TECHNO-ECONOMIC EVALUATION OF RETROFITTING CCS IN A MARKET PULP MILL AND AN INTEGRATED PULP AND BOARD MILL

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Techno-Economic Evaluation of Retrofitting CCS in a Market Pulp Mill and an Integrated Pulp and Board Mill

Key Messages

- The IEA Greenhouse Gas R&D Programme (IEAGHG) have been studying the performance and cost of integrating CO_2 Capture and Storage (CCS) into the energy intensive industries. To date, the programme has assessed the economics of deploying CCS in five different energy intensive industries. The present study extends this work to include the pulp and paper industry, with another study on the oil refining industry underway.

- The pulp and paper industry accounts for some 1.1% of the global CO_2 emissions. These emissions arise mainly from its recovery boiler, multi-fuel boiler and lime kiln. The majority of this CO_2 originates from the combustion of biomass, which renders it as carbon neutral if the biomass used as raw materials of the pulp production is grown and harvested in a sustainable manner. If the CO_2 emission from pulp and paper industry is captured and permanently stored, then this could be considered as a potential carbon sink. As such, the pulp and paper industry could be regarded as an industry with potential for the early demonstration of both bio-CCS and industrial CCS.

- This study provides an assessment of the performance and costs of retrofitting CCS in a Nordic Kraft Pulp Mill and an Integrated Pulp and Board Mill. Different configurations of capturing CO_2 (90%) from the flue gases of the recovery boiler, multi-fuel boiler and lime kiln were examined. For the standalone pulp mill, the excess steam produced by the mill is sufficient to cover the additional demand from the CCS plant. For an integrated pulp and board mill, there is less excess steam available for the CCS plant, therefore the addition an auxiliary boiler is required.

- The retrofit of an amine based post-combustion CO_2 capture plant into a pulp mill increases the steam demand by 1 to 8 GJ/air dried tonne (adt) of pulp, depending on the volume of the flue gas to be treated. This translates to a reduction in the amount of electricity exported to the grid by 0.1 – 1.0 MWh/adt pulp for the Kraft pulp mill, and by 0.1 – 0.5 MWh/adt pulp for an integrated pulp and board mill. This corresponds to between 6 and 80% reduction, and between 10 and 72% reduction in the volume of electricity exported for the Kraft pulp mill and the integrated pulp and board mill respectively.

- The %CO_2 avoided could be in the range of 9 to 90% for the Kraft Pulp Mill and 9 to 73% for the Integrated Pulp and Board Mill (as compared to the corresponding Base Cases). If the emitted biogenic CO_2 is recognised as "carbon neutral" and the captured biogenic CO_2 as "carbon negative", then the %CO_2 avoided could be in the range of 310 to 2340%.

- The retrofit of CCS increases the levelised cost of pulp (LCOP) produced by the market (standalone) pulp mill in the range of 20 to 154 €/adt (4 – 30%), and increases the LCOP produced by the integrated pulp and board mill in the range of 22 to 191 €/adt (4 – 37%). This translates to a CO_2 avoided cost (CAC) between 62 and 92 €/t CO_2 for the pulp mill and between 82 and 92 €/t CO_2 for the integrated pulp and board mill.

- This study assessed the sensitivity of the cost if incentives to the renewable electricity credit, CO_2 taxes, and negative emissions credit are provided. It can be concluded that the most favourable route to encourage the pulp industry to deploy bio-CCS is by providing sufficient incentives for their negative emissions.

Background to the Study

The IEA Greenhouse Gas R&D Programme (IEAGHG) has undertaken a series of studies evaluating the performance and cost of capturing CO_2 from different energy intensive industries.

The IPCC Fifth Assessment Report calls for solutions that can remove CO_2 from the atmosphere. The concept of sustainable Bioenergy and CO_2 Capture and Storage (Bio-CCS or BECCS) should enable a large scale removal of CO_2 from the atmosphere.

The pulp and paper industry is one of the energy intensive industries that could potentially demonstrate the deployment of both bio-CCS and industrial CCS applications simultaneously. The majority of the CO_2 emitted (around 75-100% of the total CO_2 emissions) from an integrated pulp and paper mills is classified as biogenic CO_2 emissions. If the source of the raw materials of the pulp mill is managed sustainably, these biogenic CO_2 emissions could be considered as “CO_2 neutral”. With CCS technology installed, “CO_2 negative” emissions could be realised.

IEA Greenhouse Gas R&D Programme in collaboration with VTT Technical Research Centre of Finland and ÅF-Consult Oy evaluated the performance and cost of retrofitting CO_2 capture and storage in a modern Finnish Kraft Pulp Mill (Base Case 1A) and Integrated Pulp and Board Mill (Base Case 1B).

This study presents the baseline information in understanding the performance and cost of retrofitting post-combustion CO_2 capture to a pulp mill or an integrated pulp and board mill.

Scope of Work

This study assessed two hypothetical reference mills situated in the west coast of Finland as a basis for evaluation.

The pulp mill (Base Case 1A) has an annual production of 800,000 adt of bleached softwood Kraft pulp (BSKP) which is sold as market pulp. The integrated pulp and board mill (Base Case 1B) has an annual production of 400,000 adt of board. This mill also consumes 60,000 adt/y of the softwood Kraft pulp that it produces, thus only 740,000 adt/y of BSKP is sold to the market.

This study aims to evaluate the performance and cost of retrofitting post-combustion CO_2 capture technology to the pulp mill and understand its implication on the mill’s operation in terms of fuel balance, utility requirements (i.e. steam and electricity balance) and the mill’s financial performance.

Both reference cases were evaluated for different options of capturing CO_2 from the flue gases of the recovery boiler, multi-fuel boiler and lime kiln, or a combination of these. A total of twelve different cases were evaluated; six cases each for Base Case 1A and Base Case 1B as listed in Table 1.

Table 1: Case studies evaluated

Case description	Abbreviation	Case identification*	
		Market Pulp Mill	Integrated Pulp & Board Mill
CO_2 capture from flue gas of the recovery boiler only	REC	Case 2A-1	Case 2B-1 CO2MP
CO_2 capture from flue gas of the multi-fuel boiler only	MFB	Case 2A-2	Case 2B-2
CO_2 capture from flue gas of the lime kiln only	LK	Case 2A-3	Case 2B-3
CO_2 capture from flue gases of recovery boiler and multi-fuel boiler	REC + MFB	Case 2A-4	Case 2B-4 CO2MP
CO_2 capture from flue gases of recovery boiler and lime kiln	REC + LK	Case 2A-5	Case 2B-5 CO2MP
CO_2 capture from flue gases from recovery boiler, multi-fuel boiler and lime kiln	REC + MFB + LK	Case 2A-6 MP	Case 2B-6 CO2MP

*MP = medium pressure steam at 13.0 bar (a) is used to supply the additional steam required by the CO_2 capture plant. CO2MP = CO_2 compressors are driven by a back pressure steam turbine.

Additionally, six different scenarios were assessed to determine the impact of the cost of CO_2 emissions (in the form of a CO_2 emission tax) and the credit from the incentives to the levelised cost of pulp (LCOP).

This covers incentives provided when recognising the biogenic emissions as CO_2 neutral or if captured as negative emissions. Similarly, the renewable electricity credit is also examined.

This study demonstrates the dynamics on how different financial incentives defined by the policy frameworks on CCS, renewable energy, and negative emissions could impact the levelised cost of the pulp.

Key Findings of the Study

In this work, the retrofit of post-combustion CO_2 capture process using MEA and a variant of a split flow configuration has been evaluated for two different reference mills:

- Base Case 1A – Market Kraft Pulp Mill
- Base Case 1B – Integrated Pulp and Board Mill

The performances of the entire pulp mill and the integrated pulp and board mill were evaluated to provide the detailed mass and energy balances of the different processes involved in the pulp (and board) production. The CO_2 capture and compression plant was assessed to determine the additional energy demand.

This section briefly describes the reference mills and the CO_2 capture and compression plant.

Reference Mills

The reference mills are assumed to have been built and commissioned in 2005. They are energy independent that produce significant amount of excess steam which are converted to electricity and exported to the grid. It is also assumed that the biomass (round wood - mainly consists of 50% pine and 50% spruce) used as raw materials has been harvested sustainably. Therefore, any electricity exported to the grid is considered as renewable energy. It should be noted that the mills evaluated in this study do not produce any district heating.

Figures 1 and 2 present the simplified block flow diagram of the market pulp mill and the integrated pulp and board mill.

The battery limit of the reference mills include the wood handling yard, the fibre line which consists of a continuous cooking plant (digester), brown stock handling and two-stage oxygen delignification, elemental chlorine-free bleaching (D_0-EOP-D_1-P), pulp drying, and the chemical recovery line which include the black liquor evaporator, recovery boiler, re-causticizing unit and the lime kiln. Other auxiliary units within the battery limit includes a multi-fuel boiler, a bleach chemical preparation plant, air separation unit, white liquor oxidation plant, steam turbine island and wastewater treatment plant. For Base Case 1B, a board machine is included.

The pulp mills (Base Cases 1A and 1B) consume about 5.8 m^3 of wood/adt. The fibres are extracted from the wood in the cooking plant and further refined in the O_2 delignification plant to produce the brown stock or the raw pulp. The yield from the cooking plant is about 47%. The pulp is (then) bleached based on the D_0-EOP-D_1-P procedure achieving a target brightness of 88.5%. The chemicals used in the bleaching process and the preparation of bleaching agents such as NaOH, O_2, H_2O_2, $NaClO_3$ and H_2SO_4 are imported into the battery limit. The process water used by the pulp mill is ~16 m^3/adt. The amount of waste water treated is about ~18 m^3/adt.

Table 2 summarizes the consumptions of the raw materials, chemicals and others. For Base Case 1B, the board machine imports unbleached and bleached softwood Kraft pulp (USKP and BSKP) from the pulp mill in addition to the heat and electricity it required. Also, it imports other pulps (i.e. Bleached Hardwood Kraft Pulp - BHKP and Chemi-Thermo Mechanical Pulp – CTMP), coating and fillers from outside the battery limit.

Tables 3 and 4 present the breakdown of the steam, electricity and fuel balance of both reference mills.

Fossil vs. Biogenic CO_2 Emissions

The total CO_2 emission from the reference mills is 2.1 million metric tonnes per year (MTPY). This includes both the biogenic and fossil derived emissions (as shown in Table 5).

Both the recovery boiler and the multi-fuel boiler are fired with black liquor and hog fuel (bark), respectively. Thus, these emissions are classified as biogenic CO_2 emissions.

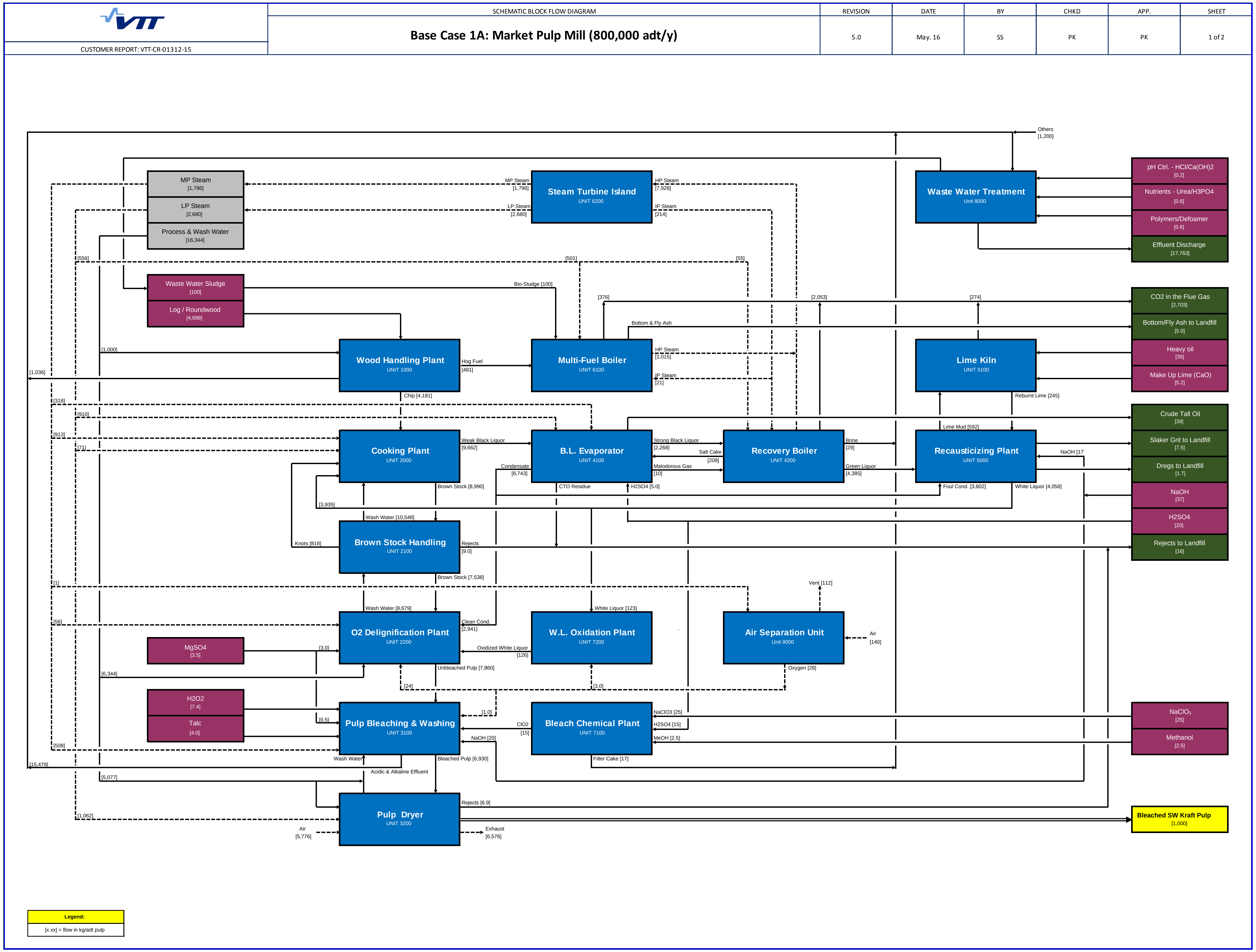

Figure 1: Block flow diagram of the market pulp mill (Base Case 1A)

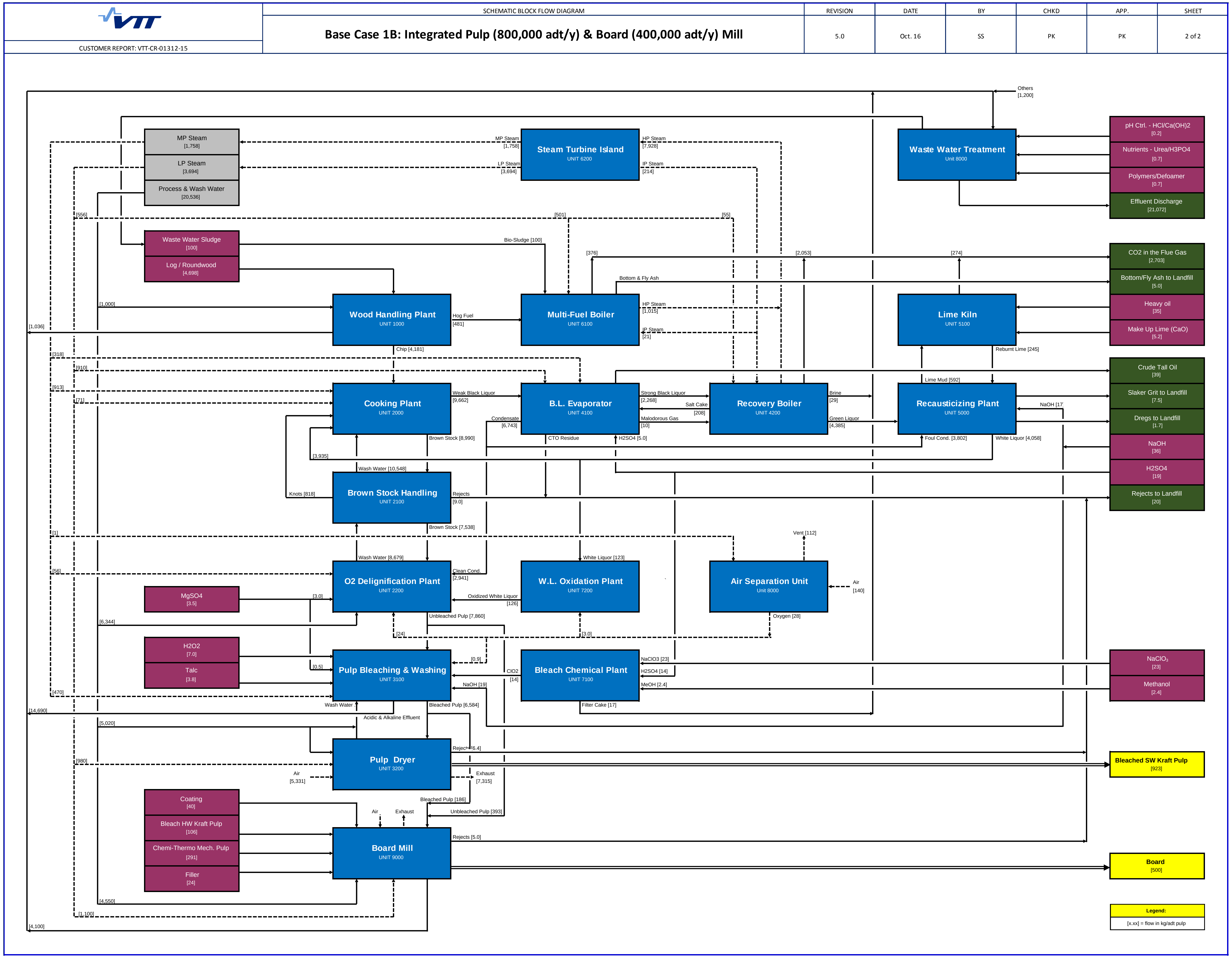

Figure 2: Block flow diagram of the integrated pulp and board mill (Base Case 1B)

Table 2: Summary of the mass balances of the reference mills without CCS indicating the raw materials and chemical consumptions and products

Raw Materials	Units*	Base Case 1A	Base Case 1B
Log (round wood)	[m^3/adt]	5.8	5.8
Bleached hardwood Kraft pulp (BHKP)	[kg/adt]	-	106.1
Chemi-thermo mechanical pulp (CTMP)	[kg/adt]	-	290.6
Filler	[kg/adt]	-	24.0
Coating	[kg/adt]	-	40.0
Chemicals			
NaOH	[kg/adt]	37.2	36.2
H_2O_2	[kg/adt]	7.4	7.0
$MgSO_4$	[kg/adt]	3.5	3.5
CaO	[kg/adt]	5.2	5.2
H_2SO_4	[kg/adt]	20.0	19.3
$NaClO_3$	[kg/adt]	24.5	23.3
Methanol	[kg/adt]	2.5	2.4
Talc	[kg/adt]	4.0	3.8
Products			
Market Pulp	[kg/adt]	1000.0	923.0
Board	[kg/adt]	-	500.0
Crude Tall Oil (CTO)	[kg/adt]	39.0	39.0
Energy			
HFO	[kg/adt]	35.0	35.0
Electricity Exported to Grid	[MWh/adt]	1127.2	666.0

* Basis of calculation – annual pulp production of 800,000 adt/y

Table 3: Summary of the Energy Usage of the Market Pulp Mill without CCS

Unit No.	Unit Name	Steam Consumption Note 1			Electricity Consumption	Fuel Consumption Note 2
		IP	MP	LP		
		[GJ/adt]			[kWh/adt]	[GJ/adt]
1000	Wood Handling Plant				44	
2000	Cooking Plant		1.800	0.151	43	
2100	Brown Stock Screening & Washing				58	
2200	Oxygen Delignification Plant		0.110		58	
3100	Pulp Bleaching		1.002		77	
3200	Pulp Drying			2.260	116	
4100	B.L. Evaporator		0.627	1.936	29	
4200	Kraft Recovery Boiler	0.346		1.066	58	31.07 Note 4
5000	Recausticising Plant				55	
5100	Lime kiln				incl. in Unit 5000	1.44 Note 5
6100	Multi-fuel boiler	0.038		0.117	29	9.86 Note 6
6200	Steam Turbine Island				(1369/398) Note 3	
7100	Bleach Chemical Plant			0.172	2	
7200	W. L. Oxidation Plant				2	
7300	Air Separation Unit		0.002		14	
8000	Waste Water Treatment				29	
0000	Mill Infrastructure / Off-sites				27	
	TOTAL	**0.384**	**3.541**	**5.703**	**641**	**42.37**

Notes:

[1] IP, MP and LP steam are available at 30 bar/352ºC, 13 bar/200ºC and 4.2 bar /154ºC, respectively. HP steam at 103 bar/505ºC is produced by the recovery boiler (REC) and the multi-fuel boiler (MFB). This is delivered to the steam turbine island

[2] Fuel consumption only covers the black liquor, hog fuel and HFO. Other combustibles burned in the REC and MFB such as non-condensable/malodorous gases, methanol, turpentine, bio-sludge and others are not included (but typically should only account for less than 0.5 GJ/adt).

[3] (X/Y) refers to the total electricity produced by the extraction (HP at 1369 kWh/adt) and condensing (LP at 398 kWh/adt) section of the steam turbine, respectively. The gross electricity production is at 1767 kWh/adt. The total electricity exported to the grid is at 1126 kWh/adt.

[4] Total fuel input of the concentrated black liquor (as fired basis)

[5] Total fuel input of the heavy fuel oil (as fired basis). This could also be referred to as the direct fuel consumption.

[6] Total fuel input of the hog fuel/bark (as fired basis).

Table 4: Summary of the Energy Usage of the Integrated Pulp & Board Mill without CCS

Unit No.	Unit Name	Steam Consumption Note 1			Electricity Consumption	Fuel Consumption Note 2
		IP	MP	LP		
		[GJ/adt]			[kWh/adt]	[GJ/adt]
1000	Wood Handling Plant				44	
2000	Cooking Plant		1.800	0.151	43	
2100	Brown Stock Screening & Washing				58	
2200	Oxygen Delignification Plant		0.110		58	
3100	Pulp Bleaching		0.927		73	
3200	Pulp Drying			2.085	107	
4100	B.L. Evaporator		0.627	1.936	29	
4200	Kraft Recovery Boiler	0.346		1.066	58	31.07 Note 4
5000	Recausticising Plant				55	
5100	Lime kiln				incl. in Unit 5000	1.44 Note 5
6100	Multi-fuel boiler	0.038		0.117	29	9.86 Note 6
6200	Steam Turbine Island				(1371/285) Note 3	
7100	Bleach Chemical Plant			0.163	2	
7200	W. L. Oxidation Plant				2	
7300	Air Separation Unit		0.002		14	
8000	Waste Water Treatment				36	
9000	Board Mill			2.341	350	
0000	Mill Infrastructure / Off-sites				33	
TOTAL		**0.384**	**3.466**	**7.860**	**984**	**42.37**

*Notes: See Notes of Table 3

Table 5: Breakdown of CO_2 emissions from the reference pulp mills

	Unit	Recovery boiler	Multi-fuel boiler	Lime kiln
Biogenic CO_2	[MTPY]	1 642 400	300 800	132 554
Fossil CO_2	[MTPY]	-	-	86 582
Total CO_2	[MTPY]	1 642 400	300 800	219 136

Only the lime kiln is fired with fossil fuel, and in this case, heavy fuel oil (HFO). Therefore, the CO_2 derived from combustion related reactions is the only source of fossil CO_2 emissions from the reference mills. On the other hand, the CO_2 derived from the process related reactions (i.e. calcination of lime mud, see Eq. 5) are considered as biogenic CO_2 emissions.

The chemical reactions presented in Equations 1 to 8 show the simplified pathway of the carbon during the chemical recovery cycle which should explain why the process related CO_2 emissions from the lime kiln are to be classified as biogenic CO_2 emissions.

Wood chips + $NaOH$ + Na_2S → Fibre + Black liquor (digester) [1]
Organic matter in black liquor + $O_2 \rightarrow CO_2 + H_2O$ (recovery boiler) [2]
$Na_2SO_4 + 2\ C \rightarrow Na_2S + 2\ CO_2$ (recovery boiler) [3]
$Na_2SO_4 + 4\ C \rightarrow Na_2S + 2CO$ (recovery boiler) [4]
$2\ NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$ (recovery boiler) [5]
$Na_2CO_3 + Ca(OH)_2 \rightarrow 2\ NaOH + CaCO_3$ (re-causticizing) [6]
$CaCO_3 \rightarrow CaO + CO_2$ (lime kiln) [7]
$CaO + H_2O \rightarrow Ca(OH)_2$ (slaker unit) [8]

It could be illustrated, that the majority of the carbon bound in the lime mud is originally derived from the organic matter of the black liquor and with some CO_2 produced from the reactions between inorganic compounds and the carbon bound in the char. During combustion of the black liquor, some of the smelts would react with the biogenic CO_2 to form Na_2CO_3 (as shown in Eq. 5). This is then converted to NaOH by the $Ca(OH)_2$ in the re-causticizing unit to form $CaCO_3$. During the calcination of $CaCO_3$ in the lime kiln, the carbon bound in the $CaCO_3$ is released as process related CO_2 emissions. This should be classified as biogenic CO_2 emissions. Around 60 wt.-% of the CO_2 from the lime kiln originates from process related reactions and 39 wt.-% originates from combustion related reactions. Fossil CO_2 emissions originating from make-up lime is 1% of total CO_2 emissions.

