103

			Period	14	15	16	17	18	19	20	21	22	23	24	25
Low Pressure Steam	To: CO2 Capture Plant	GJ		8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495	8,082,495
	From: Steelmaking	GJ		293,392	293,392	293,392	293,392	293,392	293,392	293,392	293,392	293,392	293,392	293,392	293,392
			Total	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103	7,789,103

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Natural Gas		$12,769	$19,153	$22,983	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537
	Sub-Total	**$12,769**	**$19,153**	**$22,983**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**
Consummables and Other Utilities (US$ '000)														
Chemicals & Consummables		$2,175	$3,263	$3,915	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350
	Sub-Total	**$2,175**	**$3,263**	**$3,915**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Basic Oxygen Furnace Gas		$12,890	$19,336	$23,203	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781
Blast Furnace Gas		$16,517	$24,775	$29,730	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034
Electricity		$1,841	$2,581	$3,025	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321
	Sub-Total	**$31,249**	**$46,692**	**$55,958**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour		$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128
Maintenance & Spares		$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250
	Sub-Total	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**
ANNUAL OPERATING COST (LOW PRESSURE STEAM PRODUCTION) - $'000		**$49,570**	**$72,485**	**$86,234**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**

	Period	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Natural Gas		$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537	$25,537
	Sub-Total	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**	**$25,537**
Consummables and Other Utilities (US$ '000)													
Chemicals & Consummables		$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350	$4,350
	Sub-Total	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**	**$4,350**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS													
Energy and Reductants (US$ '000)													
Basic Oxygen Furnace Gas		$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781	$25,781
Blast Furnace Gas		$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034	$33,034
Electricity		$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321	$3,321
	Sub-Total	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**	**$62,135**
FIXED O&M COST & MISC. OPEX													
Fixed O&M (US$ '000)													
Labour		$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128	$1,128
Maintenance & Spares		$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250	$2,250
	Sub-Total	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**	**$3,378**
ANNUAL OPERATING COST (LOW PRESSURE STEAM PRODUCTION) - $'000		**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**	**$95,400**

APPENDIX 1-J: ANNUAL CASH FLOW (AIR SEPARATION UNIT - LP O_2)

ASU - LOW PURITY OXYGEN PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9
Oxygen	To: Oxy-Blast Furnace	nm³		502,085,135	753,127,702	903,753,242	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269
	Buffer Requirements	nm³		10,041,703	15,062,554	18,075,065	20,083,405	20,083,405	20,083,405	20,083,405	20,083,405	20,083,405
			Total	512,126,837	768,190,256	921,828,307	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674

			Period	10	11	12	13	14	15	16	17
Oxygen	To: Oxy-Blast Furnace	nm³		1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269
	Buffer Requirements	nm³		20,083,405	20,083,405	20,083,405	20,083,405	20,083,405	20,083,405	20,083,405	20,083,405
			Total	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674

			Period	18	19	20	21	22	23	24	25
Oxygen	To: Oxy-Blast Furnace	nm³		1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269	1,004,170,269
	Buffer Requirements	nm³		20,083,405	20,083,405	20,083,405	20,083,405	20,083,405	20,083,405	20,083,405	20,083,405
			Total	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674	1,024,253,674

INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS

Energy and Reductants (US$ '000)

	Period	1	2	3	4	5	6	7	8	9
Electricity		$20,111	$28,188	$33,034	$36,265	$36,265	$36,265	$36,265	$36,265	$36,265
Steam		$271	$397	$472	$522	$522	$522	$522	$522	$522
	Sub-Total	**$20,382**	**$28,584**	**$33,506**	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**

	Period	10	11	12	13	14	15	16	17
Electricity		$36,265	$36,265	$36,265	$36,265	$36,265	$36,265	$36,265	$36,265
Steam		$522	$522	$522	$522	$522	$522	$522	$522
	Sub-Total	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**

	Period	18	19	20	21	22	23	24	25
Electricity		$36,265	$36,265	$36,265	$36,265	$36,265	$36,265	$36,265	$36,265
Steam		$522	$522	$522	$522	$522	$522	$522	$522
	Sub-Total	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**	**$36,787**

FIXED O&M COST & MISC. OPEX

Fixed O&M (US$ '000)

	Period	1	2	3	4	5	6	7	8	9
Labour		$1,880	$2,585	$3,008	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290
Maintenance & Spares		$3,350	$3,350	$3,350	$3,350	$3,350	$3,350	$3,350	$3,350	$3,350
	Sub-Total	**$5,230**	**$5,935**	**$6,358**	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**
ANNUAL OPERATING COST (ASU - LOW PURITY OXYGEN PRODUCTION) - $'000		**$25,612**	**$34,519**	**$39,864**	**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**

	Period	10	11	12	13	14	15	16	17
Labour		$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290
Maintenance & Spares		$3,350	$3,350	$3,350	$3,350	$3,350	$3,350	$3,350	$3,350
	Sub-Total	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**
ANNUAL OPERATING COST (ASU - LOW PURITY OXYGEN PRODUCTION) - $'000		**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**

	Period	18	19	20	21	22	23	24	25
Labour		$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290	$3,290
Maintenance & Spares		$3,350	$3,350	$3,350	$3,350	$3,350	$3,350	$3,350	$3,350
	Sub-Total	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**	**$6,640**
ANNUAL OPERATING COST (ASU - LOW PURITY OXYGEN PRODUCTION) - $'000		**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**	**$43,427**

APPENDIX 1-K: ANNUAL CASH FLOW (CO_2 CAPTURE AND COMPRESSION PLANT)