Capture of CO_2 from the Reference Mills

Figure 3 presents the simplified block flow diagram of the CO_2 capture plant excluding CO_2 compression train.

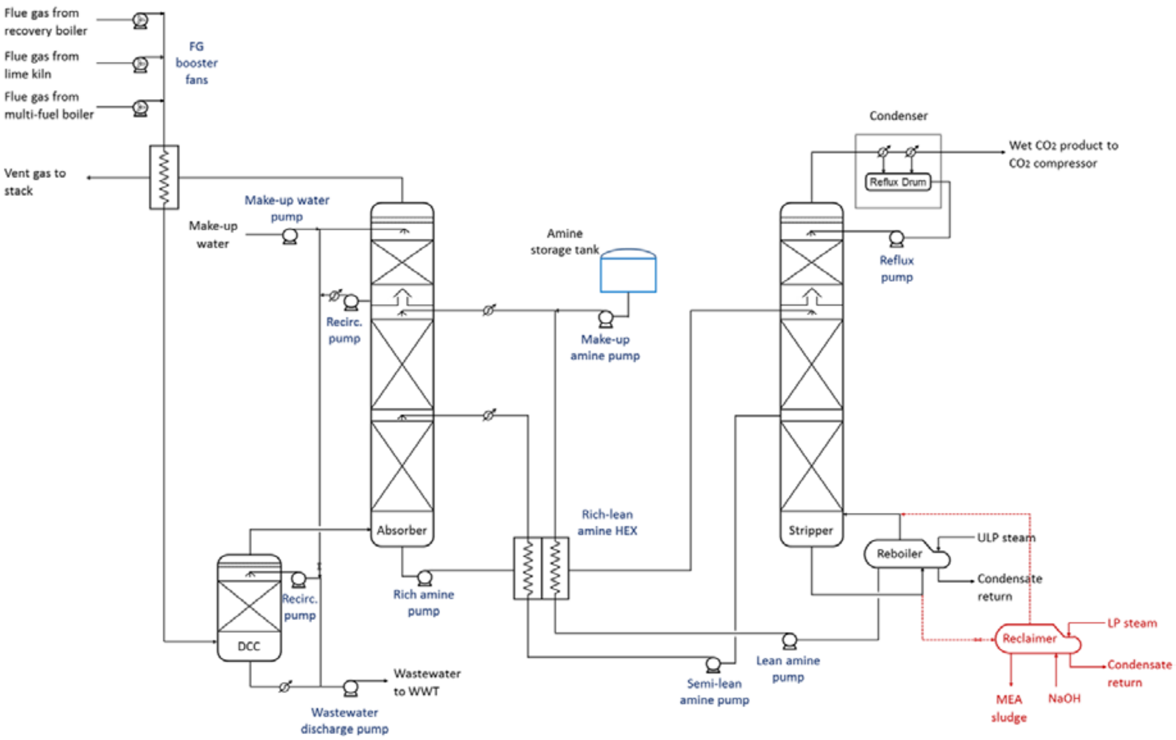

Figure 3: Simplified block flow diagram of the post-combustion CO_2 capture plant

HEX = heat exchanger, FG = flue gas, DCC = direct contact cooler, ULP = ultra-low pressure, LP = low pressure, WWT = wastewater treatment, MEA = mono-ethanolamine solvent

The CO_2 capture plant is based on chemical absorption of CO_2 from flue gases using 30% monoethanol amine (MEA) as a solvent with stripping of CO_2 in the regeneration column. The plant is designed based on a variant of a split flow configuration. This is aimed to achieve a reduction in energy consumption (as compared to the conventional post-combustion CO_2 capture configuration).

90% of the CO_2 is captured from the flue gas to be treated. For cases where multiple flue gas sources are treated, it was assumed that the flue gases are mixed and sent to a single CO_2 absorber. The retrofit of the CO_2 capture is assumed to go on-line ten years after the reference mills are commissioned.

The heat required by the regeneration of the solvent is supplied by the reboiler. This utilises Ultra Low Pressure (ULP) steam at 2 bar (saturated) generated by extracting and de-superheating LP steam from the existing steam turbine island. This is described in the next section.

Steam Supply to the Stripper Reboiler

In this study, three different configurations were explored for the modification of the steam turbine island to meet the additional steam and electricity demand of the CO_2 capture and compression plant:

- Configuration I (all cases except 2A-6^{MP}, 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP}, 2B-6^{CO2MP})
  Extraction of LP steam (at 4.2 bar(a)/154^{o}C) and de-superheated to ULP steam at 2 bar(a) saturated. The CO_2 compressor train is electrically driven.

- Configuration II (for case 2A-6^{MP})
  Extraction of MP steam (at 13.0 bar(a)/200^{o}C) and de-superheated to 2.0 bar(a) steam. The CO_2 compressor train is electrically driven

- Configuration III (for cases 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP}, 2B-6^{CO2MP})
  Use of back pressure steam turbine driven CO_2 compressor. This will be driven by extracting MP steam (at 13 bar(a)/200^{o}C) from the mill's steam turbine and supplemented by the MP steam supplied by the auxiliary boiler. The ULP steam (at 2 bar(a)/120^{o}C) required by the stripper reboiler will be derived from the ULP steam produced from the back pressure steam turbine (driving the CO_2 compressor) and complimented by the extraction and de-superheating of LP steam (at 4.2 bar(a)/154^{o}C) from the mill's steam turbine island.

For cases where the excess energy production on-site is not sufficient to meet the additional demand of the CO_2 capture plant, an auxiliary boiler will be deployed. In this case, a bubbling fluidized bed (BFB) boiler will be used. The boiler will be firing waste wood or forest residues which could be supplied by the forest industry within the vicinity of the mill. The boiler will produce steam at 13 bar(a)/200^{o}C –the same steam conditions as the existing MP steam network of the mill.

Figures 4 to 6 present the simplified block flow diagram of the three configurations evaluated in this study.

CO_2 Compression and Dehydration Unit

A four stage CO_2 compression train is used to compress the CO_2 product. After each compression stage, a knock-out drum separates any water that condenses out from the wet gas. After the third compression stage, the gas is dehydrated by a molecular sieve dryer. CO_2 exiting the last compression stage is sent to a liquid CO_2 pump for final pressurization.

The simplified block flow diagram of the CO_2 compression and dehydration train is presented in Figures 7 and 8. The molecular sieve is regenerated by recycling and heating part of the dried CO_2 product. The regeneration gas is then return to the first stage compressor.

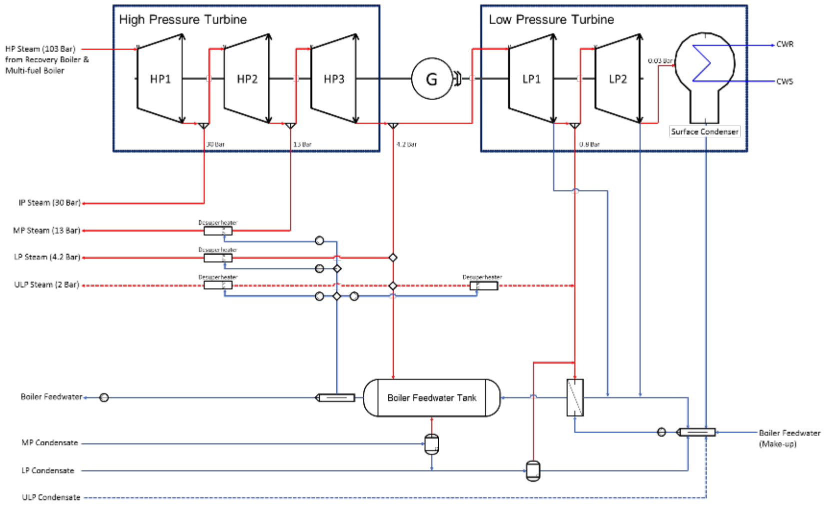

Figure 4: Simplified block flow diagram of the steam turbine island (Configuration I)

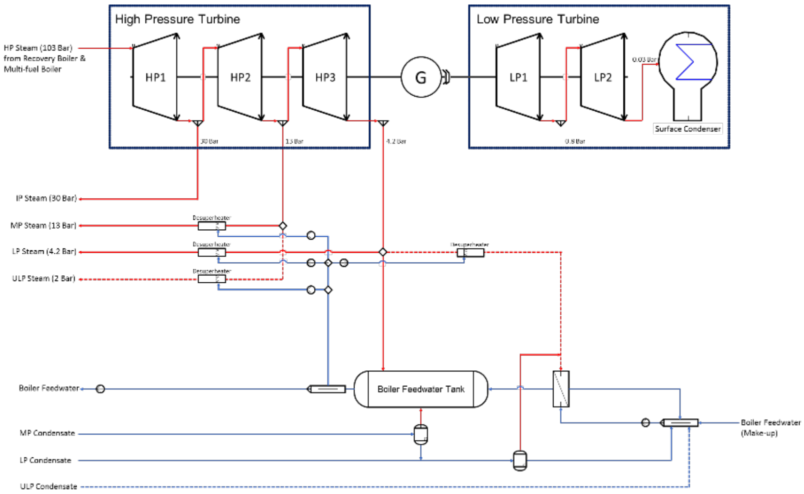

Figure 5: Simplified block flow diagram of the steam turbine island (Configuration II)

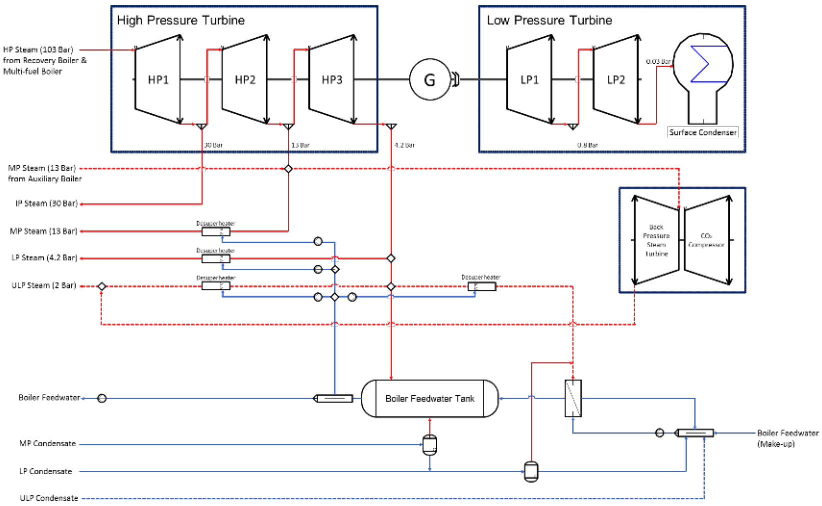

Figure 6: Simplified block flow diagram of the steam turbine island (Configuration III)

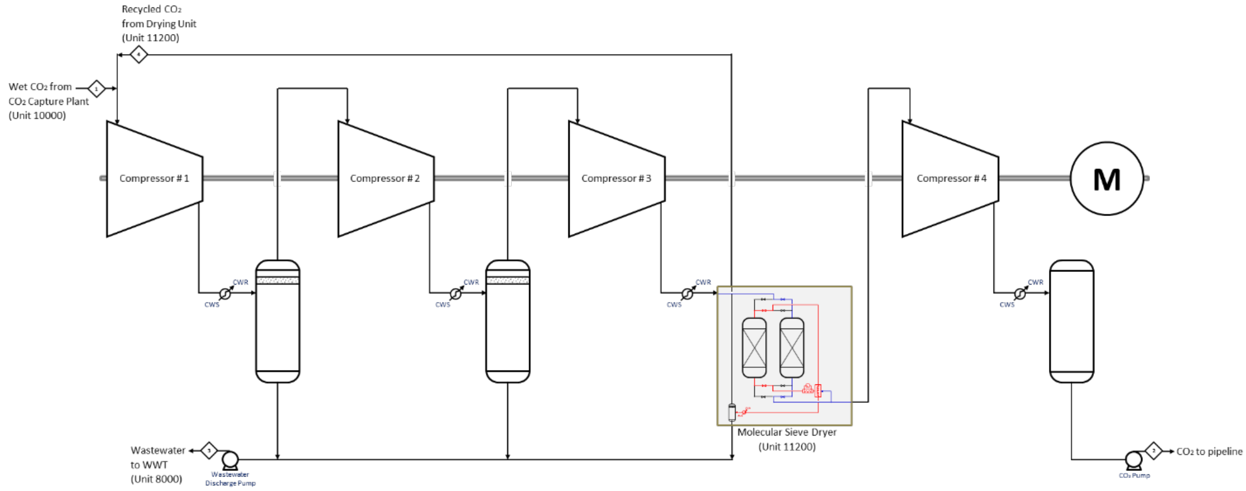

Figure 7: Simplified block flow diagram of the CO_2 compression train for all cases except cases 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP} and 2B-6^{CO2MP}

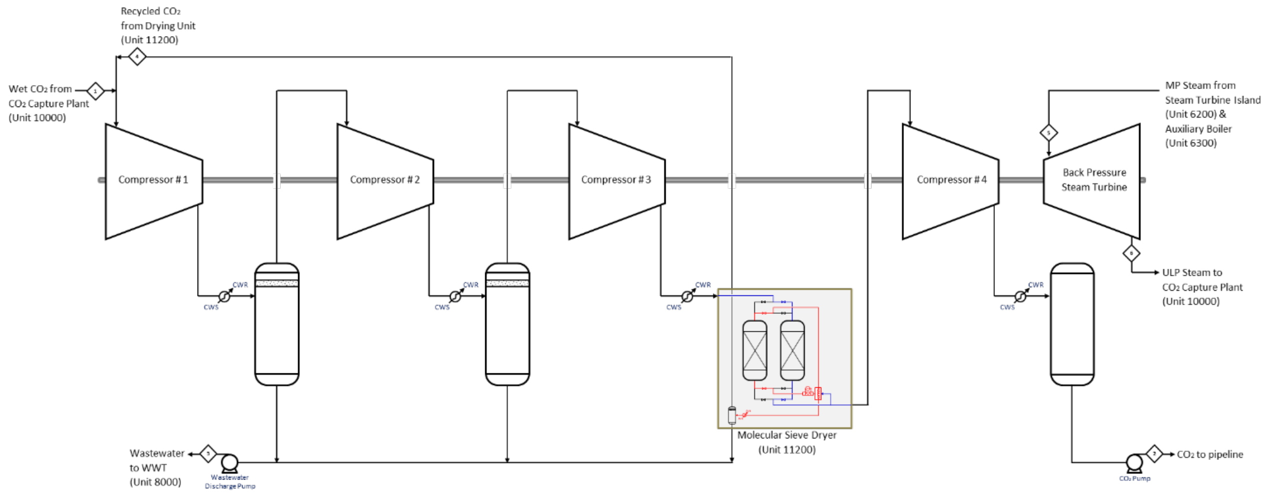

Figure 8: Simplified block flow diagram of the CO_2 compression train for cases 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP} and 2B-6^{CO2MP}

Performance of the Mills with CCS

Table 6 summarizes the steam and electricity balances when retrofitting CO_2 capture plant to an existing Kraft pulp mill (Base case 1A) and an integrated pulp and board mill (Base case 1B).

The results clearly illustrate that any retrofit of CO_2 capture involving the recovery boiler would require significant amount of steam to meet the demand of the CO_2 capture plant. In several cases, this would also require the addition of an auxiliary boiler to supplement the steam supply. This is due to the much larger volume of flue gas to be treated, thus resulting in a higher CO_2 capture rate.

Table 6 Steam and electricity balance when retrofitting a Kraft pulp mill and Kraft pulp and board mill with CCS

	Base Case	Pulp mill with CCS						Base Case	Integrated pulp and board mill with CCS					
	1A	2A-1	2A-2	2-A3	2A-4	2A-5	2A-6 MP	1B	2B-1 CO2MP	2B-2	2-B3	2B-4 CO2MP	2B-5 CO2MP	2B-6 CO2MP
Steam Demand														
Pulp Mill														
Steam 30 bar [t/h]	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
Steam 13 bar [t/h]	171.0	171.0	171.0	171.0	171.0	171.0	171.0	167.3	167.3	167.3	167.3	167.3	167.3	167.3
Steam 4.2 bar [t/h]	255.2	255.2	255.2	255.2	255.2	255.2	255.2	351.8	351.8	351.8	351.8	351.8	351.8	351.8
CCS Plant														
Steam 13 bar [t/h]	-	-	-	-	-	-	-	-	189.5[b]	-	-	223.9[b]	213.2[b]	247.6[b]
Steam 4.2 bar [t/h]	-	0.9	0.2	0.1	1.1	1.1	1.3	-	0.9	0.2	0.1	1.1	1.1	1.3
Steam 2.0 bar [t/h]	-	255.8	45.2	31.0	289.3	284.2	335.3[a]	-	255.8	45.2	31.0	289.3	284.2	335.3
Auxiliary Boiler														
Steam 30 bar [t/h]	-	-	-	-	-	-	-	-	1.5	-	-	2.3	2.2	3.4
Steam 4.2 bar [t/h]	-	-	-	-	-	-	-	-	2.7	-	-	4.3	4.1	6.5
Steam Supply														
Ex: Steam turbine														
Steam 30 bar [t/h]	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	21.7	20.4	20.4	22.5	22.4	23.5
Steam 13 bar [t/h]	171.0	171.0	171.0	171.0	171.0	171.0	171.0	167.4	292.0	167.4	167.4	290.4	285.2	263.2
Steam 4.2 bar [t/h]	255.2	256.2	255.4	255.3	256.3	256.3	256.5	351.8	355.4	351.9	351.9	357.1	356.8	359.4
Steam 2 bar [t/h]	-	255.8	45.2	31.0	289.3	284.2	335.3	-	66.3	45.2	31.0	65.3	71.0	87.8
Ex: Auxiliary boiler														
Steam 13 bar [t/h]	-	-	-	-	-	-	-	-	64.9	-	-	100.9	95.4	151.9
Ex: Back-pressure steam turbine														
Steam 2 bar [t/h]	-	-	-	-	-	-	-	-	189.5			224.0	213.2	247.6

Electricity Demand														
Pulp mill [MWe]	61.0	61.0	61.0	61.0	61.0	61.0	61.0	94.3	94.3	94.3	94.3	94.3	94.3	94.3
CCS Plant [MWe]	-	23.5	4.4	2.8	28.5	26.9	31.4	-	7.8	4.4	2.8	9.9	9.2	10.9
Auxiliary boiler [MWe]	-	-	-	-	-	-	-	-	1.6	-	-	2.4	2.3	3.7
Total [MWe]	**61.0**	**84.5**	**65.4**	**63.8**	**89.5**	**87.9**	**92.4**	**94.3**	**103.6**	**98.7**	**97.1**	**106.6**	**105.8**	**108.9**
Electricity Supply														
Ex: Steam turbine														
HP section [MWe]	130.4	130.4	130.4	130.4	130.4	130.4	113.7	130.6	124.2	130.6	130.6	124.5	124.5	127.3
LP section [MWe]	37.9	7.7	33.0	34.7	-	4.3	-	27.1	-	21.8	23.5	-	-	-
Total [MW$_e$]	**168.3**	**138.1**	**163.4**	**165.1**	**130.4**	**134.7**	**113.7**	**157.7**	124.2	**152.4**	**154.1**	124.5	124.5	127.3
Electricity export to the grid [MW$_e$]	**107.3**	**53.6**	**98.0**	**101.3**	**40.9**	**46.8**	**21.3**	**63.4**	**20.6**	**53.7**	**57.0**	**17.9**	**18.7**	**18.4**
Electricity export to the grid [MWh/adt]	**1.13**	**0.56**	**1.03**	**1.06**	**0.43**	**0.49**	**0.22**	**0.67**	**0.24**	**0.56**	**0.60**	**0.21**	**0.22**	**0.22**

[a] For case 2A-6 MP steam at 13.0 bar(a) is de-superheated to ULP steam at 2.0 bar(a) and the mass flow is incorporated in the ULP steam demand to the CCS plant.
[b] For the CO2MP cases MP steam at 13 bar(a) from the auxiliary boiler is fed directly to the CO_2 compression train (compliment with the MP steam from the steam turbine island).

For all the cases involving the retrofit of CCS in a market (standalone) pulp mill (except for case 2A-6^{MP}), the excess LP steam at 4.2 bar(a) produced by the steam turbine island should be sufficient to satisfy the steam demand of the CO_2 capture plant. In case 2A-6^{MP} (where CO_2 is captured from the flue gases of the REC, MFB and LK), the excess LP steam is not sufficient for the CO_2 capture plant. Therefore, MP steam at 13.0 bar(a) is used instead, and this is de-superheated to ULP steam at 2 bar(a).

For any cases which include the capture of CO_2 from the flue gas of the recovery boiler, the steam demand increases significantly and consequently, the net electricity export to the grid has been reduced due to the retrofit of CCS. The increase in steam demand ranges from 5.9 GJ/adt (for Case 2A-1) to 6.7 GJ/adt (for Case 2A-5) and 7.8 GJ/adt for Case 2A-6^{MP} and the reduction in the amount of electricity exported to the grid ranges from 53.7 MW_e (for Case 2A-1) to 70.2 MW_e (for Case 2A-4) and 86.0 MW_e for the MP case 2A-6^{MP}.

For cases where the CO_2 is captured from the flue gas of the multi-fuel boiler or lime kiln alone, the amount of steam required by the CO_2 capture plant should be significantly less. Consequently, would only reduce the exported electricity to the grid by around 9.3 MWe or 0.1 MWh/adt (for Case 2A-2).

Table 9 also illustrates that the amount of steam supplied by the recovery boiler and multi-fuel boiler should be identical for both reference mills - given that the integrated mill (base case 1B) is producing the same amount of pulp as compared to the standalone pulp mill (base case 1A). However, in these cases, the amount of excess LP steam available for the CO_2 capture plant is lesser (by ~96 t/h or ~2.1 GJ/adt) due to the additional demand by the board mill. Consequently, this should also reduce the volume of electricity exported to the grid by ~44 MWe or 0.46 MWh/adt.

Therefore, for cases involving the retrofit of CCS to an integrated pulp and board mill, it could be assumed that the excess steam available on-site is only sufficient to cover cases where CO_2 is captured from the multi-fuel boiler or lime kiln only. All cases involving the capture of 90% CO_2 from flue gas of the recovery boiler would require the addition of auxiliary boiler to supplement the steam supply.

In this study, for cases involving the retrofit of CCS in an integrated pulp and board mill and the capture of CO_2 from recovery boiler, it was concluded that the use of a steam turbine driven CO_2 compressor (configuration III, see Figure 6) is the optimum way to meet the extra demand of the steam by CCS plant and at same time maximize the electricity production of the existing steam turbine. If configuration II (Figure 5) is used and the steam supply is to be supplemented by the auxiliary boiler, it would results to an integrated mill with CCS requiring to import electricity from the grid.

For cases involving the retrofit of CCS to an integrated pulp and board mill and capturing CO_2 from the flue gas of the recovery boiler (i.e. for cases 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP} and 2B-6^{CO2MP}), the amount of electricity exported to the grid is significantly reduced from 63.4 MWe (base case 1B) down to 18.4 MWe (for case 2B-6^{CO2MP}) to 20.4 MWe (for case 2B-1^{CO2MP}).

CO_2 Emissions – Mills with CCS

Table 7 summarizes the CO_2 emissions of the mills with CCS based on a production capacity of 800,000 adt of softwood Kraft pulp annually and how these emissions are classified in this study.

Table 7: CO_2 emissions from the reference cases.
The CO_2 emissions are identical for both base cases 1A and 1B

Case	Case description	Total emissions (whole Site) [MTPY]	Biogenic based CO_2 emissions [MTPY]	Fossil based CO_2 emissions[1] [MTPY]	Total CO_2 captured [MTPY]	Overall CO_2 capture rate[2] %
Market pulp mill with CCS						
Case 2A-1	Recovery Boiler (REC) only	683,636	597,054	86,582	1,478,700	68.4%
Case 2A-2	Multi-fuel Boiler (MFB) only	1,891,678	1,805,097	86,582	270,658	12.5%
Case 2A-3	Lime Kiln (LK) only	1,965,328	1,965,328	-	197,008	9.1%
Case 2A-4	REC + MFB	412,736	326,155	86,582	1,749,600	80.9%
Case 2A-5	REC + LK	486,414	486,414	-	1,675,922	77.5%
Case 2A-6[MP]	All 3 (REC + MFB + LK)	215,761	215,761	-	1,946,575	90.0%
Integrated pulp & board mill with CCS						
Case 2B-1[CO2MP]	Recovery Boiler (REC) only	833,005	746,423	86,582	1,478,700	64.0%
Case 2B-2	Multi-fuel Boiler (MFB) only	1,891,678	1,805,097	86,582	270,658	12.5%
Case 2B-3	Lime Kiln (LK) only	1,965,328	1,965,328	-	197,008	9.1%
Case 2B-4[CO2MP]	REC + MFB	644,832	558,251	86,582	1,749,600	73.1%
Case 2B-5[CO2MP]	REC + LK	705,871	705,871	-	1,675,922	70.4%
Case 2B-6[CO2MP]	All 3 (REC + MFB + LK)	564,807	564,807	-	1,946,575	77.5%

[1] Emissions from the mill with CO_2 capture from the lime kiln has been calculated assuming that all fossil CO_2 is captured first before any biogenic CO_2 is captured.
[2] Overall CO_2 capture rate is calculated as total CO_2 captured / total CO_2 Emissions (without capture) of the recovery boiler, multi-fuel boiler, lime kiln and auxiliary boiler

Amount of CO_2 Avoided

Due to the fact that any biogenic emissions from the pulp mill could be considered as CO_2 neutral if emitted or CO_2 negative if captured, the amount of CO_2 avoided could be calculated depending on the accounting of the emitted and captured biogenic CO_2.

Without considering the biogenic CO_2 emissions from the pulp mill, the calculation of the amount of CO_2 Avoided is very straightforward – i.e. this should be similar to how the CO_2 avoided is calculated in other applications:

$$CO_2 \text{ Avoided} = CO_2 \text{ Emissions}_{\text{Ref. Mill}} - CO_2 \text{ Emissions}_{\text{Mill with CCS}} \quad [7]$$

However, with the consideration of the biogenic CO_2 emissions, the CO_2 Avoided should only consider the fossil based CO_2 emissions of the plant and the amount of biogenic CO_2 emissions captured and stored. The amount of CO_2 avoided in this case is calculated as:

$$CO_2 \text{ Avoided} = \text{Fossil } CO_2 \text{ Emissions}_{\text{Ref. Mill}} - (\text{Fossil } CO_2 \text{ Emissions} - \text{Captured Biogenic } CO_2)_{\text{Mill with CCS}} \quad [8]$$

The difference between the answers when calculating the amount of CO_2 avoided using Eq. 7 and Eq. 8 mainly depends on how the treatment to the emitted biogenic CO_2 is accounted for. For example, if the CO_2 reduction credit due to CCS is first allocated to reduce the Fossil CO_2 emissions and all the biogenic CO_2 emissions are accounted as CO_2 neutral, then both equations should give the same answers.

Nonetheless, when considering the level of CO_2 avoided as compared to the reference mill (in terms of $\%CO_2$ avoided):

$$\%CO_2 \text{ avoided} = 100\% \times \frac{CO_2 \text{ Emissions}_{\text{Ref. Mill}} - CO_2 \text{ Emissions}_{\text{Mill with CCS}}}{CO_2 \text{ Emissions}_{\text{Ref. Mill}}} \quad [9]$$

or

$$\%CO_2 \text{ avoided} = 100\% \times \frac{\text{Fossil } CO_2 \text{ Emissions}_{\text{Ref. Mill}} - (\text{Fossil } CO_2 \text{ Emissions} - \text{Captured Biogenic } CO_2)_{\text{Mill with CCS}}}{\text{Fossil } CO_2 \text{ Emissions}_{\text{Ref. Mill}}} \quad [10]$$

The later equation is expected to provide a higher number in terms of $\%CO_2$ avoided. These are illustrated in Tables 8 and 9.

Table 8: $\%CO_2$ avoided for pulp mill with CCS with and without the consideration of "Negative CO_2 Emission"

	Specific CO_2 Captured (t of captured CO_2 / adt of pulp)*	Specific CO_2 Avoided (t of avoided CO_2 / adt of pulp)*	% CO_2 Avoided	
			Actual**	with considerations for captured biogenic CO_2 as negative emissions***
Case 2A-1	1.848	1.848	68%	1707%
Case 2A-2	0.338	0.338	13%	313%
Case 2A-3	0.246	0.246	9%	228%
Case 2A-4	2.187	2.187	81%	2021%
Case 2A-5	2.095	2.095	78%	1936%
Case 2A-6[MP]	2.433	2.433	90%	2248%

* calculated based on 800,000 adt of bleached softwood Kraft pulp (BSKP)
** $\%CO_2$ avoided calculated based on Eq. 9.
** $\%CO_2$ avoided calculated based on Eq. 10.

Table 9: $\%CO_2$ avoided for integrated pulp and board mill with CCS with and without the consideration of "Negative CO_2 Emission"

	Specific CO_2 Captured (t of captured CO_2 / adt of pulp)*	Specific CO_2 Avoided (t of avoided CO_2 / adt of pulp)*	% CO_2 Avoided	
			Actual**	with considerations for captured biogenic CO_2 as negative emissions***
Case 2B-1[CO2MP]	1.848	1.662	61%	1707%
Case 2B-2	0.338	0.338	13%	313%
Case 2B-3	0.246	0.246	9%	228%
Case 2B-4[CO2MP]	2.187	1.897	70%	2021%
Case 2B-5[CO2MP]	2.095	1.821	67%	1936%
Case 2B-6[CO2MP]	2.433	1.997	73%	2248%

* calculated based on 800,000 adt of bleached softwood Kraft pulp (BSKP)
** $\%CO_2$ avoided calculated based on Eq. 9.
** $\%CO_2$ avoided calculated based on Eq. 10.

Economic Assessment

The cost estimates were derived in accordance with IEAGHG's standard practise for estimating the cost of the plant without and with CCS.

The cost of pulp production without and with CCS were estimated based on IEAGHG's standard assessment criteria with other assumptions adapted to accommodate the conditions of the location of the pulp mill.

The results of the economic evaluation are reported based on Earnings Before Interest, Taxes, Depreciation and Amortisation (EBITDA). The calculation of the cost of production include the investment cost of the mill and the CO_2 capture plant, the fixed operating costs (labour, maintenance and others), variable operating costs (raw-materials, chemicals, utilities, waste and logistics) and revenues (pulp, crude tall-oil and electricity). Based on the Discounted Cash Flow (DCF) analysis, the levelised cost of the pulp and board production (break-even price of pulp and board) are estimated by setting the net present value (NPV) = 0.

In this study, the following assumptions were used in the economic evaluation of the pulp mill:

- The mill is situated in a brownfield site located in the coastal area of Finland.
- The annual operating hours of the mill is 8400 h/y.
- The capture of CO_2 from the mill's different flue gases started on its 10th year of operation.
- Heavy fuel oil is imported from outside the battery limit. The mill has no access to the natural gas pipeline.
- Seawater cooling is assumed.
- Utilities are assumed not to be included in the Battery Limit. As such, the cost of cooling water, process water, condensates, and boiler feed water are charged as OPEX items.
- Discount rate: 8% (constant money values)
- Operating life: 25 years
- Construction time: 3 years for the pulp mill. 2 years for the CO_2 capture plant (started on the 8th year of mill's operation).
- Cost is estimated based on Euro (4Q 2015). Whereas if needed, the exchange rates used in this study is set at €1.00 = US$1.10.
- CO_2 transport and storage cost: 10 €/t stored
- Co-products such as electricity and CTO are sold at 40 €/MWh and 500 €/t respectively

The capital cost is presented as the Total Plant Cost (TPC) and the Total Capital Requirement (TCR).

TPC is defined as the total installed cost of the plant including a project contingency of 10%. For all of the cases the TPC has been determined through a combination of the use of cost database gathered in-house by VTT and ÅF Consult Oy, and quotes from vendors if required. The costs are reported as budgetary quote on a Plant Turnkey Estimate basis. The estimated TPC of the mill is based on the equipment cost reported in the year 2005 and the investment cost of the CO_2 capture plant is estimated based on the equipment cost reported in the year 2015.

TCR is defined as the sum of: total plant cost (TPC), spare parts cost, start-up cost, owner's cost, working capital, and interest during construction. These are estimated mainly as percentages of other cost estimates in the plant.

Table 10 presents the Total Plant Cost of the Reference Mills. Tables 11 and 12 present the total plant cost and total capital requirements of the pulp mills and integrated mills without and with CCS.

Table 10: Total plant cost – pulp (and board) mill with 800,000 adt/y annual production capacity

Unit	Description	Key Components	Nominal Capacity	Total CAPEX (MEUR 2005)	
				Base Case 1A	Base Case 1B
0000	Mill infrastructure		800000 adt/y (1A) 1140000 adt/y (1B)	67	82
1000	Wood handling	• Wood storage • De-icing • Debarking lines • Chipping lines • Knife grinder • Chip storage with chip piles • Screening lines • Related conveyors	943 m^3/h	53	53
2000	Cooking plant	• Chip bin • Impregnation vessel • Continuous digester • Blow line • Re-boiler • Turpentine recovery system	2795 adt/d	107	107
2100	Brown stock handling	• Diffuser washer • DD-washer • De-knotting • Screening		Included in Unit 2000	Included in Unit 2000
2200	Oxygen delignification	• 2-stage oxygen delignification • Two DD-washers		Included in Unit 2000	Included in Unit 2000
3100	Pulp bleaching and washing	• D_0-Eop-D_1-P stages • Four DD-washers	2667 adt/d	49	48
3200	Pulp dryer	• Screening and cleaning • Dilution head box • Twin-wire former • Combi-press with shoe-press • Airborne dryer • Cutting • Baling	2824 adt/d (1A) 2612 adt/d (1B)	112	107
4100	Black Liquor evaporation	• 7-stage evaporation • Malodorous gas collection • tall-oil plant	804 t_{H2O}/h	48	48
4200	Kraft recovery boiler	• Recovery boiler • Electrostatic precipitators • Flue gas stack • Boiler feed water plant • Condensate treatment • Ash leaching plant.	4985 t_{ds}/d	160	160
5000	recausticising plant	• Green liquor filtering • Dregss washing • Slaker • Re-causticizers • White liquor filtering	11120 $m^3{}_{WL}/d$	49	49
5100	Lime Kiln	• Lime dewatering unit • Lime mud dryer • Lime kiln • Lime cooler • ESP filters	t_{CaO}/d	Included in Unit 5000	Included in Unit 5000
6100	Multi-fuel boiler	• FB boiler • Electrostatic precipitators • Flue gas stack	82 MW_{th}	56	56
6200	Steam turbine Island	• Extraction / back pressure turbine • Condensing turbine • Generator set	187 MW_e (1A) 175 MW_e (1B)	51	49
7100	Bleach chemical plant	• Reactor • Heat exchanger • Absorber • Salt cake washer	34 t ClO_2/d (1A) 32 t ClO_2/d (1B)	14	13
7200	White liquor oxidation			Included in Unit 7100	Included in Unit 7100
7300	Air separation unit	• Process Air Pre-treatment Unit • Main Air Compressor • Cold box • Product O_2 compression	64 t/d	8	8
8000	Waste water treatment	• Mechanical treatment • Active sludge treatment	49000 m^3/d (1A) 57000 m^3/d (1B)	25	27
9000	Board Mill	• Board Machine	400,000 adt/y (1B)	-	136

Total	**€ 799 million**	**€ 943 million**

Table 11: Total Capital Requirement – Pulp Mill without and with CCS (800,000 adt/y of pulp - annual production)

	Total Plant Cost - Pulp Mill / Changes to Mill (for CCS Cases) (million €)	Total Plant Cost - CO_2 Capture Plant (million €)	Total Plant Cost CO_2 Compression (million €)	Project Contingency (million €)	Total Plant Cost - TPC (million €)	Total Capital Requirement - TCR (million €)
Base Case 1A	798.50	-	-	79.85	878.35	1,341.50
Case 2A-1	10.55	227.92	14.48	25.29	278.24	355.44
Case 2A-2	9.81	61.67	3.93	7.54	82.95	105.59
Case 2A-3	9.54	36.10	2.30	4.79	52.73	67.17
Case 2A-4	11.95	253.09	16.08	28.11	309.23	395.22
Case 2A-5	11.78	239.31	15.20	26.63	292.92	374.38
Case 2A-6[MP]	15.21	264.01	16.77	29.60	325.58	416.61

Table 12: Total Capital Requirement – Integrated Pulp and Board Mill without and with CCS (400,000 adt/y of board - annual production)

	Total Plant Cost - Pulp Mill / Changes to Mill (for CCS Cases) (million €)	Total Plant Cost - CO_2 Capture Plant (million €)	Total Plant Cost CO_2 Compression (million €)	Project Contingency (million €)	Total Plant Cost - TPC (million €)	Total Capital Requirement - TCR (million €)
Base Case 1B	942.60	-	-	94.26	1036.86	1592.17
Case 2B-1[CO2MP]	35.53	227.92	28.95	29.24	321.64	412.99
Case 2B-2	9.89	61.67	3.93	7.55	83.03	105.70
Case 2B-3	9.61	36.10	2.30	4.80	52.81	67.21
Case 2B-4 [CO2MP]	47.93	253.09	32.15	33.32	366.49	471.00
Case 2B-5 [CO2MP]	46.76	239.31	30.40	31.65	348.12	447.40
Case 2B-6[CO2MP]	53.17	264.01	33.54	35.07	385.78	496.69

The TCR of the mills without CO_2 capture (Base Case) includes the following:

- 1% of TPC to cover the spare parts
- Start-up cost which includes:
    - 2% of TPC to cover the start-up CAPEX
    - 2.1% of annual fuel bill to cover additional fuel cost during start-up
    - 25% of annual operating expense (O&M, Fuel and Raw Materials)
    - 8.3% of chemicals cost
- 7% owner's cost
- 8% interest during construction
- Working capital which covers 30 days of feedstock, fuel and other raw materials, and 15 days of finished products.

The TCR for the retrofit of the Pulp Mill or Integrated Pulp and Board Mill with CO_2 Capture includes the following:

- 1% of TPC to cover the spare parts
- 3% of TPC to cover the start-up cost (including all the start-up CAPEX and OPEX)
- 7% owner's cost
- 8% interest during construction
- Additional working capital covering the inventories of the MEA and the make-up solvent

The OPEX of the plant include the fixed and variable operating cost. The fixed cost consists of the direct and indirect labour cost, annual maintenance cost, other fixed costs which included local taxes, insurance and others.

The variable operating cost are estimated based on the price of the raw materials, chemicals, utilities, waste disposal charges, product logistics, and revenues from the co-product and electricity sold to the grid.

Table 13 and 14 summarised the annual operating of the pulp mill and the integrated pulp and board without and with CCS.

Table 13: Annual operating cost of the pulp mill without and with CCS

	Base Case 1A	Case 2A-1 (REC)	Case 2A-2 (MFB)	Case 2A-3 (LK)	Case 2A-4 (REC+MFB)	Case 2A-5 (REC+LK)	Case 2A-6^{MP} (ALL 3)
1. Fixed Cost							
1a. Direct Labour	€ 7,200,000	€ 8,400,000	€ 8,100,000	€ 8,100,000	€ 8,400,000	€ 8,400,000	€ 8,400,000
1b. Indirect Labour Cost	€ 2,880,000	€ 3,360,000	€ 3,240,000	€ 3,240,000	€ 3,360,000	€ 3,360,000	€ 3,360,000
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 20,000,000	€ 22,782,411	€ 20,829,503	€ 20,527,285	€ 23,092,267	€ 22,929,169	€ 23,255,838
1d. Maintenance	€ 35,139,500	€ 43,507,340	€ 37,628,009	€ 36,727,296	€ 44,436,907	€ 43,953,553	€ 44,933,558
2. Variable Cost							
2a. Raw Materials / Feedstock	€ 185,600,000	€ 185,600,000	€ 185,600,000	€ 185,600,000	€ 185,600,000	€ 185,600,000	€ 185,600,000
2b. Chemicals	€ 27,250,400	€ 30,192,207	€ 27,789,593	€ 27,624,514	€ 30,732,453	€ 30,567,498	€ 31,106,523
2c. Fuel Cost	€ 11,200,000	€ 11,200,000	€ 11,200,000	€ 11,200,000	€ 11,200,000	€ 11,200,000	€ 11,200,000
2d. Other Utilities	€ 6,646,071	€ 12,056,841	€ 7,859,765	€ 7,327,160	€ 11,566,879	€ 11,920,696	€ 13,379,451
2e. Waste Processing & Disposal Charges	€ 1,521,925	€ 1,975,956	€ 1,618,132	€ 1,577,345	€ 2,068,834	€ 2,031,357	€ 2,126,974
3. Other Revenues							
3a. Crude Tall Oil (Sold to the Market)	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000
3b. Electricity (Sold to the Grid)	-€ 36,068,800	-€ 18,025,600	-€ 32,928,000	-€ 34,036,800	-€ 13,758,400	-€ 15,724,800	-€ 7,156,800
4. Other Cost							
4a. Marketing, Logistics and Distribution	€ 40,000,000	€ 40,000,000	€ 40,000,000	€ 40,000,000	€ 40,000,000	€ 40,000,000	€ 40,000,000
4b. CO_2 Transport and Storage Cost	€ 0	€ 14,787,000	€ 2,706,577	€ 1,878,042	€ 17,495,997	€ 16,667,082	€ 19,376,079

Table 14: Annual operating cost of the integrated pulp and board mill without and with CCS

	Base Case 1B	Case 2B-1[CO2MP] (REC)	Case 2B-2 (MFB)	Case 2B-3 (LK)	Case 2B-4[CO2MP] (REC+MFB)	Case 2B-5[CO2MP] (REC+LK)	Case 2B-6[CO2MP] (ALL 3)
1. Fixed Cost							
1a. Direct Labour	€ 14,400,000	€ 16,200,000	€ 15,300,000	€ 15,300,000	€ 16,200,000	€ 16,200,000	€ 16,200,000
1b. Indirect Labour Cost	€ 5,760,000	€ 6,480,000	€ 6,120,000	€ 6,120,000	€ 6,480,000	€ 6,480,000	€ 6,480,000
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 28,460,000	€ 31,676,433	€ 29,290,303	€ 28,988,086	€ 32,124,869	€ 31,941,153	€ 32,317,842
1d. Maintenance	€ 41,478,800	€ 51,149,029	€ 43,969,710	€ 43,068,997	€ 52,494,336	€ 51,949,130	€ 53,079,198
2. Variable Cost							
2a. Raw Materials / Feedstock	€ 345,915,556	€ 345,915,556	€ 345,915,556	€ 345,915,556	€ 345,915,556	€ 345,915,556	€ 345,915,556
2b. Chemicals	€ 26,206,779	€ 29,148,586	€ 26,745,972	€ 26,580,893	€ 29,688,832	€ 29,523,877	€ 30,062,902
2c. Fuel Cost	€ 11,200,000	€ 18,750,940	€ 11,200,000	€ 11,200,000	€ 22,932,999	€ 22,294,073	€ 28,857,582
2d. Other Utilities	€ 5,583,751	€ 11,108,421	€ 6,823,652	€ 6,289,366	€ 11,911,663	€ 11,386,750	€ 13,733,341
2e. Waste Processing & Disposal Charges	€ 1,796,134	€ 2,272,759	€ 1,892,342	€ 1,851,555	€ 2,378,150	€ 2,338,762	€ 2,454,016
3. Other Revenues							
3a. Crude Tall Oil (Sold to the Market)	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000	-€ 15,600,000
3b. Electricity (Sold to the Grid)	-€ 21,312,000	-€ 6,915,247	-€ 18,048,000	-€ 19,156,800	-€ 6,004,878	-€ 6,289,372	-€ 6,194,306
4. Other Cost							
4a. Marketing, Logistics and Distribution	€ 56,920,000	€ 56,920,000	€ 56,920,000	€ 56,920,000	€ 56,920,000	€ 56,920,000	€ 56,920,000
4b. CO_2 Transport and Storage Cost	€ 0	€ 14,787,000	€ 2,706,577	€ 1,878,042	€ 17,495,997	€ 16,667,082	€ 19,376,079

Levelised Cost of Pulp and Board

The Levelised Cost of Pulp Production (LCOP) and the Levelised Cost of Board Production (LCOB) are used to calculate the unit cost of producing the market pulp and board over the plant's economic lifetime. This is defined as the price of the market pulp and the board which enables the present value from the sales of pulp and board (including the additional revenues from the sale of CTO and electricity) over the economic lifetime of the plant to equal the present value of all the costs of building, maintaining and operating the plant over its lifetime. In other words, this is the breakeven price of the pulp or board when the net present value or NPV is set to zero.

The LCOP of the pulp produced from the mills without and with CCS is estimated using the discounted cash flow (DCF) analysis. The DCF calculation is executed based on IEAGHG's economic assessment model developed in-house in cooperation with VTT. Using this method allows the determination of real cost of pulp production and cost of CO_2 avoidance. Furthermore, it also determines the increase in the price of pulp after the retrofit of the CCS on the 10th year of the mill's operation.

The calculation requires the assessment of retrofitting CO_2 capture to an existing pulp mill, the economic assessment model incorporates the following assumptions:

- In all the CCS cases, it is assumed that the new capture plant is built while the mill is still in operation.
- It is also assumed that all the tie-ins required and the necessary internal modifications could be completed within the regular maintenance shut down period.
- On the first year of operation for the CO_2 capture plant, the operating hour is slightly reduced to 7560 hours.
- The model accounts for the differentiation between biogenic and fossil based CO_2 emissions.

The cash flow includes the following items:

- Revenues
- Fixed operating cost
- Variable operating cost
- Cost of CO_2 emissions (which includes CO_2 emissions tax, CO_2 emissions credit, renewable electricity credit, CO_2 negative emissions credit).
- Cost of CO_2 transport and storage
- Capital expenditures
- Working capital

As a starting point, the variable operating cost of the mill from year 1 to year 9 was calculated using the break-even price of the pulp of Base Case 1A (i.e. 523 €/adt pulp). The new price of the pulp after the retrofit was estimated using the overall cash flow and by setting the net present value or NPV = 0.

All the calculations assume constant prices (in real terms) for fuel and other costs and constant operating capacity factors throughout the plant lifetime, apart from lower capacity factors in the mill's first year of operation and the lower capacity of the CO_2 capture plant during its start-up. This study also assumed that the electricity price sold to the grid is constant at 40 €/MWh, and the CTO is also sold to the market at constant price of 500 €/tonne.

With the given information and assumptions, the following were calculated:

- Levelised cost of pulp production or breakeven price of the pulp after the retrofit.
- CO_2 avoidance cost.

To evaluate the impact of the cost of CO_2 emissions to the levelised cost of the market pulp, the following scenarios were evaluated:

- Scenario #1:
  No CO_2 emissions tax or any incentives to the biogenic CO_2 emissions (Base Number)

- Scenario #2:
  CO_2 emissions tax at 10 €/t and the biogenic CO_2 emitted by the mills is not recognized as CO_2 neutral (i.e. biogenic CO_2 is not exempted to the tax).

- Scenario #3:
  CO_2 emissions tax at 10 €/t and the biogenic CO_2 is recognized as CO_2 neutral – therefore exempting these emissions from the tax.

- Scenario #4:
  CO_2 emissions tax at 10 €/t, the biogenic CO_2 is exempted from the tax and an additional incentive is credited to the renewable electricity exported to the grid at 10% of the electricity selling price (at €4/MWh for the Base Number).

If CCS is retrofitted, the following additional scenarios were also evaluated to assess the effect of the financial credit given to the negative CO_2 emissions.

- Scenario #5:
  The same conditions as in Scenario 3 and with the negative CO_2 emissions given an additional credit of 10 €/t.

- Scenario #6:
  The same conditions as in Scenario 4 and with the negative CO_2 emissions given an additional credit of 10 €/t.

The different scenarios described above are summarized in Figure 9.

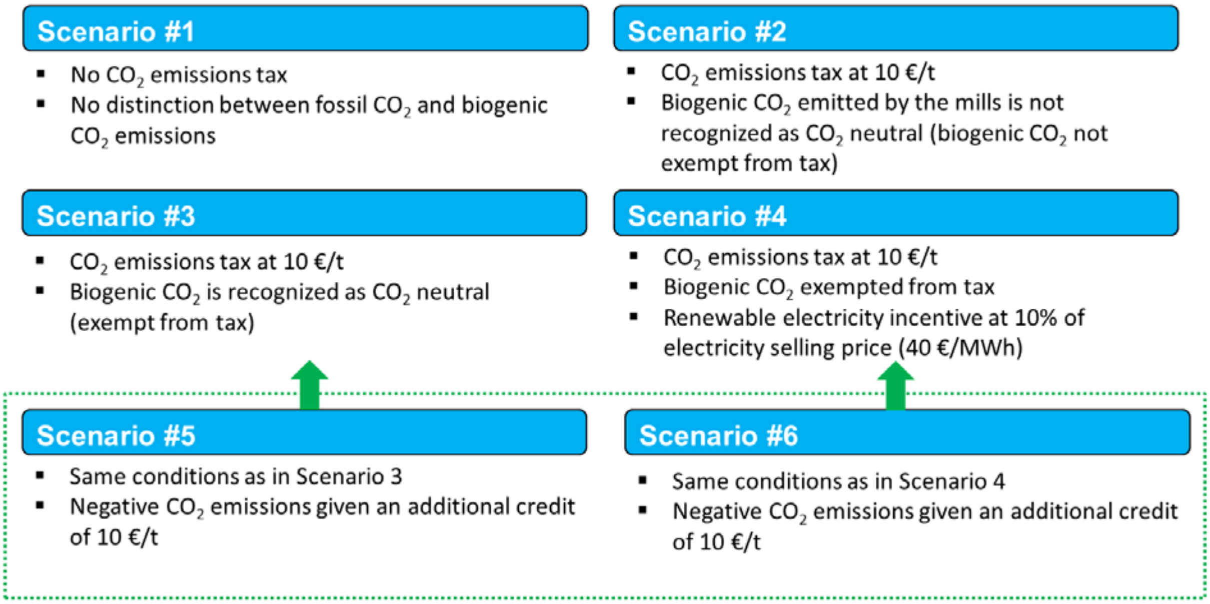

Figure 9: Summary of the different policy framework scenarios evaluated.

It should be noted that the CO_2 tax at 10 €/t reflects the current scenario where the EU ETS price for CO_2 is very low. Additionally, for Scenario #4, the incentive at 4 €/MWh credited to the renewable electricity that is sold to the grid also reflects the current Nordic market where incentives given to the renewable electricity are slowly being withdrawn.

Tables 15 and 16 summarise the LCOP of the pulp mill and integrated pulp and board mill for the all the CCS cases evaluated and subjected to the six different scenarios as defined above.