CO_2 CAPTURE & COMPRESSION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
CARBON DIOXIDE	Ex: Hot Metal Production	tonnes		1,829,346	2,744,019	3,292,823	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692
	Total Gas Processed	tonnes	*Total*	1,829,346	2,744,019	3,292,823	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692	3,658,692
	Total CO2 Captured	tonnes	*Total*	1,719,680	2,579,520	3,095,424	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360	3,439,360

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS																										
Energy and Reductants (US$ '000)																										
Electricity		$23,921	$33,529	$39,294	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137	$43,137
Steam		$51,437	$75,215	$89,482	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994	$98,994
	Sub-Total	**$75,359**	**$108,745**	**$128,776**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**	**$142,131**
Consummables and Other Utilities (US$ '000)																										
MDEA/Pz Solvent		$948	$1,422	$1,707	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896	$1,896
Raw Water		$599	$899	$1,079	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199	$1,199
	Sub-Total	**$1,548**	**$2,321**	**$2,786**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**	**$3,095**
Waste Processing and Disposal Cost																										
Waste Processing Fee (US$ '000)																										
MDEA Sludge Disposal Fee		$218	$327	$392	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436	$436
	Sub-Total	**$218**	**$327**	**$392**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**	**$436**
FIXED O&M COST & MISC. OPEX																										
Fixed O&M (US$ '000)																										
Labour		$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880	$1,880
Maintenance & Spares		$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448	$14,448
	Sub-Total	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**	**$16,328**
ANNUAL OPERATING COST (CO2 CAPTURE & COMPRESSION) - $'000		**$93,452**	**$127,721**	**$148,282**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**	**$161,990**

APPENDIX 1-L: ANNUAL CASH FLOW (REHEATING AND HOT ROLLING MILLS)

HOT ROLLED COIL PRODUCTION

Application of CO_2 Capture to an Integrated Steelworks (OBF / MDEA CO_2 CAPTURE)

ANNUAL PRODUCTION:

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Hot Rolled Coil	To: Sales	Tonnes		2,000,000	3,000,000	3,600,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000
			Total	2,000,000	3,000,000	3,600,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000

			Period	14	15	16	17	18	19	20	21	22	23	24	25
Hot Rolled Coil	To: Sales	Tonnes		4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000
			Total	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Consummables and Other Utilities (US$ '000)															
Works Back Up Rolls	(for HSM)		$4,500	$6,750	$8,100	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000
Banding	(for Finish Products)		$180	$270	$324	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360
Raw Water			$454	$681	$817	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908
		Sub-Total	**$5,134**	**$7,701**	**$9,241**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS															
Energy and Reductants (US$ '000)															
Coke Oven Gas	(for Reheating Furnace)		$28,796	$43,194	$51,832	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592
Electricity			$17,590	$24,654	$28,893	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719
		Sub-Total	**$46,385**	**$67,848**	**$80,726**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**
Raw Materials and Recycled Materials (US$ '000)															
Slab	(ex Continuous Casting)		$883,324	$1,249,164	$1,468,668	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004
Oxygen	(ex ASU)		$364	$464	$524	$564	$564	$564	$564	$564	$564	$564	$564	$564	$564
Scrap (Internal)	(to BOS Furnace)		($16,294)	($24,441)	($29,329)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)
Mill Scales	(to Sinter Plant)		($585)	($877)	($1,052)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)
		Sub-Total	**$866,810**	**$1,224,310**	**$1,438,810**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**
FIXED O&M COST & MISC. OPEX															
Fixed O&M (US$ '000)															
Labour			$25,539	$35,348	$41,233	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157
Maintenance & Spares			$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000
		Sub-Total	**$61,539**	**$71,348**	**$77,233**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**
Misc. O&M (US$ '000)															
Misc. Works Expenses			$3,874	$5,810	$6,973	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747
Misc. Operational Expenses			$721	$1,082	$1,298	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443
		Sub-Total	**$4,595**	**$6,892**	**$8,271**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**
ANNUAL OPERATING COST (HOT ROLLED COIL PRODUCTION) - $'000			**$984,463**	**$1,378,100**	**$1,614,282**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**

		Period	14	15	16	17	18	19	20	21	22	23	24	25
EXTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Consummables and Other Utilities (US$ '000)														
Works Back Up Rolls	(for HSM)		$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000	$9,000
Banding	(for Finish Products)		$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360	$360
Raw Water			$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908	$908
		Sub-Total	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**	**$10,268**
INTERNALLY SOURCED MATERIALS, ENERGY AND REDUCTANTS														
Energy and Reductants (US$ '000)														
Coke Oven Gas	(for Reheating Furnace)		$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592	$57,592
Electricity			$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719	$31,719
		Sub-Total	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**	**$89,311**
Raw Materials and Recycled Materials (US$ '000)														
Slab	(ex Continuous Casting)		$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004	$1,615,004
Oxygen	(ex ASU)		$564	$564	$564	$564	$564	$564	$564	$564	$564	$564	$564	$564
Scrap (Internal)	(to BOS Furnace)		($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)	($32,588)
Mill Scales	(to Sinter Plant)		($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)	($1,169)
		Sub-Total	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**	**$1,581,811**
FIXED O&M COST & MISC. OPEX														
Fixed O&M (US$ '000)														
Labour			$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157	$45,157
Maintenance & Spares			$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000
		Sub-Total	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**	**$81,157**
Misc. O&M (US$ '000)														
Misc. Works Expenses			$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747	$7,747
Misc. Operational Expenses			$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443	$1,443
		Sub-Total	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**	**$9,190**
ANNUAL OPERATING COST (HOT ROLLED COIL PRODUCTION) - $'000			**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**	**$1,771,736**