Table 15: LCOP or the breakeven price of the pulp (€/adt) for the pulp mill without and with CCS*

***The breakeven price for all the CCS case represents the price of the pulp after the retrofit of the CO_2 capture plant.**

	Base Case 1A	Case 2A-1 (REC)	Case 2A-2 (MFB)	Case 2A-3 (LK)	Case 2A-4 (REC+MFB)	Case 2A-5 (REC+LK)	Case 2A-6[MP] (ALL 3)
Scenario 1	522.6 €	642.8 €	553.5 €	543.1 €	659.0 €	652.0 €	676.5 €
Scenario 2	549.7 €	651.3 €	577.2 €	567.7 €	664.2 €	658.1 €	679.2 €
Scenario 3	523.7 €	643.9 €	554.5 €	543.1 €	660.1 €	652.0 €	676.5 €
Scenario 4	519.2 €	641.6 €	550.4 €	538.8 €	658.4 €	650.0 €	675.6 €
Scenario 5	523.7 €	625.3 €	551.1 €	541.7 €	638.2 €	632.1 €	653.2 €
Scenario 6	519.2 €	623.1 €	547.0 €	537.4 €	636.5 €	630.1 €	652.3 €

Table 16: LCOP or the breakeven price of the pulp (€/adt) for the integrated pulp and board mill without and with CCS*

***The breakeven price for all the CCS case represents the price of the pulp after the retrofit of the CO_2 capture plant.**

	Base Case 1B	Case 2B-1[CO2MP] (REC)	Case 2B-2 (MFB)	Case 2B-3 (LK)	Case 2B-4[CO2MP] (REC+MFB)	Case 2B-5[CO2MP] (REC+LK)	Case 2B-6[CO2MP] (ALL 3)
Scenario 1	522.6 €	670.9 €	556.3 €	545.0 €	695.0 €	687.0 €	713.6 €
Scenario 2	549.7 €	679.9 €	579.7 €	569.5 €	701.5 €	694.4 €	719.1 €
Scenario 3	523.7 €	672.0 €	557.3 €	544.9 €	696.1 €	686.9 €	713.5 €
Scenario 4	519.2 €	669.4 €	553.3 €	540.7 €	693.6 €	684.4 €	711.0 €
Scenario 5	523.7 €	651.9 €	553.7 €	543.4 €	672.3 €	665.4 €	688.2 €
Scenario 6	519.2 €	649.3 €	549.6 €	539.2 €	669.9 €	662.9 €	685.8 €

Cost of CO_2 avoided

Costs of CO_2 avoided were calculated by comparing the CO_2 emissions per adt of pulp and the LCOP of plants with capture and a reference plant without capture.

$$CO_2 \text{ Avoidance Cost (CAC)} = \frac{LCOP_{CCS} - LCOP_{Reference}}{CO_2Emissions_{Reference} - CO_2Emissions_{CCS}}$$

where:

- CAC is expressed in € per tonne of CO_2
- LCOP is expressed in Euro per adt of pulp
- CO_2 emission is expressed in tonnes of CO_2 per adt of pulp

To calculate the cost of CO_2 avoided for the integrated pulp and board mill without and with CCS, it was assumed to use the levelised cost of board (for integrated mill without CCS) constant and calculate the LCOP instead. The reason to this assumption is to make the results consistent and comparable to all cases. It should be noted that indirect CO_2 emissions from the additional pulp (i.e. CTMP and BHKP) imported from outside the battery limit is not accounted for in the calculation.

Tables 17 and 18 summarise the result of the CAC of the pulp mill and integrated pulp and board mill for the all the CCS cases evaluated and also subjected to the six different scenarios as defined earlier.

Table 17: CO_2 avoidance cost (€/t CO_2) of the pulp mill with CCS for each scenario

	Case 2A-1 (REC)	Case 2A-2 (MFB)	Case 2A-3 (LK)	Case 2A-4 (REC+MFB)	Case 2A-5 (REC+LK)	Case 2A-6^{MP} (ALL 3)
Scenario 1	65.0 €	91.1 €	83.1 €	62.4 €	61.8 €	63.2 €
Scenario 2	55.0 €	81.1 €	73.1 €	52.3 €	51.7 €	53.2 €
Scenario 3	65.0 €	91.1 €	78.7 €	62.4 €	61.2 €	62.8 €
Scenario 4	66.2 €	92.3 €	79.7 €	63.7 €	62.4 €	64.3 €
Scenario 5	55.0 €	81.1 €	73.1 €	52.3 €	51.7 €	53.2 €
Scenario 6	56.2 €	82.3 €	74.1 €	53.6 €	52.9 €	54.7 €

Table 18: CO_2 avoidance cost (€/t CO_2) of the integrated pulp and board mill with CCS for each scenario

	Case 2B-1^{CO2MP} (REC)	Case 2B-2 (MFB)	Case 2B-3 (LK)	Case 2B-4^{CO2MP} (REC+MFB)	Case 2B-5^{CO2MP} (REC+LK)	Case 2B-6^{CO2MP} (ALL 3)
Scenario 1	82.3 €	91.8 €	84.0 €	83.9 €	83.4 €	88.3 €
Scenario 2	72.3 €	81.7 €	73.9 €	73.9 €	73.3 €	78.3 €
Scenario 3	82.3 €	91.8 €	79.5 €	83.9 €	82.8 €	87.7 €
Scenario 4	83.4 €	93.0 €	80.6 €	84.9 €	83.8 €	88.7 €
Scenario 5	71.2 €	81.7 €	73.9 €	72.3 €	71.8 €	76.0 €
Scenario 6	72.3 €	82.9 €	75.0 €	73.3 €	72.8 €	77.0 €

Conclusions

- This study has evaluated the technical feasibility of retrofitting post-combustion CO_2 capture plant using MEA as solvent to (a) an existing Kraft pulp mill producing 800,000 adt pulp annually and (b) an existing integrated pulp and board mill producing 740,000 adt pulp and 400,000 adt 3-ply folding boxboard annually.

- Capture cases assessed in this study include the capture of CO_2 from the flue gases of the recovery boiler, the multi-fuel boiler and the lime kiln and various combinations of these.

- It should be highlighted that performance of retrofitting CCS in an existing industrial complex is very site specific. This is also true if CCS is deployed to an existing pulp mill.

- The retrofit of post-combustion CO_2 capture to an existing pulp mill or pulp and board mill is strongly dependent on the existing arrangement for the electricity and steam production on-site.

- In a typical modern Nordic Kraft pulp mill, excess LP steam is often available from the combustion of black liquor and bark. Depending on the volume of flue gas to be treated in the CO_2 capture plant and the partial pressure of CO_2 in the flue gas, the excess steam on-site should be sufficient to meet the steam demand of the CO_2 capture plant.

- However, for any cases involving the retrofit of CCS in an integrated pulp and board mill and 90% capture of CO_2 from the flue gas of the recovery boiler, it could be concluded that the excess available steam on-site is not sufficient. Therefore, an auxiliary boiler should be required to supplement the steam supply. It was also concluded, based on the different case scenarios evaluated, the use of steam turbine driven CO_2 compressor together with addition of auxiliary boiler (based on Configuration III, Figure 6) is the optimum way to meet steam and electricity demand of the CO_2 capture plant and at the same time maximize the amount of electricity exported to the grid.

- It could be noted that the retrofit of the CO_2 capture plant in a standalone pulp mill could increase the steam demand by 0.72 GJ/adt (for Case 2A-3) to 7.78 GJ/adt (for Case 2A-6MP). Likewise, the electricity demand could increase by 2.8 MWe (for Case 2A-3) to 31.4 MWe (for Case 2A-6^{MP}).

- On the other hand, the retrofit of the CO_2 capture plant in an integrated pulp and board mill could increase the steam demand by 0.72 GJ/adt (for Case 2B-3) to 12.98 GJ/adt (for Case 2B-6CO2MP). Likewise, the electricity demand could increase by 2.8 MWe (for Case 2B-3) to 14.6 MWe (for Case 2B-6^{CO2MP}).

- In general, because of the additional energy demand of the CO_2 capture plant, the amount of electricity exported to the grid is significantly reduced. This means that the amount of renewable electricity produced is also reduced.

- The costs of pulp production with and without CCS were estimated as far as possible based on IEAGHG's general practice and standard assessment criteria. The methodology on how the economic evaluation was assessed and the assumption used are described in the main report.

- The total plant cost (TPC) and total capital requirement (TCR) of the mill without and with CCS are summarised in Tables 10 to 12. From this study, it could be noted that the TCR of retrofitting CCS in an existing pulp mill could range from 65 to 500 million €.

- The annual operating cost of the pulp mill without and with CCS is summarised in Tables 13 and 14. From this study, the following could be noted:

    - As compared to the base case, the increase in the fixed operating cost is due to:
        - ⇒ Personnel needed for the CO_2 capture plant
        - ⇒ Associated increase to the indirect labour cost due to the increase of the direct labour cost
        - ⇒ Annual O&M is increased due to the added equipment of the CO_2 capture plant and associated modifications to the main mill
        - ⇒ Other fixed cost is increased by 1% of the TPC of the retrofitted plant (including contingency)

- The increase in variable operating cost mainly includes:
  - ⇒ Increase in chemical cost due to the make-up MEA solvent and the additional NaOH needed by the CO_2 capture plant.
  - ⇒ Increase in utilities due to the additional process and cooling water required by the CO_2 capture plant.
  - ⇒ Increase in waste disposal due to the processing of sludge from the reclaimer.
  - ⇒ There is no increase in the fuel or raw material cost of the plant (except for cases where auxiliary boiler is deployed, thus additional fuel cost – i.e. forest residue/waste wood – is added).

- One of the main impacts to the annual operating cost of the mill is due to the reduced amount of electricity that could be exported to the grid. This could result in reduced revenues of around 2 to 30 million €/y.

- Additional operating cost outside the pulp production would include the cost of CO_2 transport and storage at 10 €/t of CO_2 captured. This could increase the cost by 1.9 to 19.8 million €/y.

- To evaluate the impact of the cost of CCS to the levelised cost or breakeven price of the pulp, six different scenarios were examined.

  - Tables 15 to 18 summarised the estimated levelised cost of pulp production and the cost of CO_2 avoided for all the cases examined under the six different scenarios.

  - It could be noted that the impact of retrofitting CCS to the cost of pulp production (for the market pulp mill and integrated pulp and board mill without and with CCS) could be classified under three different regimes based on the level of overall CO_2 capture rate (of the whole site). This include the following categories:
    - ⇒ Category A: Overall capture rate between 5 and 15%
    - ⇒ Category B: Overall capture rate between 65 and 80%
    - ⇒ Category C: Overall capture rate of greater than 80%

  - On the other hand, the impact of retrofitting CCS to the cost of the pulp production (for the integrated pulp and board mill without and with CCS), the difference between Category B and Category C are minimal. This is due to the added cost of the auxiliary boiler.

  - Under Scenario 1, the cost of retrofitting CCS without any influence of the regulatory framework related to CO_2 emissions, and/or incentives provided to the renewable electricity and negative emission were examined. The results indicated that after the retrofit, the breakeven price of pulp would increase from 523 €/adt (for Base Case 1A) to 540 – 555 €/adt for cases under Category A, to 640 to 660 €/adt for cases under Category B, and to 675 €/adt for cases under Category C.

  - For cases involving integrated pulp and board mill, the addition of the auxiliary boiler increased the breakeven price pulp in the range of 670 to 715 €/adt (mainly cases under Category B and C).

- With Scenario 1 (for the market pulp mill without and with CCS), it could be observed that most of the price increase could be attributed to the following:

	Category A	Category B & C
CAPEX of CCS Plant including modification to the mill	53-55%	49-51%
Fixed operating cost	21-24%	15-16%
Variable operating cost	8-9%	11-13%
CO_2 Transport and Storage cost	13-14%	21-22%

- Under Scenario 2, where CO_2 tax is set at 10 €/t and the biogenic CO_2 emissions are NOT tax exempt, the increase in the pulp price is considered modest at 4 to 12 €/adt for cases with higher capture rate (i.e. cases under Category B and C) if compared to the corresponding prices reported under Scenario 1.

- On the other hand, under Scenario 3 where CO_2 tax is set at 10 €/t and biogenic CO_2 emissions are tax exempt or Scenario 4 where additional incentives is given to the Renewable Electricity exported to the grid, the increase in the pulp price for all the cases is considered very minimal as compared to the corresponding prices reported in Scenario 1. This further demonstrates that if the biogenic CO_2 emission are recognised as CO_2 neutral and without any incentives to the negative CO_2 emission, then retrofitting CCS will only be seen as an added cost without any benefit to the mill's bottom line.

- Under Scenarios 5 and 6 with incentive provided to the negative CO_2 emissions at 10 €/t, it is expected that this incentive should offset the cost of CO_2 transport and storage – therefore reducing the price of pulp as compared to the corresponding cases under Scenarios 3 and 4. Nonetheless, it should be noted that this is not true for cases where it involves the capture of CO_2 from the lime kiln where minimal reduction in pulp price is observed.

- Various sensitivity analyses were undertaken to determine the impact of the electricity selling price, CO_2 emission tax, renewable electricity credit and negative CO2 emissions credit on the breakeven price of the pulp and cost of CO_2 avoidance. These are presented in the main report.

- The pulp and paper industry is a potential candidate for large-scale demonstration of bio-CCS that accounts for the negative CO_2 emissions. It is essential to explore the potential of deploying CCS in the pulp and paper industry as this could lead to the first necessary business case for implementation of bio-CCS in the near future.

- However, it is essential to note that the feasibility of retrofitting CCS will strongly depend on the policy framework relevant to the CO_2 emission tax and incentives provided to the renewable electricity exported to the grid and to the negative CO_2 emissions.

- Providing a higher negative CO_2 emission credit may be the most favourable route to encourage the pulp industry to deploy CCS. This study shows that a negative CO_2 emission credit of 60 – 65 €/t CO_2 is needed for the Kraft pulp mill in order to make CCS feasible (for high capture rate cases excluding the lime kiln and the multi-fuel boiler). For the integrated pulp and board mill, the corresponding negative CO_2 emission credit would need to be around 75 €/t CO_2.

Recommendations

For future studies, it is highly recommended to evaluate the following case scenarios:

- Partial capture of CO_2 for any cases involving the capture of CO_2 from flue gas of recovery boiler and examines the performance and cost of the mill with CCS based on the limitation of the availability of excess steam on-site.

- The alternative option of a CCU project rather than CCS for cases with lower capture rates.

FINAL REPORT

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Criteria for the Techno-Economic Assessment of Pulp (and Board) Mills Retrofitted with CCS

Report history

Ver.	Author	Date	Comments
0	Hankalin, Onarheim, Kangas, Kaijaluoto	2015-02-06	For IEAGHG comments
0.1	Kangas	2015-02-10	For discussion
0.2	Hankalin	2015-03-03	Corrected based on SS, EH and PK comments
0.3	Kangas, Hankalin	2015-03-06	Additional details
0.4	Hankalin	2016-09-28	Fine tuning
0.5	Santos	2016-10-12	Fine tuning
0.6	Santos	2016-12-13	Fine tuning and final review

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1 Reference Document Overview

This reference document describes the design basis of the pulp (and board) mill and the cost estimating criteria to be used as a common basis for assessing the techno-economics of the pulp (and board) mills without and with CCS.

The design and economic criteria outlined in the sections below will be used as a reference for developing the P&P mill configurations to be analysed in this study.

Where applicable, information retrieved from IEAGHG document "Criteria for Technical and Economic Assessment of Plants with Low CO_2 Emissions" Version C-6, March 2014, are included.

The P&P mill will produce market pulp only or market pulp and board. The basic schemes of the mills to be analysed in the study include two different cases:

- **Base case 1A:** Market pulp mill with a capacity of producing 800,000 adt/y of bleached softwood Kraft pulp (BSKP)

- **Base case 1B:** Integrated pulp and board mill with a capacity of producing 740,000 adt/y of bleached softwood Kraft pulp and 400,000 adt/y of 3-ply folding box board (250 g m^{-2}).

For the CCS cases, the following schemes will be evaluated:

- Case 2A & 2B-1: Capture of CO_2 in the Kraft Recovery Boiler only
- Case 2A & 2B-2: Capture of CO_2 in the Multi-fuel Boiler only
- Case 2A & 2B-3: Capture of CO_2 in the Lime Kiln only
- Case 2A & 2B-4: Capture of CO_2 in both Kraft & Multi-boilers
- Case 2A & 2B-5: Capture of CO_2 in both Kraft Boiler & Lime Kiln
- Case 2A & 2B-6: Capture of CO_2 in Kraft, Multi-fuel Boilers & Lime Kiln

The mills to be evaluated is expected to energy independent. The black liquor and the barks are burned in the recovery boiler and multi-fuel boiler respectively producing HP steam. The steam is sent to the steam turbine island to generate process steam and electricity. Any excess steam not used by the mill are converted to electricity and exported to the grid.

The CO_2 capture plant is based on post-combustion CO_2 capture technology using MEA as solvent. It is assumed to achieve 90% capture rate (of the treated gas) for all of the cases evaluated.

Should the electricity produced within the mill will not be sufficient to fulfil the additional electricity required by the CCS facilities, a new auxiliary boiler firing forest residues will be deployed.

2 Technical Criteria

This section summarizes the design criteria and assumptions used as a common basis for the design of the mill without and with CCS.

2.1 Mill's Location and Battery Limit

The mill is located in north western coast of Finland between Kemi and Raahe. No extraordinary construction requirements or constraints on equipment delivery have been assumed.

The battery limit of the report is the mill fence area. The mill is not integrated with other mills or processes except power connection to the national grid.

It is also assumed that infrastructures such as rail lines, roads, fresh water supply and high voltage electricity transmission lines, high pressure CO_2 pipeline are accessible to the mill. This is considered outside the battery limits of the plant. These infrastructure are not included in the scope of the plant cost estimates.

2.2 Key Features of the P&P Mill

2.2.1 Capacity

For Base Case 1A, the market pulp mill is producing 840,000 adt/y unbleached softwood Kraft pulp (USKP). This corresponds to a production of 800,000 adt/y of bleached softwood Kraft pulp (BSKP).

For Base Case 1B, the integrated pulp and board mill is also producing 840,000 adt/y of USKP. Correspondingly, this mill will produce 740,000 adt/y of BSKP and 400,000 adt/y of 3-ply folding box board.

For all the CCS cases, the pulp and board production capacities are kept constant.

The mill performance is calculated based on the annual average ambient conditions.

For the economic assessment, the mill is assumed to operate at its design performance with no performance degradation over time.

2.2.2 Capacity Factor

Expected annual operating hours of 8400 h/y is assumed. This corresponds to a production of 100 adt/h of unbleached softwood Kraft pulp.

2.2.3 Configuration

The P&P mill consists of one train and integrates the following sections. (Numbers refer to in this section are the unit number presented in the Block Flow Diagram).

- Wood Handling	Unit 1000
- Cooking	Unit 2000
- Brown Stock Handling	Unit 2100
- Oxygen Delignification	Unit 2200
- Pulp Bleaching and Washing	Unit 3100
- Pulp Drying	Unit 3200
- Black Liquor Evaporation	Unit 4100
- Kraft Recovery Boiler	Unit 4200
- Recausticising	Unit 5000
- Lime Kiln	Unit 5100
- Multi-fuel Boiler	Unit 6100

- Steam Turbine Island Unit 6200
- Bleach Chemical Preparation Unit 7100
- White Liquor Oxidising Unit 7200
- Air Separation Unit 7300
- Waste Water Treatment Unit 8000
- Board Mill Unit 9000
- CO2 Capture Unit 10000
- CO2 Compression and Drying Unit 11000

No heat is exported outside the mill area. All steam is consumed in the mill and the turbines are sized accordingly. Power is exported to the national power grid. There is a condensing unit in the end of the turbine.

Oxygen delignification and four-stage pulp bleaching is used for the bleaching the pulp. O_2 and ClO_2 are manufactured on-site, other cooking chemicals are purchased.

2.3 Climatic and Meteorological Data

The following annual average values are assumed:

- Air temperature 15°C, pressure 1 bar and humidity 75%
- Temperature of raw materials and chemicals 15°C
- Incoming water temperature is 10°C

2.4 Mill's Battery Limits

2.4.1 Process and utility streams

- Input
  - Wood
  - Chemicals
  - Water
  - Fuel
  - Pulps – BHKP, CTMP (for board mill)

- Output
  - Pulp
  - Board
  - Electricity
  - Water effluent
  - Cooling water
  - Solid waste
  - Flue gas
  - Compressed CO2
  - Solid waste
  - Chemicals

2.5 Raw Materials, Chemicals and Fuels

2.5.1 Wood

The mill uses Finnish softwood as raw material. Both spruce (Picea abies) and pine (Pinus sylvestris) are used. The raw material arrives at the mill as logs. The logs are debarked and chipped at the mill and the bark is fired in a multi-fuel boiler. A dry debarking method is applied.

2.5.2 Chemicals

Following chemicals are used in pulp mill. Some of them are purchased outside the battery limit and some are produced in the mill.

- NaOH (Purchased outside)
- H_2O_2 (Purchased outside)
- Lime (Purchased outside)
- $MgSO_4$ (Purchased outside)
- H_2SO_4 (Purchased outside)
- $NaClO_3$ (Purchased outside)
- Methanol (Purchased outside)
- Talc (Purchased outside)
- Oxygen (Produced on-site)
- ClO_2 (Produced on-site)

Following chemicals are used in board mill and thus purchased outside battery limits:

- Fillers (e.g. carbonate)
- Coating (mixture of kaolin, talc, carbonate, starch, latex)

Following chemicals are used in CO2 capture process and thus purchased outside battery limits:

- MEA, 30 wt-%

Should there be a need for a Flue Gas Desulphurization plant following chemicals are used:

- Ca(OH)2

In addition small amounts of other chemicals are used at cite (biocides, de-foamers, etc.) However they are neglected in this study. All chemicals are reported as 100% effective if not otherwise noted.

2.5.3 Fuels

Large share of the mill energy consumption is bio-based. The recovery boiler is fired with black liquor (80 w-% dry solids after evaporation and 82.5 w-% as fired), where roughly half of the solids are dissolved organic material from wood. In addition, bark and bio-sludge are combusted in the multi-fuel boiler for producing steam. There is a surplus of steam produced on-site. These are used to generate additional electricity in a condensing turbines.

If there is a deficit of steam after the retrofit of CCS, the following options will be explored: (1.) additional wood chips could be bought from outside the battery limit and used as supplementary fuel to the multi-fuel boiler, or (2.) waste wood/forest residues could also be bought from outside the battery limit and used as fuel for the auxiliary boiler.

Only the lime kiln is fired with fossil fuel. In the reference model, heavy fuel oil (HFO) with LHV of 41.0 MJ/kg is used as there is no natural gas available in western coast of Finland. The HFO is delivered by ships.

Properties of applied fuels are presented in Table 1.

In addition, some minor intermediate components (turpentine, methanol, malodorous gases) are produced. These components are listed in Table 2. However the volume of these intermediate components is low. In this study it is assumed that all these components are burned in the recovery boiler.

Table 1. Properties of used fuel

		Black liquor[a]	Bark	HFO	Wood chips
LHV	[MJ kg^{-1} DM^{-1}]	13.7	20.5	41.0	19.5
C	[m-% DM]	31.0 %	49.9 %		50.0 %
O	[m-% DM]	22.0 %	41.9 %	0.2 %	41.5 %
H	[m-% DM]	3.4 %	5.6 %	10.1 %	6.1 %
N	[m-% DM]	0.10 %	0.40 %	0.40 %	0.40 %
S	[m-% DM]	7.07 %	0.03 %	0.98 %	0.05 %
Na	[m-% DM]	21.7 %			
K	[m-% DM]	2.7 %			
Cl	[m-% DM]	0.08 %			
Ash	[m-% DM]	-	2.6 %	0.03 %	2 %
Water	[m-%]	20 %	50 %	0.15 %	55 %
Density	[kg m^{-3}]	1450	300[b]	1005	325[b]
Ref		[1]	[2]	[3]	

[a] As fired; [b] Loose density

Table 2. Properties of minor fuels

		Turpentine	Methanol	DNCG*	CNCG*
LHV	[MJ kg^{-1} DM^{-1}]	41.3	19.9		
C	[m-% DM]	83.0 %	37.5 %		
O	[m-% DM]		49.9 %	21 %	8.3 %
H	[m-% DM]	12.2 %	12.6 %		0.7 %
N	[m-% DM]	1.6 %		79 %	44.0 %
S	[m-% DM]	3.2 %		<0.5%	47.0 %
Water	[m-% DM]		15 %		
Density		860	796		
Ref		[4]	[4]	[5]	[6]

* DNCG: Diluted non-condensable gases; CNCG: Concentrated non-condensable gases

2.5.4 Fuel Heating Value

Lower Heating Value (LHV, as received) is used as the standard.

Additionally, plant performance and efficiency are also quoted on an LHV basis.

[1] P. Kangas, S. Kaijaluoto, M. Määttänen, Nord. Pulp Pap. Res. J. 29 (2014) 620.
[2] E. Alakangas, Suomessa Käytettävien Polttoaineiden Ominaisuuksia, Espoo, 2000.
[3] Mastera LS 420
[4] Adams Terry. 2007. Alternative fuel impact on lime reburning kiln performance. TAPPI. 9 pages.
[5] European IPPC Bureau 2013. Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board (DRAFT), Seville, Spain. http://tinyurl.com/ot7wrn8
[6] Lin, 2008, NCG collection and Incineration, Tappi Kraft Recovery Short Course, http://tinyurl.com/ndlvqqa

2.6 Products and By-Products Specifications

2.6.1 Pulp

Properties of brown stock (after cooking) are:

- Yield: 47% (from chips)
- Kappa number: 29

Properties on unbleached pulp (after oxygen delignification) are:

- Yield: 46% (from chips)
- Kappa number: 14
- Brightness: 35 %
- (Production 840 000 ADT/a)

Properties of bleached pulp (after four-stage bleaching) are:

- Yield: 44% (from chips)
- Brightness: 88.5%
- (Production 800 000 ADT/a)

2.6.2 Board

Properties of the board are as follows:

- 3-ply folding box board, basis weight 250 g m^{-2}.
- Coating: 20 g m^{-2}
- Top layer: 40 g m^{-2} – 90% BHK and 10% of filler
- Middle layer: 160 g m^{-2} – 80% of CTMP, 15% of unbleached softwood kraft pulp and 5% of filler
- Bottom layer: 30 g m^{-2} – 45% of BSK, 45% BHK and 10% of filler

2.6.3 Electric Power

The site is connected to the national grid. Any surplus electricity produced on-site is exported.

- High voltage grid connection: 110 kV
- Frequency: 50 Hz

2.6.4 Steam

There are numerous consumers of steam in the mill. For the steam parameters please refer to Chapter 2.9.

2.6.5 Carbon Dioxide

The CCS plants in this study are designed to capture 90% of the CO2 in the treated flue gas.

CO_2 is delivered from the mill site by pipeline at a pressure of 11.0 MPa and a temperature of ≤30°C. No buffer storage of CO_2 is included within the mill battery limits. It is assumed that the CO_2 transport and disposal system can accommodate any variations in the quantity of CO_2 delivered by the capture plants.

CO_2 purity maximum impurities (vol. basis) are as follows:

- H2O 500 ppm.

2.7 Environmental Performance

2.7.1 Gaseous Emissions

The emissions from the mill is operated with the limit[7] of:

- SO_X 100 mg/Nm^3 (6% O_2, dry)
- NO_X 200 mg/Nm^3 (6% O_2, dry)
- TRS 10 mg/Nm^3 (6% O_2, dry)
- Particulates 50 mg/Nm^3 (6% O_2, dry)

Trace compounds from CO_2 capture processes are not yet clearly defined in the EU Industrial Emissions Directive. Therefore they have no emission limits here.

2.7.2 Liquid Effluent

The liquid effluent (overall) from pulp and board mill shall not exceed following limits[8,9]:

- Flow 20 m^3/t of pulp and board
- Chemical Oxygen Demand (COD) 10 kg/t of pulp and board
- Total Suspended Solids (TSS) 1 kg/t of pulp and board
- Adsorbable Organic Halides (AOX) 0.1 kg/t of pulp and board

2.7.3 Solid Wastes

Solid wastes are landfilled. MEA sludge is sent to a specialist company for disposal.

2.7.4 Noise

All the equipment of the mill are designed to obtain a sound pressure level of 85 dB(A) at 1 meter from the equipment.

2.8 Units of Measurement

The units of measurement are in SI units.

“adt” refers to air dry tonnes of pulp, where dry content is 90%.

2.9 Utilities

2.9.1 Cooling Water

- *Seawater cooling is applied*
    - Source: seawater in once through system
    - Service: for steam turbine condenser and CO_2 compression unit.
    - Type: clear filtered and chlorinated, without suspended solids and organic matter.
    - Salinity: 0,3 %
    - Supply / design temperature: 10 °C

- Condensing turbine parameters are following:
    - Temperature: 39°C
    - Pressure: 0.07 bar
    - Temperature difference, $\Delta T = 5$ °C

[7] Typical limits for gaseous emissions for pulp mills in Finland.
[8] Average from UPM-Kymmene pulp mills, http://tinyurl.com/mznmhmq
[9] Metsä Fibre, New Äänekoski mill, http://tinyurl.com/peze4vc

2.9.2 Demineralized Water

- Type: treated raw water
- Design temperature: 10 °C

2.9.3 Steam

Recovery boiler and multi-fuel boiler are producing following steam fractions:

- High pressure steam, 505°C and 103 bar
- Intermediate steam for soot blowing, 352°C and 30 bar
- Medium pressure steam, 200°C and 13 bar
- Low pressure steam, 154°C and 4.2 bar

2.10 Codes and Standards

The design of the process and utility units are in general accordance with the main International and EU Standard Codes.

3 Economic Criteria

The following section describes the main cost estimating bases used to make the economic assessment of the P&P mill configuration options (with and without CO_2 capture).

3.1 Mill's Economic Life

The pulp mill and the board machine are assumed to be built approximately 10 years ago. Pulp mill and board machine are fully depreciated. Thus there are no additional capital costs related to pulp and board mills.

3.1.1 CO_2 Project Schedule

- Project start	2013
- Plant operation start	2015
- Construction time (years)	2
- CO_2 capture plant operating life (years)	15

3.2 Total Capital Requirement

The Total Capital Requirement (TCR) includes:

- Total CO_2 Plant Cost (TPC)
- Retrofit cost for the pulp mill
- Interest during construction
- Spare parts cost for the retrofitted parts
- Start-up costs of the retrofitted parts
- Owner's cost
- Working capital

The estimate is in euro (€), based on 2015 price level.

3.3 Total Plant Cost

3.3.1 Estimate Accuracy

CAPEX are estimated for CO_2 plant and for retro-fitted parts of the pulp mill. The costs are distinguished from each other. All capital costs are allocated for CO_2 production.

Estimating capital expenses is based on in-house cost databases of ÅF Consult and VTT, literature and other publicly available information. The cost estimating accuracy is ±35%.

3.3.2 Contingency of the CO_2 Capture Project

A project contingency of 10% of the TPC is assumed for the CO_2 plant. A contingency of 10% is assumed for mature technology.

3.3.3 Design and Construction Period

Plant design and construction period is 2 years for the CO2 capture plant. The same period is assumed for other retrofitted units.

It is assumed that construction of the CO_2 capture plant is made during normal operation of the pulp mill. Connections to the pulp mill are built within 1-2 months. Thus additional down time for the pulp mill is minimized.

During the start-up period of CO_2 capture plant no additional down time is assumed to pulp mill as the flue gas can be directed to stack or to CO_2 capture plant as needed.

3.3.4 Financial Leverage (Debt / Invested Capital)

It is assumed that whole CO2 plant is financed with debt – no invested capital is applied.

3.3.5 Discount Rate

Cash flow and net present value, NPV, are calculated for the capture of CO_2 during 15 years. Discount cash flow calculations are expressed at a discount rate of 8%.

3.3.6 Interest during Construction

Interest during construction is calculated from the plant construction schedule and start-up period. Interest rate is assumed same as the discount rate.

3.3.7 Inflation Rate

Not considered.

3.3.8 Depreciation

Linear depreciation of CO_2 plant under 10 years after start-up is assumed. However, this is not included in the Discounted Cash Flow calculation. Results are reported on Earnings Before Interest, Taxation, Depreciation and Amortisation (EBITDA) basis.

3.3.9 Spare Parts Cost

1% of the TPC is assumed to cover spare part costs. It is assumed that spare parts have no value at the end of the plant life due to obsolescence.

3.3.10 Start-Up Cost

Start-up cost of the mill includes:

- 2% of TPC to cover the start-up CAPEX
- 2.1% of annual fuel bill to cover additional fuel cost during start-up
- 25% of annual operating expense (O&M, Fuel and Raw Materials)
- 8.3% of chemicals cost

Start-up cost of the CO2 capture plant includes:

- 3% of TPC to cover the start-up CAPEX
- Additional 0.5% of TPC to cover start-up CAPEX if auxiliary boiler is added.

3.3.11 Owner's Cost

7% of the TPC of retrofitted units is assumed to cover the Owner cost and fees.

Owner costs cover the costs of feasibility studies, surveys, land purchase, construction or improvement to roads and railways, water supply etc. beyond the site boundary, owner's engineering staff costs, permitting and legal fees, arranging financing and other miscellaneous costs. Owner costs are assumed to be all incurred in the first year of construction, allowing for the fact that some of the costs would be incurred before the start of construction.

3.3.12 Decommissioning Cost

The salvage value of equipment and materials is assumed to be equal to the costs of dismantling and site restoration, resulting in a zero net cost of decommissioning.

3.4 Operating and Maintenance Costs

OPEX is defined for the CO_2 capture plant. All additional operational costs due retro-fitting of pulp mill are allocated to CO_2 production. OPEX is defined and broken down to major items and consumptions are reported based on pulp, board and CO_2 production. The influence of CO_2 capture plant operation to the costs of pulp and board production is reported.

3.4.1 Variable Costs

Consumables are the principal components of variable O&M costs. These include raw material, water, chemicals, solid waste disposal, fuel and other. Prices are obtained from literature and relevant public databases.[10] Applied prices are shown in Table 3.

Table 3. Costs of consumables

Component	Price	Unit
Raw Materials		
Log / roundwood	40	€/m^3
Bleached Hardwood Kraft Pulp	650	€/adt
Chemi-thermo Mechanical Pulp	400	€/adt
Coating	300	€/t
Fillers	200	€/t
Chemicals		
NaOH	370	€/t
H_2O_2	500	€/t
CaO	120	€/t
$MgSO_4$	300	€/t
H_2SO_4	50	€/t
Methanol	350	€/t
$NaClO_3$	500	€/t
Talc	200	€/t
MEA solvent	1 620	€/t
Co-Product (to Market)		
Crude Tall Oil (CTO)	500	€/t
Utilities		
Cooling Water	0.05	€/m3
Process Water	0.1	€/m3
Boiler Feed Water Make-up	0.2	€/m3
Energy and Fuel		
Heavy Fuel Oil (HFO)	400	€/m3
Waste Wood / Forest Residues	18.8	€/m3
Electricity (sold to the grid)	40	€/MWh
Waste		
Rejects from Brown Stock Handling	10	€/t
Residues from CTO Production	10	€/t
Bottom and Fly Ash	10	€/t
Dregss	10	€/t
Slaker grits	10	€/t
Rejects from Pulp Dryer	10	€/t
MEA sludge disposal	190	€/t
Waste Water Effluent Discharge	0.09	€/m3
Other Miscellaneous Cost		
Product Logistics and Delivery	50	€/t
Other Fixed Cost (incl. Insurance and Local Tax)	25	€/t
CO2 Transport and Storage	10	€/t

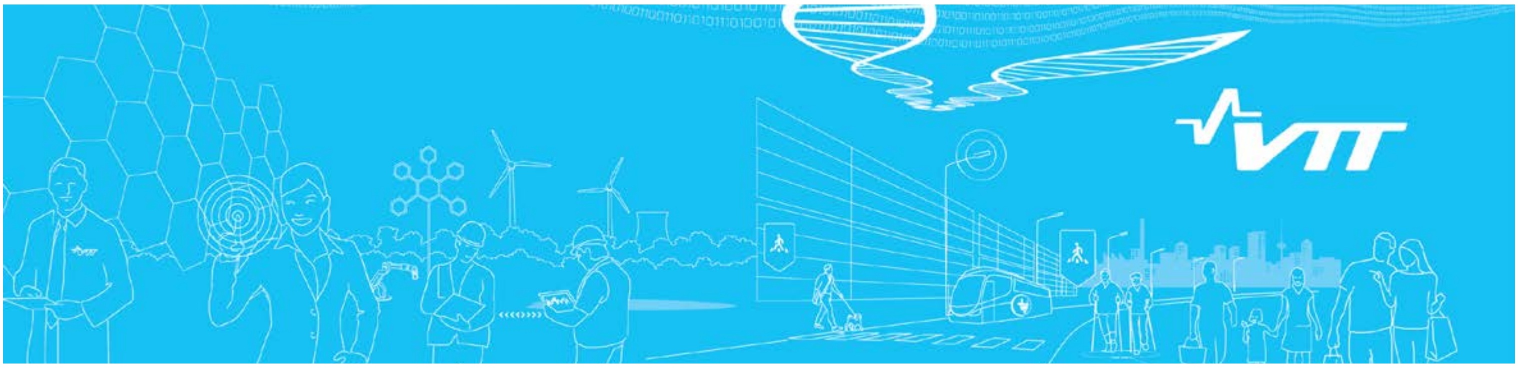
[10] Relevant price information are explained in "P. Kangas, S. Kaijaluoto, M. Määttänen, Nord. Pulp Pap. Res. J. 29 (2014) 620" and most of prices used in this study are relevant to the Nordic market.

A fixed value of 50 €/t is applied for logistics costs of pulp and board. This cost includes transportation from Finland to Central-Europe.

3.4.2 Fixed Costs

Labor and maintenance cost are taken into account if they are changed due to retrofitted units and the CO_2 capture plant. All additional costs are allocated for CO_2 capture.

- Direct labor
  - The yearly cost of the direct labor is calculated assuming, for each individual, an average cost equal to 60,000 €/y. The number of personnel engaged is estimated considering a 5 shift working pattern.
- Administrative and support labor
  - All other company services not directly involved in the operation of the plant fall in this category, such as:
    - Management
    - Administration
    - Personnel services
    - Technical services
    - Clerical staff.
  - Administrative and support labour is assumed to be 40% of the direct labour cost.
- Maintenance
  - Annual maintenance cost of the mill is assumed at around 4% of the capex.
  - Annual maintenance cost of the retrofitted parts are estimated as a percentage of the total plant cost of the facilities, as shown in the following:
    - 3% of the capex for the CO2 capture and compression plant
    - 3% of the capex for the auxiliary boiler
  - Maintenance labour is assumed to be 40% of the overall maintenance cost.



CUSTOMER REPORT

VTT-CR-01301-15 | 23.2.2017

CCS in P&P Industry – Reference Plants: Performance

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Summary

The performance of a modern Nordic Kraft Pulp Mill is presented. The evaluation is based on using process simulation to calculate the mass and energy balances. All relevant units of the pulp making process, from wood handling to pulp drying (fibre line), and from black liquor evaporator to recausticizing plant (chemical recovery line) are included in the model. Additionally, associated units such as bleach chemical preparation plant, air separation unit, wastewater treatment plant, multi-fuel boiler, steam turbine island, and board mill are also incorporated.

Two base cases are defined: (i) stand-alone pulp mill producing 800 000 air dry tonnes (adt) of softwood Kraft pulp annually, and (ii) integrated pulp and board mill producing 740 000 net adt of softwood Kraft pulp and 400 000 adt of 3-ply folding box board annually. The defined mills presented in this report are used as the "Reference Mills" to assess the techno-economics of CCS deployment in the pulp and paper industry.

The overall mass balance presenting the consumption of the raw materials and chemicals during pulp and board production and the overall energy balance presenting the fuel, steam and electricity consumption of the mill are discussed in this report.

The reference mills are considered energy independent and export excess electricity to the grid.

The CO_2 emissions of the reference mills amount to 2.1 Mt annually (1.6 Mt from the recovery boiler, 0.3 Mt from the multi-fuel boiler and 0.2 Mt from the lime kiln). Around 90% of the overall CO_2 emitted are classified as biogenic CO_2. Provided that the raw materials of the pulp mill are sourced sustainably, these emissions are considered CO_2 neutral.

Espoo 9.1.2017

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List of Abbreviations

ASU	air separation unit
adt	air-dried tonne
BAT	best available technology
BHKP	bleached hardwood kraft pulp
BL	black liquor
BLOX	black liquor oxidation
BOD	biological oxygen demand
BSKP	bleached softwood kraft pulp
CNCG	concentrated non-condensable gas
COD	chemical oxygen demand
CTMP	chemi-thermo mechanical pulp
CTO	crude tall oil
D_0-E_{OP}-D_1-P	pulp bleaching sequence (D = ClO_2; E = NaOH; O = O_2; and P = H_2O_2).
DD	drum displaced
DNCG	dilute non-condensable gas
ECF	elemental chlorine free
ESP	electro-static precipitator
HFO	heavy fuel oil
HP	high pressure
HWWS	hot and warm water system
IP	intermediate pressure
LP	low pressure
MP	medium pressure
TCF	total chlorine free
TRS	total reduced sulfur
TDS	total dissolved solids
USKP	unbleached softwood kraft pulp

1. Background

Globally, the pulp and paper industry is the fifth largest industrial sources of fossil CO_2 emissions. In addition, biogenic CO_2 emissions from the pulp and paper industry are even higher than fossil emissions. Recently, the IEA CCS roadmap has identified this industry with high potential for CCS deployment in industry sectors outside the power production sector.

The current trend in the Nordic countries is a significant growth in pulp and board production. On the other hand, paper consumption in Europe has decreased, and paper production capacities have been cut. Additionally, there is also a clear change in the structure of the Nordic pulp and paper industry - i.e. where share of more electrical energy intensive mechanical pulping process has been reduced and chemical pulping processes have gained market share. As a consequence, the reference mills are defined as (i) softwood kraft pulp mill and (ii) integrated softwood kraft pulp mill and board mill. These two mill configurations represent the currently most feasible Nordic mills.

Both reference mills are energy independent. They produce more energy than what is utilised within the battery limit. This is due to the large amount of woody materials dissolved in the chemical pulping processes and later burned in the Kraft recovery boiler.

The pulp and paper industry is the largest user and producer of renewable energy. Additional bio-based side streams (such as chips, forest residues, bio-sludge, etc.) can easily be utilised for additional energy production at the mills if more heat and power is needed for CCS solutions.

2. Methodology

2.1 Reference mill modelling

The performance of the reference mills is evaluated by modelling the mass and energy balances of a typical modern Nordic kraft pulp mill. All relevant units from wood handling to pulp drying and from evaporation to steam turbine are included into the model. In addition, the bleaching chemical plant, air separation unit and wastewater treatment are defined as part of the model. The process modelling is conducted with the Wingems 5.3 process simulator [1], which is widely used for pulp mill process modelling. Results of this study are shown as unit consumption of different raw materials, chemicals, utilities, etc. Results are given per tonne of air dried product and as annual consumption. A detailed description of the reference pulp mill is available in [2].

2.2 Validation

Results of the reference mill were compared to the FRAM model [3,4] and BAT reference documentation [5] by authors in [2]. In addition, the reference mill results were validated against process parameters for most modern Finnish pulp mills and reported in [2]. The mill performance is equivalent to FRAM and BAT specifications and comparable to most retrofits undertaken recently by the Finnish pulp industry.

3. Process description of the reference mill

The reference Nordic Kraft pulp mill (**Base Case 1A**) has an annual production of 800 000 adt softwood pulp. The raw materials for the process consist of the pine (*Pinus sylvestris*) and the spruce (*Picea abies*) with 50/50% mix. The annual operating time is 8400 hours. The fibre line is based on continuous cooking process, two-stage oxygen delignification, D_0-E_{OP}-D_1-P bleaching stages and pulp drying. The dried pulp is sold as “Market Pulp”. The chemical recovery island has seven-stage evaporator, with the concentrated black liquor being combusted in the recovery boiler. The recausticising and lime kiln are used for preparing cooking chemicals. Bark is combusted in the multi-fuel boiler. The lime kiln is fired with heavy fuel oil. Unused steam is converted to electricity in the steam turbine island and excess electricity is sold to the grid. No heat integration to district heating is available.

The integrated pulp and board mill (**Base Case 1B**) is producing 800 000 adt of softwood pulp and 400 000 adt of 3-ply folding box board. The board mill consumes about 60 000 adt of produced pulp annually and imports heat and electricity from the Kraft pulp mill. The net production of pulp is 740 000 adt. The remaining pulp and the board are sold to the market. The configuration of the Kraft pulp mill is identical to the pulp mill in Base Case 1A.

The battery limit of the reference pulp mill consists of the following units:

- Unit 1000 Wood Handling
- Unit 2000 Cooking Plant
- Unit 2100 Brown Stock Handling
- Unit 2200 Oxygen Delignification Plant
- Unit 3100 Pulp Bleaching and Washing
- Unit 3200 Pulp Drying
- Unit 4100 Black Liquor Evaporator
- Unit 4200 Kraft Recovery Boiler
- Unit 5000 Recausticising Plant
- Unit 5100 Lime Kiln
- Unit 6100 Multi-fuel Boiler
- Unit 6200 Steam Turbine Island
- Unit 7100 Bleach Chemical Plant
- Unit 7200 White Liquor Oxidiser
- Unit 7300 Air Separation Unit
- Unit 8000 Wastewater Treatment Plant
- Unit 9000 Board machine (applicable in Base Case 1B only)

The overall block flow diagrams of the reference pulp mills (Base Case 1A and 1B) and related units are presented in Annexes I and II.

The unit consumptions of the each unit processes of the reference mills are reported in per adt of pulp, with 800 000 adt/y of pulp production as basis. If Base Cases 1A and 1B differ, the unit consumptions are given for both cases. The overall mass and energy balances for both Base Cases 1A and 1B are summarized in Chapter 4 – Mill level results.

No additional biofuel is needed for the base cases. The reference mill is described in detail in [2] and applied in [6]. A short overview of the pulping processes is given below. Detailed description can be found in literature [7–9].

3.1 Wood handling (Unit-1000)

Main units of wood handling are: (i) Wood storage, (ii) de-icing, (iii) debarking lines, (iv) chipping lines, (v) knife grinder, (vi) chip storage with chip piles, (vii) screening lines, and (viii) related conveyors.

The best option is to feed fresh wood to the pulp mill. However, some wood storage is always needed. The average capacity of wood storage typically covers one month of consumption. During summer time it might be necessary to water the stored wood in order to prevent extensive drying. During winter time de-icing with warm water is needed before debarking.

The purpose of debarking is to remove bark with minimal wood losses. Bark in the pulping process reduces the quality of the pulp. Dry debarking is applied in the reference pulp mill. Water is applied after the debarking drum when the logs are washed. This minimises the effluent flow from the wood handling and reduces the moisture content of the bark to be combusted in the multi-fuel boiler [10].

The debarked wood is chipped. The target is to produce as uniform chips as possible, in order to facilitate the cooking process. The chips are screened and stored in piles for continuous operation of the pulp mill. An overall flow diagram of the wood handling plant is presented in Figure 1. Main streams are summarized in Table 1 and the key parameters used in the calculations are presented in Table 2.

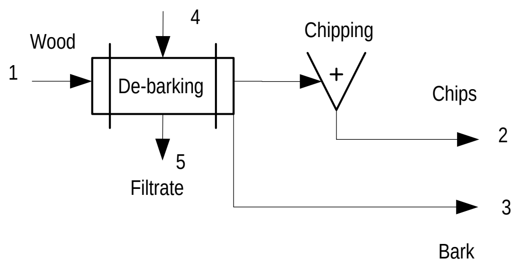


Figure 1: Overview of wood handling (Unit-1000)

Table 1: Main streams of the wood handling (Unit-1000)

Stream		Wood	Chips	Bark	Water	Effluent
In/Out		In	Out	Out	In	Out
Index		1	2	3	4	5
Total flow	[kg/adt]	4698	4181	481	1000	1036
Suspended solids	[kg/adt]	2297	2090	192		
Dissolved solids	[kg/adt]			3		11
Suspended solids	[%]	50%	50%	40%	0%	0%
Temperature	[°C]	15	15	30	35	30

Table 2: Wood handling and chipping parameters (Unit-1000) [2]

Parameter	Unit	Value
Water consumption	[t/adt]	1
% bark dissolved	[t/adt]	7
Dry content of pressed bark	[%]	40

3.2 Cooking plant (Unit-2000)

Delignification of chips begins in the cooking plant. Main units are; (i) chip bin, (ii) impregnation vessel, (iii) continuous digester, (iv) blow line, (v) re-boiler, and (vi) turpentine recovery system.

The aim of cooking is to remove the lignin from the wood and facilitate defibrillation. This is conducted by applying cooking chemicals (NaOH and Na_2S) and heat in continuous digester. The white liquor is referred to as fresh cooking liquor. Black liquor is the spent cooking liquor with dissolved woody materials. Some cooking liquors are impregnated into the chips before the digester. Also steam generated in the reboiler is used for heating the incoming chips. The cooking temperature is 160°C and the H-factor is 1200. The final cooking kappa is 29 and the yield of incoming chips is ~ 47% (o.d. basis). Cooked pulp is blown into the brown stock handling. Typically, turpentine is recovered from the blow line vapour, but in this study it is assumed as part of the weak black liquor treated at the evaporation plant. An overall block diagram of the cooking plant is presented in Figure 2. Main streams are summarized in Table 3 and the relevant operating parameters are presented in Table 4.

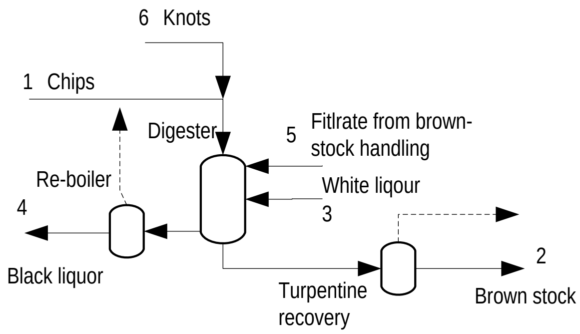


Figure 2: Cooking plant (Unit-2000)

Table 3: Main streams of the cooking plant (Unit-2000)

Stream		Chips	Brown stock	White liquor	Black liquor	Filtrate	Knots
In/Out		In	Out	In	Out	In	In
Index		1	2	3	4	5	6
Total flow	[kg/adt]	4181	8990	3935	9662	10548	818
Suspended solids	[kg/adt]	2090	980				164
Dissolved solids	[kg/adt]		739	677	1700	780	
Suspended solids	[%]	50%	11%				20%
Temperature	[°C]	15	98	95	101	86	83

Table 4: Cooking parameters (Unit-2000) [2]

Parameter	Unit	Value
Pre-steaming temperature	[°C]	30
Steaming temperature	[°C]	105
Liquor to wood ratio at impregnation	[]	5.4
Impregnation temperature	[°C]	115
Liquor to wood ratio at cooking	[]	4.5
Cooking temperature	[°C]	160
H-factor	[]	1200
Kappa after cooking	[]	29
Final pulp consistency	[%]	10.9
Final cooking yield	[%]	47.4
Knot cooking yield	[%]	60
Heat duty	[GJ/adt]	1.9

3.3 Brown stock handling (Unit-2100)

Main units of the brown stock handling are; (i) two brown stock washing units and (ii) de-knotting and screening units. The first washing unit is a diffuser type washer and the second unit is a drum displacer (DD) type washer. The purpose of brown stock washing is to recover dissolved wood and dissolved inorganic material from the brown stock. The aim of de-knotting is to separate un-cooked pieces of wood (e.g. knots, un-cooked chips) and recycle those back to the cooking. The target of screening is to remove other unsuitable materials from wood (pieces of metal, plastic, sand or bark) from the brown stocks. Rejects from screening are sent to the landfill. An overall block diagram of the brown stock handling unit is presented in Figure 3. Main streams are summarized in Table 5 and the main process parameters are presented in Table 6.

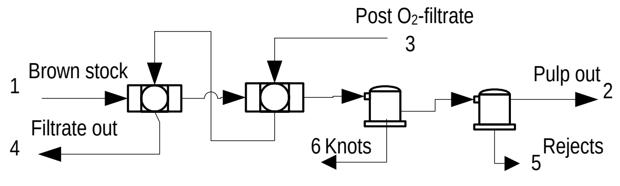


Figure 3: Overview of the brown stock handling (Unit-2100)

Table 5: Main streams of the brown stock handling (Unit-2100)

Stream		Brown stock	Brown stock	Filtrate	Filtrate	Rejects	Knots
In/Out		In	Out	In	Out	Out	Out
Index		1	2	3	4	5	6
Total flow	[kg/adt]	8990	7538	8679	10548	9	818
Suspended solids	[kg/adt]	980	977			3	164
Dissolved solids	[kg/adt]	739	117	158	780		
Suspended solids	[%]	11%	13%			30%	20%
Temperature	[°C]	98	94	94	86	83	83

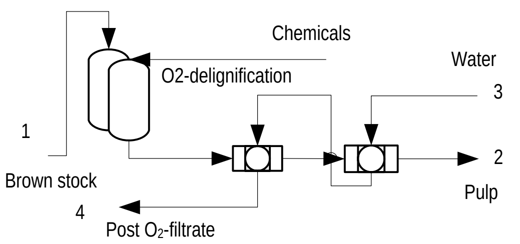
Table 6: Brown stock handling parameters (Unit-2100) [2]

Parameter	Unit	Value
Diffuser		
Pulp consistency in washing	[%]	10
E_{10} efficiency factor	[]	6.0
Pulp consistency after washer	[%]	10
Washer		
Pulp cons. In washing	[%]	11
E_{10} efficiency factor	[]	9.2
Pulp cons. after washer	[%]	13
De-knotting		
Screening cons.	[%]	3.8
Accept cons.	[%]	5
Reject cons.	[%]	20
Knot fraction	[%]	1.7
Screening		
Screening cons.	[%]	2.5
Accept cons.	[%]	4.5
Reject cons.	[%]	30
Reject fraction	[%]	0.3

3.4 Oxygen delignification plant (Unit-2200)

The delignification process of fibres continues in the two-stage oxygen delignification plant. The main benefits of the oxygen delignification process is to provide better selectivity in the lignin removal and improved pulp yield when compared to extended cooking to lower the kappa number. Oxygen delignification is conducted at elevated temperatures (90-100°C) in an alkaline medium. In addition to oxygen, oxidised white liquor is used in this process. The Kappa number after two-stage oxygen delignification is 14 and the yield loss is ~ 2% of the pulp. A dilution factor of 2.5 is applied for the washing waters. Roughly 30% of washing waters is evaporator condensate and the remaining 70% is fresh water. Counter-current washing through O_2-delignification, brown stock handling and finally cooking plant is applied.

A block diagram of the oxygen delignification plant is presented in Figure 4. Main process streams are summarized in Table 7 and the main process parameters are presented in Table



8.

Figure 4: Oxygen delignification plant (Unit-2200)

Table 7: Main streams of the oxygen delignification plant (Unit-2200)

Stream		Brown stock	Brown stock	Water	Filtrate
In/Out		In	Out	In	Out
Index		1	2	3	4
Total flow	[kg/adt]	7538	7860	9285	8679
Suspended solids	[kg/adt]	977	943		
Dissolved solids	[kg/adt]	117	3.6		158
Suspended solids	[%]	13	12		
Temperature	[°C]	94	79	79	94

Table 8: Oxygen delignification parameters (Unit-2200) [2]

Parameter	Unit	Stage 1	Stage 2	Total
O_2-delignification				
Consistency	[%]	12	12	
Reactor temperature	[C]	90	98	
O_2 charge	[kg/adt]	12	12	24
Oxidized white liquor charge*	[kg/adt]	7	7	14
$MgSO_4$ charge	[kg/adt]	3	0	3
Kappa number after O2-delignification	[]			14
Yield losses	[%]			1.8
Heat duty	[GJ/adt]			0.2
Washing				
Pulp consistency in washing	[%]	10	5.5	
E_{10} efficiency factor	[]	5.7	4.8	
Pulp consistency after washer	[%]	11	12	
Dilution factor				2.5

*Equivalent of 126 kg/adt of liquor at TDS = 19.5%.

3.5 Pulp bleaching and washing (Unit-3100)

Pulp brightness is further improved in the four-stage pulp bleaching unit by removing the remaining lignin compounds in the pulp. Bleaching is done by elemental chlorine free (ECF) applying D_0-E_{OP}-D_1-P sequence. Chlorine dioxide is used as bleaching chemical in D0 and D1 stages. Alkaline stages are EOP and P, where NaOH, H_2O_2 and O_2 are applied. The target pulp brightness after bleaching is 88.5% (ISO Brightness). The total pulp loss during bleaching is 5%.

Each of the bleaching stages is followed by a washing unit, where drum displacer type washers are utilised. The pulp consistency in the washers is 12 – 13% and the washing efficiency (E10) is ~ 5. The total fresh water used during pulp bleaching is about 9 m^3/adt.

A block diagram of the pulp bleaching and washing unit is presented in Figure 5. Main streams are summarised in Table 9 and the main process parameters are presented in Table 10.

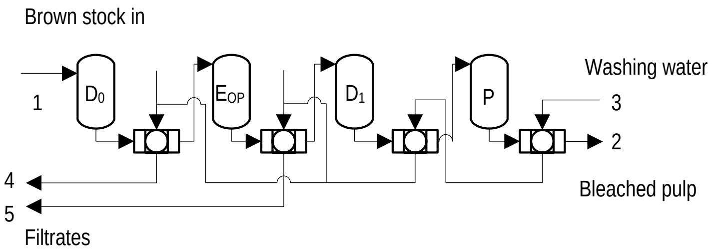


Figure 5: Pulp bleaching and washing (Unit-3100)

Table 9: Main streams of the pulp bleaching and washing (Unit-3100)

Stream		Brown stock	Bleached pulp	Water	Acidic effluent*	Alkaline effluent*
In/Out		In	Out	In	Out	Out
Index		1	2	3	4	5
Total flow	[kg/adt][B]	7860	6930	9000**	8980	6499
Suspended solids	[kg/adt][B]	943	901			
Dissolved solids	[kg/adt][B]	3.6	17		34	56
Suspended solids	[%]	12%	13%			
Temperature	[°C]	79	59	50	70	82

* Note: Effluents include effluent collected from the pulp dryer as well; [B] The production of bleached pulp is 5% smaller in Base Case 1B than in Base Case 1A. See mill level results in Table 32 and in Annexes 1 and 2; ** Includes the fresh water (4000 kg/adt) used in the dryer.

Table 10: Pulp bleaching and washing parameters (Unit-3100) [2]

Parameter	Unit	D_0	E_{OP}	D_1	P	Total
Bleaching						
Consistency	[%]	9	10	9	10	
Reactor temperature	[°C]	70	85	70	80	
Bleaching losses	[%]	1.5	1.5	1	1	5
ClO_2 charge	[kg a-Cl/adt]*,B	24.9		14.1		39.0
NaOH charge	[kg/adt]**,B		10	1.8	8	19.8
H_2O_2 charge	[kg/adt]**,B		3.7		3.7	7.4
O_2 charge	[kg/adt]**,B		1			1.0
$MgSO_4$ charge	[kg/adt]**,B		0.5			0.5
Talc charge	[kg/adt]**,B	2	2			4.0
Heat duty	[GJ/adt][B]					0.9
Washing						
Pulp consistency in washer	[%]	12	12	12	12	
E_{10} efficiency factor	[]	5.2	5.2	5.1	5.1	
Pulp consistency after washer	[%]	13	13	13	13	
Fresh water to stage	[m^3/adt][B]	3	2		4	9

* Active chlorine: 2.63 kg of a-Cl is equivalent to 1.0 kg of ClO_2; ** Chemical charges reported as o.d. basis (i.e. 100% purity); [B] The production of bleached pulp is 5% smaller in Base Case 1B than in Base Case 1A. See mill level results in Table 32 and in Annexes 1 and 2.

3.6 Pulp dryer (Unit-3200)

Bleached pulp is dried. The following units are applied (i) screening and cleaning, (ii) dilution head box, (iii) twin-wire former, (iv) combi-press with shoe-press and (v) airborne dryer. Dried pulp is also (vi) cut, (vii) baled, and (viii) stored. The bleached pulp consistency is 13% after bleaching. A consistency of 50% is achieved after pressing and 90% is achieved for the market pulp after hot air drying.

In the airborne dryer, hot air is blown into the pulp web where the moisture is removed to the target dryness. This technique allows a gentler treatment to the pulp and improves its rewetting properties. Humidity of the incoming air and exhaust is defined according to the work reported in [11]. A block diagram of pulp drying is presented in Figure 6 and main streams are summarized in Table 11. Key process parameters are presented in Table 12.

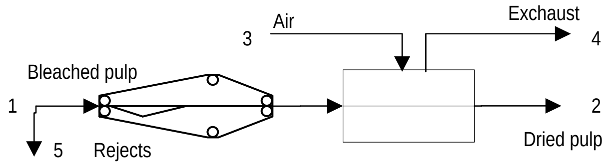


Figure 6: Pulp dryer (Unit-3200)

Table 11: Main streams of the pulp dryer (Unit-3200)

Stream		Bleached pulp	Dried pulp	Air	Exhaust	Rejects
In/Out		In	Out	In	Out	Out
Index		1	2	3	4	5
Total flow	[kg/adt][B]	6930	1000	5776	6576	7
Suspended solids	[kg/adt][B]	901	900			
Dissolved solids	[kg/adt][B]	17	2			
Suspended solids	[%]	13%	90			13%
Relative humidity	[%]			28	41	
Temperature	[°C]	59	75	35	80	59

[B] The production of dried pulp is 8% smaller in Base Case 1B than in Base Case 1A. See mill level results in Table 32 and in Annexes 1 and 2.

Table 12 Pulp dryer parameters (Unit-3200) [2]

Parameter	Unit	Value
Reject fraction	[%]	0.1
Consistency after press	[%]	50
Outlet sheet temp	[°C]	75
Outlet sheet cons.	[%]	90
Section heat losses	[%]	1
Exhaust air temp	[°C]	80
Percent blow-through steam	[%]	2
Exhaust air moisture	[g H_2O/kg dry air]	150
Heat duty	[GJ/adt][B]	2.0

[B] The production of dried pulp is 8% smaller in Base Case 1B than in Base Case 1A. See mill level results in Table 32 and in Annexes 1 and 2.

3.7 Black liquor evaporation (Unit-4100)

The target of the black liquor evaporation plant is to remove the excess water from the weak black liquor before combustion in the recovery boiler. Additionally, side streams can be extracted where chemicals such as crude tall oil, methanol and turpentine can be recovered from the evaporation plant. In this study, the evaporation takes place in a seven stage evaporation plant. Only crude tall oil (CTO) is recovered as by-product. Other chemicals (such as methanol, turpentine) are assumed to be incinerated together with black liquor in the recovery boiler as the recoverable amount of these species is minimal. Furthermore, it is also assumed that all the malodorous gases are combusted in the recovery boiler. As a consequence, the gas collection system is not included in the calculation of the heat and mass balance.

The target of the evaporation plant is to produce black liquor with at least 80% dry solid content. When the saltcake from the ash leaching plant is added to the black liquor, the dry solids as fired should increase to around 82%. Roughly 40 kg/adt of crude tall oil is collected.

A block diagram of the black liquor evaporation plant is presented in Figure 7 and related stream data is summarized in Table 13. Key process parameters are presented in Table 14.

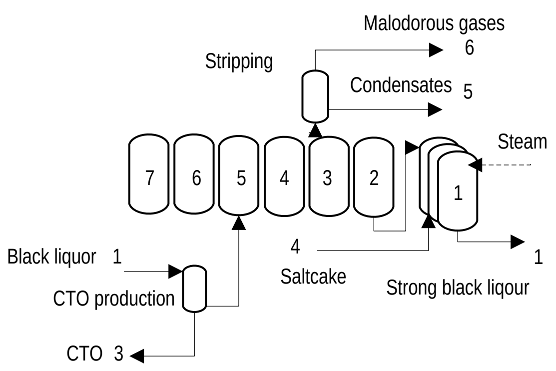


Figure 7: Black liquor evaporation (Unit-4100)

Table 13: Main streams of the black liquor evaporation (Unit-4100)

Stream		Weak black liquor	Strong black liquor	Crude tall oil (CTO)	Saltcake	Condensates	Malodorous gases[a]
In/Out		In	Out	In	In	Out	Out
Index		1	2	3	4	5	6
Total flow	[kg/adt]	9662	2268	39	208	6743	10
Dissolved solids	[kg/adt]	1700	1864	39			10
Dry solids	[%]	18%	82%				
Temperature	[°C]	101	119	101	180	80	

[a] Malodorous gases, methanol and turpentine are combusted with strong black liquor.

Table 14: Black liquor evaporation parameters (Unit-4100) [2]

Parameter	Unit	Value
Black liquor target DS	[%]	80
CTO yield	[%]	95
H_2SO_4 use in tall oil plant	[kg/t CTO]	130
Heat duty	[GJ/adt]	2.8

3.8 Kraft recovery boiler (Unit-4200)

In the Kraft pulp mill, the recovery boiler has two main tasks: to recycle the cooking chemicals from the black liquor and to convert the dissolved woody materials in the black liquor to energy. The lower furnace is operated in a reducing environment (sub-stoichiometric conditions) in order to ensure the recovery of the cooking chemicals. The upper furnace is operated in an oxidising environment (i.e. greater than stoichiometric conditions) in order to ensure full combustion of the organic matters.

The recovery boiler includes the following units: (i) recovery boiler, (ii) electrostatic precipitators (ESPs), (iii) flue gas stack, (iv) boiler feed water plant, (v) condensate treatment, and (vi) ash leaching plant.

Steam parameters assumed in this study are 505°C and 103 bar. Malodorous gases, methanol and turpentine are combusted in the recovery boiler together with black liquor. Incoming air is preheated. Fly ash is leached in order to control the levels of potassium and chlorine in the recovery cycle (as excess amount of these compounds could expose the recovery boiler to stickies and corrosion). Brine from ash leaching is discharged with the wastewater. Intermediate pressure steam is used for soot blowing.

An overall block flow diagram of the recovery boiler is presented in Figure 8. Related process streams are summarized in Table 15 and key parameters are presented in Table 16.

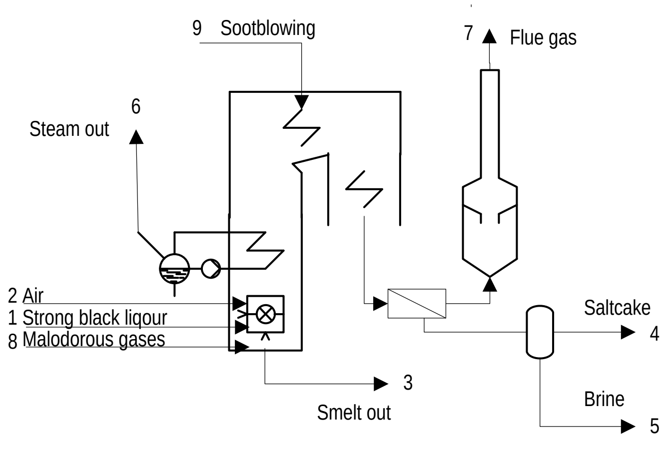


Figure 8: Kraft recovery boiler (Unit-4200)

Table 15: Main streams of the Kraft recovery boiler (Unit-4200)

Stream		Strong black liquor	Air	Smelt	Saltcake	Brine	Steam	Flue gas	Mal-odorous gases[a]	Soot blowing
In/Out		In	In	Out	Out	Out	Out	Out	In	In
Index		1	2	3	4	5	6	7	8	9
Total flow	[kg/adt]	2268	8877	729	208	29	6913	10189	10	193
Dissolved solids	[kg/adt]	1864							10	
Dry solids	[%]	82%								
Temperature	[°C]	119	139	850	180	180	505	189		352
CO_2 emissions	[kg/adt]							2053		

[a] Malodorous gases, methanol and turpentine are combusted with strong black liquor.

Table 16: Kraft recovery boiler parameters (Unit-4200) [2]

Parameter	Unit	Value
Recovery boiler		
Steam temperature	[°C]	505
Steam pressure	[bar]	103
Excess air	[%]	15
Loading factor		1
Dregss per solids entering furnace	[kg/t ds]	0.35
Reduction ratio	[%]	95
Smelt temperature	[°C]	850
Flue gas temperature	[°C]	180
Chlorine enrichment factor		2.35
Potassium enrichment factor		1.35
Temp after LP air heater	[°C]	116
Temp after MP air heater	[°C]	165
Soot blowing steam fraction		0.03
Ash leaching		
Chlorine separation in ash leaching	[%]	80
Potassium separation in ash leaching	[%]	75
Sodium losses in ash leaching	[%]	25
Sulfur losses in ash leaching	[%]	17

3.9 Recausticising plant (Unit-5000)

The purpose of the recausticising plant is to convert the smelt from the recovery boiler to produce the fresh cooking chemicals or white liquor.

The smelt obtained from the recovery boiler is mixed and stabilised with the weak wash obtained from the lime mud washer to produce the green liquor (which is a solution that mainly consists of sodium carbonates). This liquor is recovered from the clarifier (also to separate out the dregs). The recovered solution is mixed with the lime to convert the sodium carbonate to sodium hydroxide. The recausticised solution is filtered to separate the white liquor from the lime mud.

The properties of the white liquor or fresh cooking liquor are adjusted at the recausticising plant by adding fresh batch of sodium hydroxide. The target causticity of the white liquor is 82% with a sulfidity of 40% and an effective alkali concentration of 112 g NaOH/l. See Table 18 for details.

Main process steps include (i) green liquor filtering, (ii) dregs washing, (iii) slaker, (iv) recausticisers, and (v) white liquor filtering. An overall block flow diagram is presented in Figure 9 and main streams are summarized in Table 17.

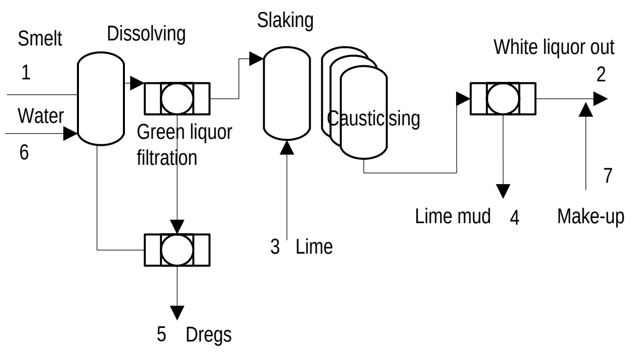


Figure 9: recausticising plant (Units-5000)

Table 17: Main streams of the recausticising plant (Unit-5000)

Stream		Smelt	White liquor	Lime	Lime mud	Dregss	Water	Make-up
In/Out		In	Out	In	Out	Out	In	In
Index		1	2	3	4	5	6	7
Total flow	[kg/adt]	729	4059	240	592	2	3802	18
Dissolved solids	[kg/adt]		677		9			
Suspended solids	[kg/adt]				452			
Dry solids	[%]		17%		78%			100%
Temperature	[°C]	850	95	97	102	112	92	25

Table 18: Recausticising plant parameters (Unit-5000) [2]

Parameter	Unit	Value
Effective alkali on wood	[% NaOH]	20.5
Sulfidity	[%]	40
Causticity	[%]	82
Conc. of effective alkali	[g NaOH/l]	112
Charge Ox WL into O_2-stages	[fraction NaOH]	0.0135

3.10 Lime kiln (Unit-5100)

The lime cycle is the other chemical cycle in the pulp mills. The fresh lime is used in the recausticising plant and this is produced by reburning the lime mud in a rotary kiln (where calcium carbonate is converted back to calcium oxide). The main units of the lime plant are: (i) lime dewatering unit, (ii) lime mud dryer, (iii) lime kiln, (iv) lime cooler and (v) ESP filters. This study assumed that heavy fuel oil is used as fuel in the lime kiln.

The flue gas of the lime kiln is expected to have a higher CO_2 concentration compared to the flue gases of the recovery boiler or the multi-fuel boiler. This is due to the CO_2 produced by the chemical conversion of the lime mud (i.e. conversion of $CaCO_3$ to CaO) in addition to the CO_2 produced from burning of the fuel oil in the rotary kiln.

An overall block diagram of the lime kiln is presented in Figure 10 and related stream values are summarized in Table 19. Key parameters are presented in Table 20.

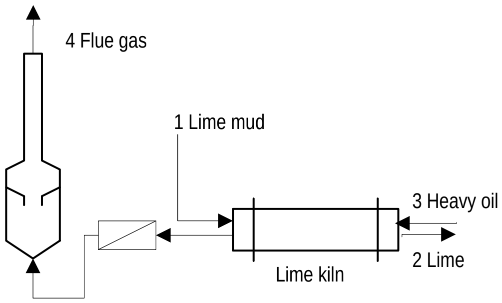


Figure 10: Lime kiln (Unit-5100)

Table 19: Main streams of the lime kiln (Unit-5100)

Stream		Lime mud	Lime	Heavy oil	Flue gas
In/Out		In	Out	In	Out
Index		1	2	3	4
Total flow	[kg/adt]	592	240	35	856
Dissolved solids	[kg/adt]	9			
Suspended solids	[kg/adt]	452			
Dry solids	[%]	78%			
Temperature	[°C]	102	97		250
CO_2 emissions	[kg/adt]				273

Table 20: Lime kiln parameters (Unit-5100)

Parameter	Unit	Value
Exit lime temperature	[°C]	300
Exit flue gas temperature	[°C]	250
Excess air	[%]	10
$CaCO_3$ conversion	[%]	98
Heat losses	[%]	12

3.11 Multi-fuel boiler (Unit-6100)

For Base Cases 1A and 1B there is no need to source any fuel from outside the battery limit. The bark collected from the wood handling plant should be sufficient to produce enough steam to fulfil the energy demand for both cases. Bark is combusted in a multi-fuel boiler. Other fuels, such as forest residues, chips and peat can be used as well. Sludge from the wastewater treatment plant is also combusted in the multi-fuel boiler. The amount of sludge is ~ 5% of the amount of bark.

The multi-fuel boiler consists of the following units; (i) fluidized bed boiler, (ii) electrostatic precipitators (ESPs), and (iii) flue gas stack. Boiler feed water and condensate systems are shared with the recovery boiler unit. The multi-fuel boiler is designed to produce high pressure (HP) steam with the same steam parameters (505°C and 103 bar) as HP steam from the recovery boiler. Incoming air is preheated. Ash is collected and sent to the landfill. An overview of the multi-fuel boiler is presented in Figure 11 and related streams are summarized in Table 21. Key parameters are presented in Table 22.

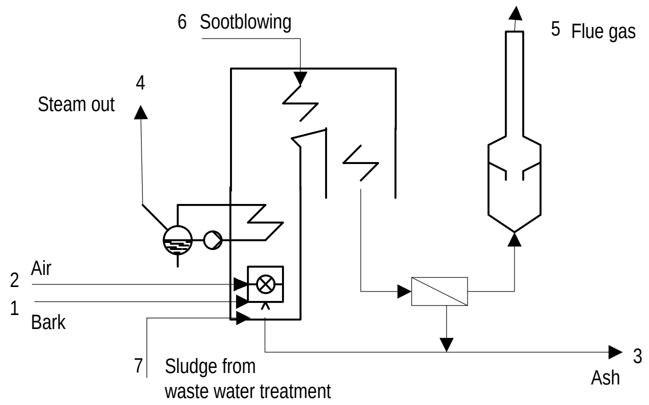


Figure 11: Multi-fuel boiler (Unit-6100)

Table 21: Main streams of the Multi-fuel boiler (Unit-6100)

Stream		Bark	Air	Ash	Steam	Flue gas	Soot blowing	Sludge[B]
In/Out		In	In	Out	Out	Out	In	In
Index		1	2	3	4	5	6	7
Total flow	[kg/adt]	481	1313	5	1015	1885	21	25
Suspended solids	[kg/adt]	192						10
Dry solids	[%]	40%						40%
Temperature	[°C]	70	139	189	505	189	352	70
CO_2 emissions	[kg/adt]					376		

[B] The sludge generation is slightly higher in Base Case 1B. However, this small change is omitted in this study.

Table 22: Multi-fuel boiler parameters (Unit-6100)

Parameter	Unit	Value
Steam temperature	[°C]	505
Steam pressure	[bar]	103
Excess air	[%]	15
Loading factor		1
Flue gas temperature	[°C]	180
Temp after LP air heater	[°C]	116
Temp after MP air heater	[°C]	165

3.12 Steam turbine island (Unit-6200)

The steam turbine island includes (i) an extraction-condensing type turbine, and (ii) generator set. HP steam (103 bar and 505°C) is obtained from the recovery and multi-fuel boilers. HP steam is delivered to the steam turbine to produce electricity. The steam turbine is capable of extracting steam at three different levels:

1) 30 bar intermediate pressure (IP) steam for soot blowing

2) 13 bar medium pressure (MP) steam for the pulp mill processes

3) 4.2 bar low pressure (LP) steam for the pulp and board mill processes

The remaining un-extracted steam is condensed at 0.03 bar and is accounted for in the model. There is no option for district heating included in this study. An overview of the turbine is presented in Figure 12 and related streams are summarized in Table 23. Turbine parameters are presented in Table 24.

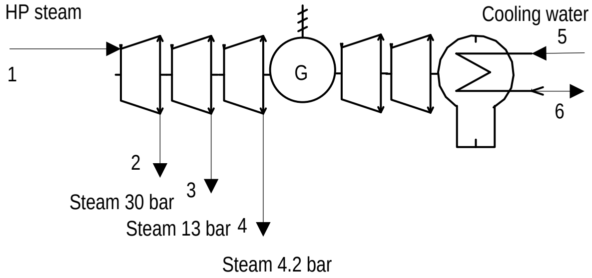


Figure 12: Turbine unit (Unit-6200)

Table 23: Main streams of the turbine unit (Unit-6200). Total flows for Base Cases 1A and 1B

Stream		HP Steam 103 bar	IP Steam 30 bar	MP Steam 13 bar	LP Steam 4.2 bar	Cooling water in	Cooling water out
In/Out		In	Out	Out	Out	In	Out
Index		1	2	3	4	5	6
Total flow (1A)	[kg/adt]	7928	214	1795	2680	124866	124866
Total flow (1B)	[kg/adt]	7928	214	1757	3694	90174	90174
Temperature	[°C]	505	352	200	154	10	20

Table 24: Turbine unit parameters (Unit-6200) [2]

Parameter	Unit	1	2	3	4	5	Generator
Section output pressure	[bar]	30	13	4.2	0.8	0.03	
Section isentropic efficiency	[%]	85	90	90	80	75	99

3.13 Bleach chemical plant (Unit-7100)

Chlorine dioxide is one of the chemicals used in pulp bleaching (i.e. stages D_0 and D_1). To employ ECF bleaching, the R8 process is applied to produce the chlorine dioxide. This process uses $NaClO_3$, methanol and H_2SO_4 as the raw materials. Solid residue, saltcake, from the bleach chemical plant is discharged with pulp mill wastewater as diluted solution. The process flow diagram is presented in Figure 13. The main streams are presented in Table 25 [10].

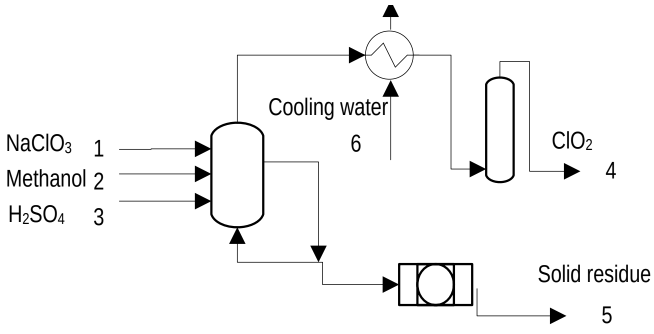


Figure 13: Bleaching chemical plant (Unit-7100)

Table 25: Main streams of the bleach chemical plant (Unit-7100) [5,12]

Stream	$NaClO_3$	Methanol	H_2SO_4	ClO_2	Solid residue	Cooling water
In/Out	In	In	In	Out	Out	In/Out
Index	1	2	3	4	5	6
Total flow [kg/adt][B]	24	3	15	15	19	4450

[B] Bleaching chemical consumption is slightly smaller for base case 1B as 5% of the pulp is not bleached. This is small change omitted here.

3.14 White liquor oxidizer (Unit-7200)

Alkaline conditions are needed during pulp delignification in the oxygen delignification unit. White liquor is often used for this purpose. White liquor is pre-oxidized in the white liquor oxidizer to convert any sodium sulfide to sodium thiosulfate. This is to ensure that no additional oxidation will occur during the oxygen delignification process. To pre-oxidise the white liquor, oxygen from the air separation unit is used. An example of the technology is given in [13]. A block diagram is presented in Figure 14 and related streams are summarized in Table 26.

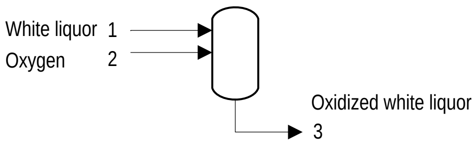


Figure 14: White liquor oxidizer (Unit-7200)

Table 26: Main streams of the white liquor oxidizer (Unit-7200)

Stream	White liquor	Oxygen	Oxidized white liquor
In/Out	In	In	Out
Index	1	2	3
Total flow* [kg/adt]	123	3	126

*TDS = 19.5%. Equivalent to 24 kg/adt of 100% WL.

3.15 Air separation unit (Unit-7300)

Oxygen is utilised in the pulp mill for oxygen delignification, pulp bleaching and white liquor oxidising. In this study the oxygen is produced on-site and a cryogenic air separation unit (ASU) is applied [14]. The gaseous oxygen produced from the ASU has a purity of >99.9% and is delivered at 10 bar.

A block flow diagram is presented in Figure 15 including the following units; (i) process air filter, (ii) main air compressor, (iii) process air pre-cooling and pre-treatment, (iv) cold box, and (v) product compressor. Typically, gaseous nitrogen and crude argon could be co-produced. This study assumed that there is no market for these co-products thus these are purged to the atmosphere. Main streams are summarized in Table 27. The electricity consumption of the ASU is estimated at around 0.68 kWh/Nm^3 O_2 [15].

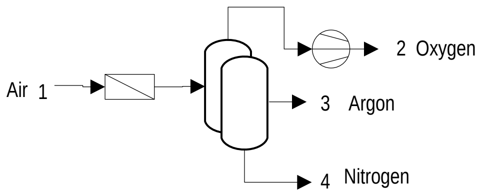


Figure 15: Air separation unit (Unit-7300)

Table 27: Main streams of the air separation unit (Unit-7300)

Stream	Air	Oxygen	Nitrogen	Argon and other losses
In/Out	In	Out	Out	Out
Index	1	2	4	3
Total flow [kg/adt]^B	140	28	110	2

^{B} Consumption of oxygen is slightly smaller for case 1B as 5% of the pulp is not bleached. This small change is not reported here.

3.16 Wastewater treatment (Unit-8000)

Various streams of wastewater from the pulp and board mill carry different kind of organic and inorganic load. In order to purify these wastewater types, a combination of mechanical and biological wastewater treatment processes are applied. Collected wastewater streams are illustrated in Figure 16: (i) acidic filtrate from D_0 and D_1-stages of the pulp bleaching, (ii) Alkaline filtrate from E_{OP} and P-stages of the pulp bleaching, (iii) filtrates from dry debarking, (iv) effluent from the board machine, and (v) other wastewater collected from the mill. The discharge from the wastewater treatment plant should meet EU standard for disposal to the sea. Roughly 10 kg (as bone dry) bio-sludge/adt pulp is generated. The concentration of sludge is 10% [16]. Sludge collected from the wastewater treatment plant is incinerated in the multi-fuel boiler after dewatering and drying. Stream data of the wastewater treatment is summarized in Table 28 and key parameters are presented in Table 29.

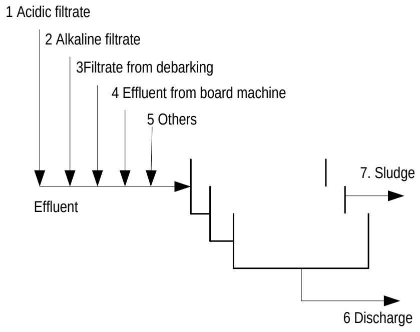


Figure 16: Wastewater treatment (Unit-8000)

Table 28: Main streams of the wastewater treatment (Unit-8000)

Stream		Acidic	Alkaline	Debarking	Board machine	Others	Discharge	Sludge
In/Out		In	In	In	In	In	Out	Out
Index		1	2	3	4	5	6	7
Total flow (1A)	[kg/adt]*	8980	6499	1036	-	1200	17715	100**
Total flow (1B)	[kg/adt]*	8522	6167	1036	4100	1200	21026	100**

*Total flow given here per 800 000 adt/y pulp for both cases 1A and 1B.; **Amount of sludge is same for both base cases 1A and 1B. Small increase due to the board machine effluents is omitted here.

Table 29: Parameters of wastewater treatment (Unit-8000). Derived from [17]

Parameter	Unit	Value
Sludge generation	[kg/adt pulp]*	10
Sludge consistency	[%]	10%
HCl charge	[kg/adt]*	0.1
Polymer	[kg/adt]*	0.1
Defoamer	[kg/adt]*	0.5
$Ca(OH)_2$	[kg/adt]*	0.1
Urea	[kg/adt]*	0.5
H3PO4	[kg/adt]*	0.1

* Flow are given here as o.d. (100%).

3.17 Board machine (Unit-9000)

The integrated pulp and board mill as defined for Base Case 1B assumes that a 3-ply folding box board machine is installed on-site. The parameters of the board are given in Table 31, where it can be seen that some of the pulp produced from the pulp mill (around 60 000 adt/y or 7.5% of the total production) is consumed directly by the board mill.

Figure 17 illustrates an overview of the board machine. The level of details presented in this report is limited as it is only to illustrate that the board mill is a consumer of the pulp, steam and electricity of the pulp mill. A detailed simulation model utilised in [11] is used in the calculation of the streams values shown in Table 30.

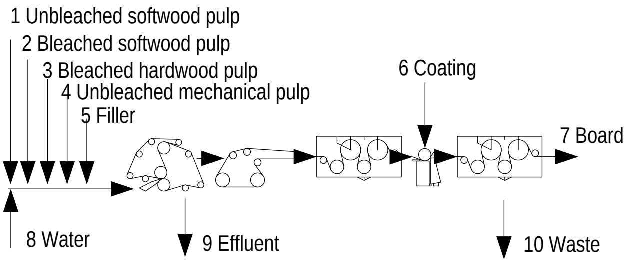


Figure 17: Board machine (Unit-9000)

Table 30: Main streams of the board machine (Unit-9000)

Stream	USKP	BSKP	BHKP	CTMP	Filler	Coating	Board	Water	Effluent	Waste
In/Out	In	In	In	In	In	In	Out	In	Out	Out
Index	1	2	3	4	5	6	7	8	9	10
Total flow [kg/adt]*	393[1]	185[2]	106[3]	291[3]	24	40	500	4550	4100	5

*per adt of pulp; [1]wet pulp (12% consistency); [2]wet pulp (13% consistency); [3]adt pulp (90% consistency)

Table 31: Board machine parameters (Unit-9000). Un-published data from [11]

Parameter	Unit	Value
Machine		
Capacity	[adt[b]/a]	400000
Operation time	[h/a]	8400
Width	[mm]	5000
Machine speed	[m/min]	635
Basis weight	[g/m²]	250
Moisture	[%]	2
Trims and waste	[%]	2
Heat duty	[GJ/adt[b]]	5.0
Electricity	[kWh/adt[b]]	700
Top layer		
Basis weight	[g/m²]	40
BHKP	[%]	100
Filler*	[%]	10
Coating	[g/m²]	20
Middle layer		
Basis weight	[g/m²]	160
USKP	[%]	15
CTMP	[%]	85
Filler*	[%]	4
Back layer		
Basis weight	[g/m²]	25
BHKP	[%]	50
BSKP	[%]	50
Filler*	[%]	10

[b] adt refers to air dried tonne of board here; *Amount of filler is given per 100% of pulps.

The board machine is assumed to produce board with a weight basis of 250 g/m^2 with a moisture content of 2%. The top layer of the board is made of bleached hardwood kraft pulp (BHKP) and coated to the desired surface. The middle layer is primarily made of chemi-thermo mechanical pulp (CTMP) with some amount of unbleached softwood kraft pulp (USKP); and the bottom layer is made of bleached hardwood (BHKP) and softwood (BSKP) kraft pulp. The machine has a width of 5000 mm and operates at a speed of 635 m/min. Waste generation is 1% of total production of board. This waste cannot be recycled, but un-coated and coated broke are reused for board productions.

4. Mill level results

4.1 Mill material balance

The performance of Nordic Kraft pulp mill is summarized in Table 32, where all the raw materials, chemicals, utilities, waste and products are shown.

Table 32: Reference pulp mill balance

	Unit	Base case 1A	Base case 1B	Unit	Base case 1A	Base case 1B
Raw material						
Wood	[m^3/adt]	5.8	5.8	[Mm^3/y]	4.6	4.6
BHKP	[kg/adt]		106	[kt/y]		84.8
CTMP	[kg/adt]		291	[kt/y]		232.5
Filler	[kg/adt]		24	[kt/y]		19.3
Coating	[kg/adt]		40	[kt/y]		32.0
Chemicals						
NaOH	[kg/adt]	37.2	36.2	[kt/y]	29.8	29.0
H_2O_2	[kg/adt]	7.4	7.0	[kt/y]	5.9	5.6
MgSO4	[kg/adt]	3.5	3.5	[kt/y]	2.8	2.8
CaO	[kg/adt]	5.2	5.2	[kt/y]	4.2	4.2
H_2SO_4	[kg/adt]	20.0	19.3	[kt/y]	16.0	15.4
$NaClO_3$	[kg/adt]	24.5	23.2	[kt/y]	19.6	18.6
Methanol	[kg/adt]	2.5	2.4	[kt/y]	2.0	1.9
Talc	[kg/adt]	4.0	3.8	[kt/y]	3.2	3.0
Utilities						
Cooling water	[m^3/adt]	129	94	[Mm^3/y]	103.6	75.4
Process water	[m^3/adt]	16.4	20.6	[Mm^3/y]	13.1	16.4
Boiler water	[m^3/adt]	1.0	1.0	[Mm^3/y]	0.8	0.8
HFO	[kg/adt]	35	35	[kt/y]	28.0	28.0
Waste						
Wastewater	[m^3/adt]	17.7	21.0	[Mm^3/y]	14.2	16.8
Ash	[kg/adt]	5.0	5.0	[kt/y]	4.0	4.0
gritss	[kg/adt]	7.5	7.5	[kt/y]	6.0	6.0
Dregss	[kg/adt]	1.7	1.7	[kt/y]	1.3	1.3
Pulp and board waste	[kg/adt]	15.9	20.8	[kt/y]	12.7	16.6
Products						
Pulp	[kg/adt]	1000	923	[kt/y]	800	738
Board	[kg/adt]		500	[kt/y]		400
CTO	[kg/adt]	39	39	[kt/y]	31.2	31.2
Electricity	[kWh/adt]	1127	666	[GWh/y]	902	533

4.2 Mill heat balance

The heat balance of the reference mills is shown in Table 33. Major consumers of heat are listed. Pulp drying and the board machine are the largest heat consumers of the mills followed by cooking plant and pulp bleaching. Intermediate pressure steam is used for soot blowing of the recovery and multi-fuel boilers. There is sufficient heat available for both reference cases; therefore there is no need of any additional biofuel from outside of the battery limit. The total heat consumed by the pulp and board mill is ~10 GJ/adt and ~5 GJ/adt, respectively. These figures are in line with the performance of the reference mills reported in [2] and [10].

Table 33: Mill heat balance; major consumers

Unit	Description	Steam type	Unit	Base case 1A	Base case 1B	Unit	Base case 1A	Base case 1B
2000	Cooking Plant	MP steam	[kg/adt]	913	913	[kt/y]	730	730
		LP steam	[kg/adt]	71	71	[kt/y]	57	57
2200	Oxygen Delignification Plant	MP steam	[kg/adt]	56	56	[kt/y]	45	45
3100	Pulp Bleaching	MP steam	[kg/adt]	508	470	[kt/y]	406	376
3200	Pulp Drying	LP steam	[kg/adt]	1062	980	[kt/y]	850	784
4100	Evaporator	LP steam	[kg/adt]	910	910	[kt/y]	728	728
		MP steam	[kg/adt]	318	318	[kt/y]	254	254
4200	Kraft Recovery Boiler	IP steam	[kg/adt]	193	193	[kt/y]	154	154
		LP steam	[kg/adt]	501	501	[kt/y]	401	401
6100	Multi-fuel boiler	IP steam	[kg/adt]	21	21	[kt/y]	17	17
		LP steam	[kg/adt]	55	55	[kt/y]	44	44
7100	Bleaching chemical plant	LP steam	[kg/adt]	81	77	[kt/y]	65	61
7300	Air separation unit	MP steam	[kg/adt]	1	1	[kt/y]	1	1
9000	Board machine	LP steam	[kg/adt]		1100	[kt/y]	0	880
	Total	LP steam	[kg/adt]	2680	3694	[kt/y]	2144	2955
		MP steam	[kg/adt]	1796	1758	[kt/y]	1437	1406
		IP steam	[kg/adt]	214	214	[kt/y]	171	171

NOTE: the unit consumptions of Base case 1A and 1B reported in this table are calculated based on 800 000 adt/y of pulp production

4.3 Hot and warm water system

An efficient hot and warm water system (HWWS) is assumed for the reference mill. It is expected that excess heat from the pulp mill is fully utilized for heating the incoming process water used within the battery limit. No additional low pressure steam is required for the heating of the incoming cold water is assumed. Likewise, it is neither expected that there will be additional low quality heat sources that could be recovered within the site by any potential users (e.g. CCS).

In many cases, e.g. in the FRAM reference mill [18], a less efficient HWWS is applied and additional steam is needed for heating the process water. In such cases, detailed studies have been conducted to assess the potential reduction of low pressure steam usage of the HWWS [18–20]. The studies have concluded that a moderate reduction (i.e. < 10% LP steam) could be achieved by redesigning the heat exchange network. The aim of these studies was to reach same level as in the reference mill presented in this study.

4.4 Mill electricity balance

The electricity consumption of the reference mills are listed in Table 34. It could be noted that the board machine is the largest consumer of electricity due to the large volume of suspended pulp being pumped. Other large consumers are the pulp dryer unit and the pulp bleaching and washing unit. Additional consumers which are not defined separately in this report are included in the electricity consumption of the mill infrastructure. These should include off-site units, process control and instrumentation, office buildings, street lighting and others.

The total electricity consumption is 640 kWh/adt and 990 kWh/adt of pulp for Base Cases 1A and 1B, respectively. These figure are well in line with the best available techniques [10] and other reference mills [2]. The on-site electricity production is reported in Table 34.

Table 34: Mill electricity balance. Distribution to units from [10]

Unit	Description	Unit	Base case 1A	Base case 1B	Unit	Base case 1A	Base case 1B
0000	Mill infrastructere	[kWh/adt]	27	33	[GWh/y]	22	26
1000	Wood handling	[kWh/adt]	44	44	[GWh/y]	35	35
2000	Cooking plant	[kWh/adt]	43	43	[GWh/y]	34	34
2100	Brown stock handling	[kWh/adt]	58	58	[GWh/y]	46	46
2200	Oxygen delignification	[kWh/adt]	58	58	[GWh/y]	46	46
3100	Pulp bleaching and washing	[kWh/adt]	77	73	[GWh/y]	62	59
3200	Pulp dryer	[kWh/adt]	116	107	[GWh/y]	93	86
4100	Black liquor evaporation	[kWh/adt]	29	29	[GWh/y]	23	23
4200	Kraft recovery boiler	[kWh/adt]	58	58	[GWh/y]	46	46
5000	recausticising plant	[kWh/adt]	55	55	[GWh/y]	44	44
5100	Lime kiln	[kWh/adt]	See 5000	See 5000	[GWh/y]		
6100	Multi-fuel boiler	[kWh/adt]	29	29	[GWh/y]	23	23
6200	Turbine	[kWh/adt]	(1369/398)*	(1371/285)*	[GWh/y]	(1184)	(1100)
7100	Bleach chemical plant	[kWh/adt]	2	2	[GWh/y]	2	1
7200	White liquor oxidation	[kWh/adt]	2	2	[GWh/y]	2	2
7300	Air separation unit	[kWh/adt]	14	14	[GWh/y]	11	11
8000	Wastewater treatment	[kWh/adt]	29	36	[GWh/y]	23	29
9000	Board machine	[kWh/adt]		350	[GWh/y]		280
	Total usage	[kWh/adt]	640	990	[GWh/y]	512	792
	Total production	[kWh/adt]	(1767)	(1656)	[GWh/y]	(1414)	(1325)
	Net production	[kWh/adt]	(1127)	(666)	[GWh/y]	(902)	(533)

*X/Y; X indicates the production of back-pressure turbine and Y the production of condensing turbine; NOTE: the unit consumptions of Base case 1A and 1B are given here per 800 000 adt pulp production capacity

4.5 Environmental performance

Table 35 presents a summary of the sources of emissions within the battery limit of Base Cases 1A and 1B. The recovery boiler is by far the largest source of emissions (for NO_X, SO_X, TRS and CO_2). This is about 5-10 times higher than the emissions from the lime kiln or the multi-fuel boiler.

The flue gas of the lime kiln has the highest CO_2 concentration. This is due to the calcination reaction occurring in the lime kiln in addition to the contribution from the combustion of the fuel oil.

Table 35: Reference mill emissions to air. SOX, NOX, TRS and particulates from [10,21,22]

	Unit	Recovery boiler[a]	Multi-fuel boiler	Lime kiln	Unit	Recovery boiler	Multi-fuel boiler	Lime kiln
Temperature	[°C]	184	189	250	[°C]			
Flow	[kg/adt]	10189	1885	856	[kt/y]	8151	1508	684
CO_2	[w-%]	20%	20%	32%	[kt/y]	1643	301	218
N_2	[w-%]	66%	56%	47%	[kt/y]	5418	843	322
O_2	[w-%]	3%	2%	1%	[kt/y]	214	31	9
H_2O	[w-%]	11%	22%	20%	[kt/y]	876	332	135
SO_X	[ppm]	60	40	50	[t/y]	489	60	34
NO_X	[ppm]	125	150	175	[t/y]	1019	226	120
TRS	[ppm]	15	15	15	[t/y]	122	23	10
Particulates	[ppm]	30[1]	15[2]	30[3]	[t/y]	245	23	21

[a] Malodorous gases, methanol and turpentine are combusted in the recovery boiler;[1] Fly ash mainly Na_2SO_4; [2] Contains compounds of Al, Ca and Si; [3] Fly ash mainly $CaCO_3$;

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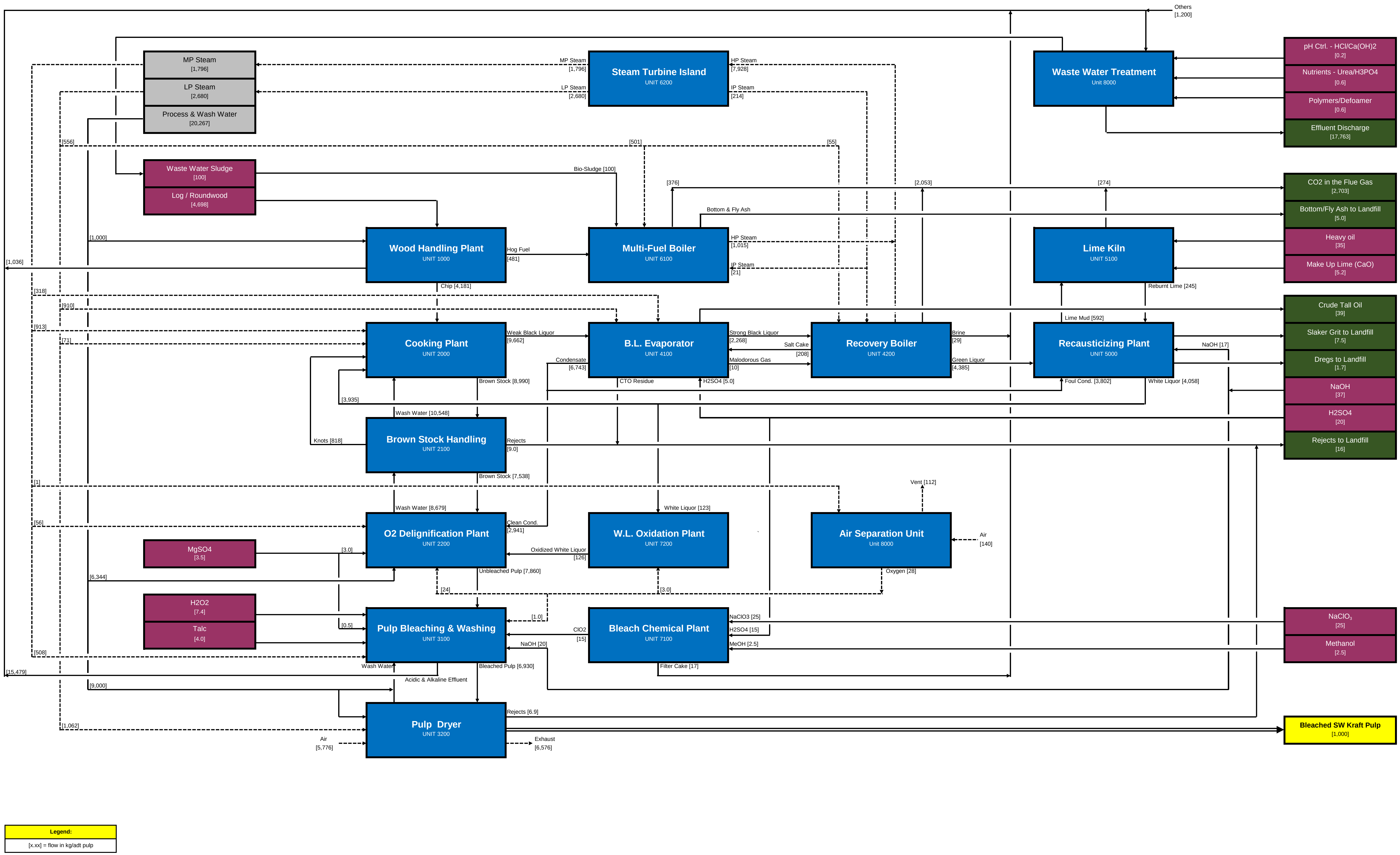
Annexes

1. Overall Block Flow Diagram
2. Block Flow Diagram – Major Units
3. Turbine specifications
4. Understanding the Biogenic Nature of the CO_2 Emissions from the Lime Kiln within the Pulp Mill

CCS in P&P industry
Annex I: Overall Block Flow Diagram

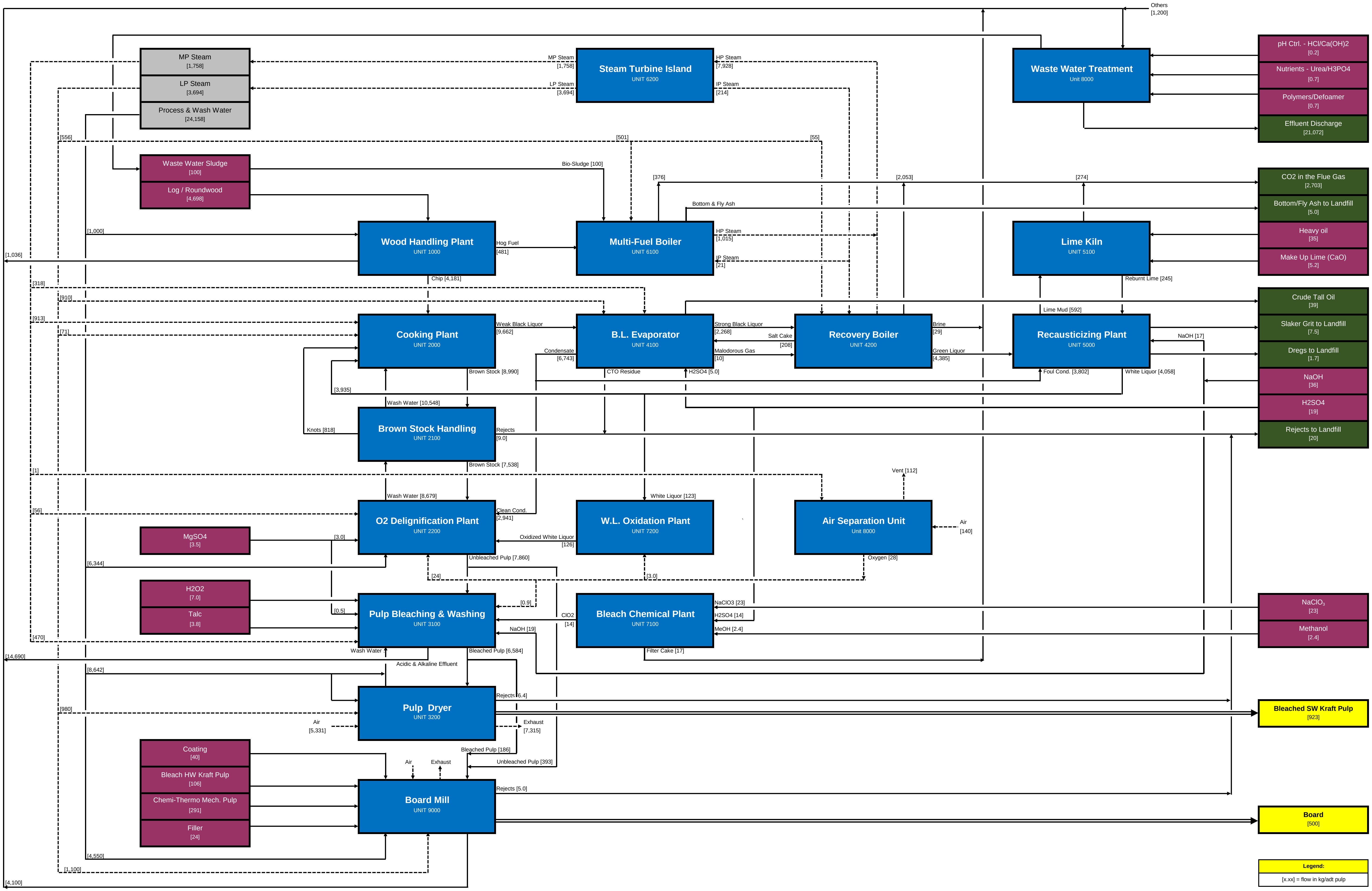
- Annex I-1: Base Case 1A – Market Pulp Mill
- Annex I-2: Base Case 1B – Integrated Pulp and Board Mill

VTT	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
CUSTOMER REPORT: VTT-CR-01312-15	**Base Case 1A: Market Pulp Mill (800,000 adt/y)**	5.0	Dec. 15	SS	PK	PK	1 of 2



CUSTOMER REPORT: VTT-CR-01312-15

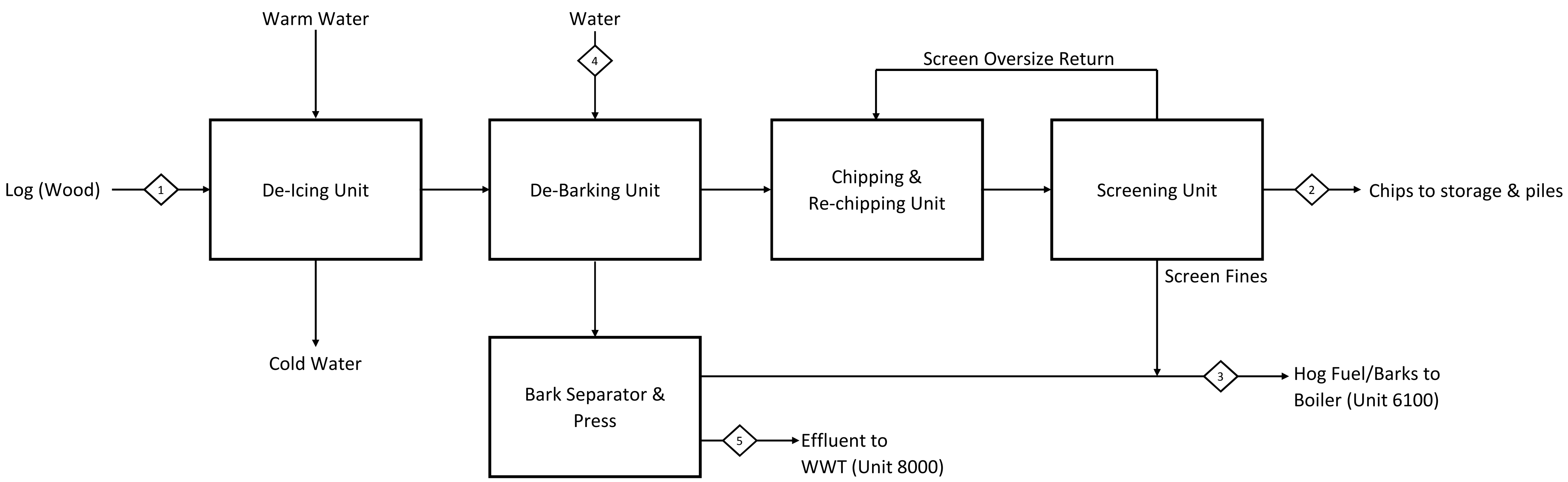
SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
Base Case 1B: Integrated Pulp (800,000 adt/y) & Board (400,000 adt/y) Mill	5.0	Dec. 15	SS	PK	PK	2 of 2



CCS in P&P industry
Annex II: Block Flow Diagram – Major Units

- Unit 1000: Wood Handling Plant
- Unit 2000: Cooking Plant
- Unit 2100: Brown Stock Handling
- Unit 2200: O_2 Delignification Plant & W.L. Oxidising Plant
- Unit 3100: Pulp Bleaching and Washing
- Unit 3200: Pulp Drying Unit
- Unit 4100: Black Liquor Evaporation Unit
- Unit 4200: Kraft Recovery Boiler
- Unit 5000: Recausticizing Plant & Lime Kiln
- Unit 6100: Multi-fuel Boiler
- Unit 6200: Steam Turbine Island
- Unit 7100: Bleach Chemical Plant
- Unit 7300: Air Separation Unit
- Unit 8000: Waste Water Treatment Plant
- Unit 9000: Board Mill

CUSTOMER REPORT: VTT-CR-01312-15	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
	Unit 1000: Wood Handling Plant	5.0	Dec-15	SS	PK	PK	1 of 15



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Log (Roundwood)	4698	447.4	3758
2	Out	Chips	4181	398.2	3345
3	Out	Bark and hog fuel	481	45.8	385
4	In	Process Water	1000	95.2	800
5	Out	Effluent	1036	98.7	829

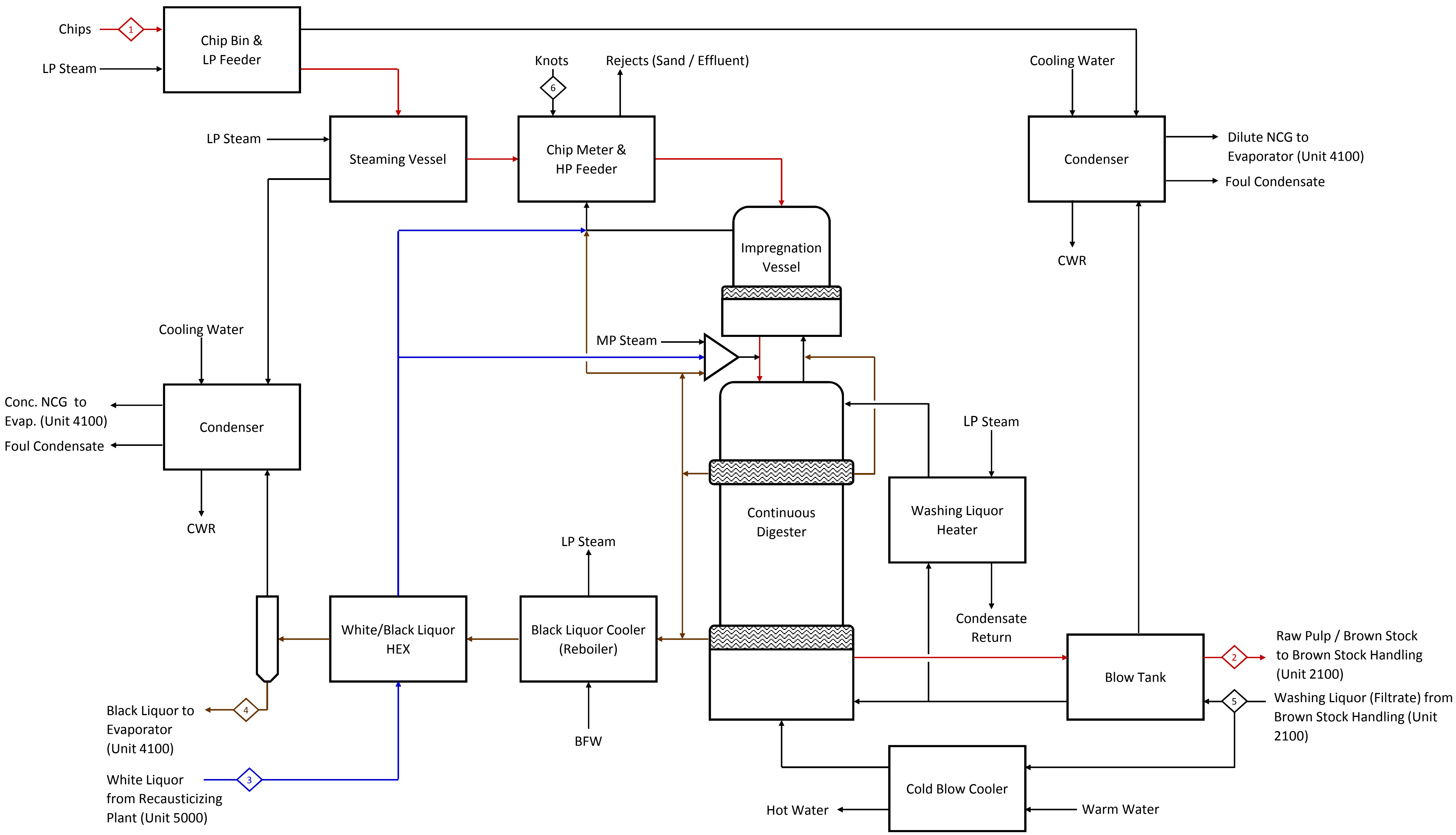
Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Log (Roundwood)	4698	447.4	3758
2	Out	Chips	4181	398.2	3345
3	Out	Bark and hog fuel	481	45.8	385
4	In	Process Water	1000	95.2	800
5	Out	Effluent	1036	98.7	829

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

CUSTOMER REPORT: VTT-CR-01312-15	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
	Unit 2000: Cooking Plant	5.0	Dec-15	SS	PK	PK	2 of 15



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Chips	4181	398.2	3345
2	Out	Brown Stock	8990	856.2	7192
3	In	White liquor	3935	374.8	3148
4	Out	Weak Black Liquor	9662	920.2	7730
5	In	Filtrate (Washing Water)	10548	1004.6	8438
6	In	Knots	818	77.9	654
	In	MP Steam	913	87.0	730
	In	LP Steam	71	6.8	57

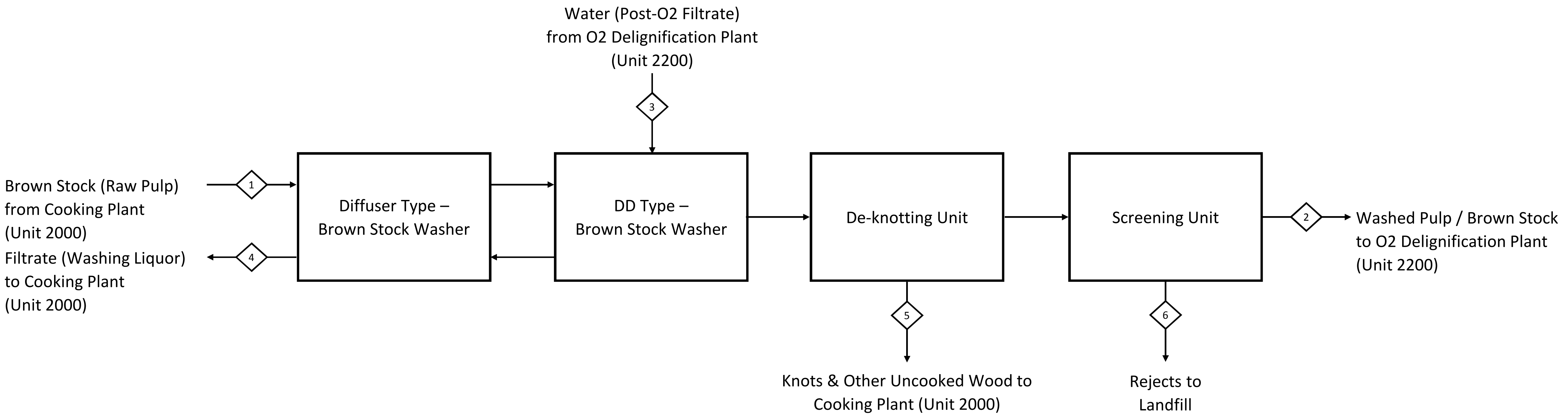
Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Chips	4181	398.2	3345
2	Out	Brown Stock	8990	856.2	7192
3	In	White liquor	3935	374.8	3148
4	Out	Weak Black Liquor	9662	920.2	7730
5	In	Filtrate (Washing Water)	10548	1004.6	8438
6	In	Knots	818	77.9	654
	In	MP Steam	913	87.0	730
	In	LP Steam	71	6.8	57

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
Unit 2100: Brown Stock Handling	5.0	Dec-15	SS	PK	PK	3 of 15



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Brown Stock	8990	856.2	7192
2	Out	Brown Stock	7538	717.9	6030
3	In	Filtrate (Washing Water)	8679	826.6	6943
4	Out	Filtrate (Washing Water)	10548	1004.6	8438
5	Out	Knots	818	77.9	654
6	Out	Rejects	9.0	0.86	7.2

Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

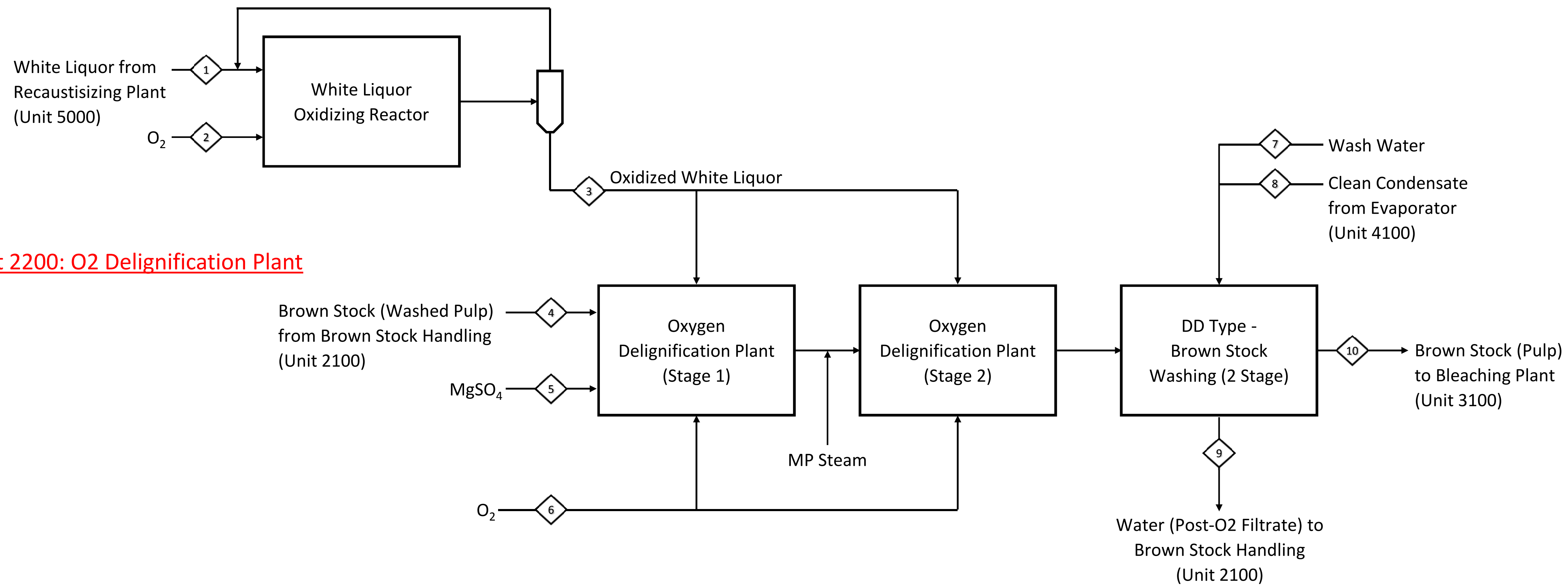
No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Brown Stock	8990	856.2	7192
2	Out	Brown Stock	7538	717.9	6030
3	In	Filtrate (Washing Water)	8679	826.6	6943
4	Out	Filtrate (Washing Water)	10548	1004.6	8438
5	Out	Knots	818	77.9	654
6	Out	Rejects	9.0	0.86	7.2

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

Unit 2200: Oxygen Delignification & Unit 7200: W.L. Oxidising Plant

Unit 7200: White Liquor Oxidising Plant

Unit 2200: O2 Delignification Plant



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	White Liquor	123	11.7	98
2	In	O2	3.0	0.3	2.4
3		Oxidized White Liquor	126	12.0	101
4	In	Brown Stock	7538	717.9	6030
5	In	MgSO4	3.0	0.3	2.4
6	In	O2	24.0	2.29	19.2
7	In	Washing Water	6344	604.2	5075
8	In	Clean Condensates	2941	280.1	2353
9	Out	Filtrate (Washing Water)	8679	826.6	6943
10	Out	Unbleached Pulp	7860	748.6	6288
	In	MP Steam	56	5.3	45

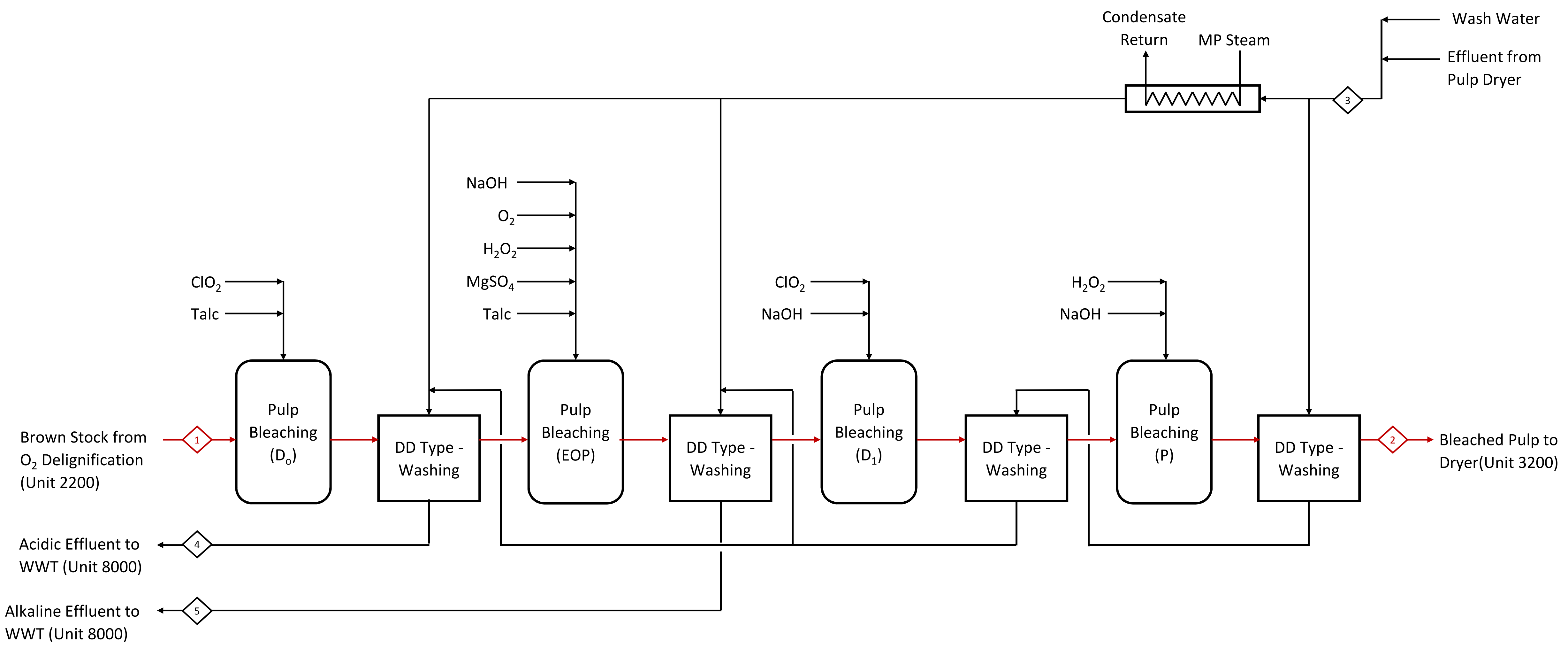
Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	White Liquor	123	11.7	98
2	In	O2	3.0	0.3	2.4
3		Oxidized White Liquor	126	12.0	101
4	In	Brown Stock	7538	717.9	6030
5	In	MgSO4	3.0	0.3	2.4
6	In	O2	24.0	2.29	19.2
7	In	Washing Water	6344	604.2	5075
8	In	Clean Condensates	2941	280.1	2353
9	Out	Filtrate (Washing Water)	8679	826.6	6943
10	Out	Unbleached Pulp	7860	748.6	6288
	In	MP Steam	56	5.3	45

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

Unit 3100: Pulp Bleaching and Washing



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Unbleached Pulp	7860	748.6	6288
2	Out	Bleached Pulp	6930	660.0	5544
3	In	Washing Water	12923	1230.8	10338
4	Out	Acidic Effluent	8980	855.2	7184
5	Out	Alkaline Effluent	6499	619.0	5199
	In	ClO2	14.8	1.41	11.9
	In	NaOH	19.8	1.89	15.8
	In	H2O2	7.4	0.70	5.9
	In	O2	1.0	0.10	0.8
	In	MgSO4	0.5	0.05	0.4
	In	Talc	4.0	0.38	3.2
	In	MP Steam	508.0	48.38	406.4

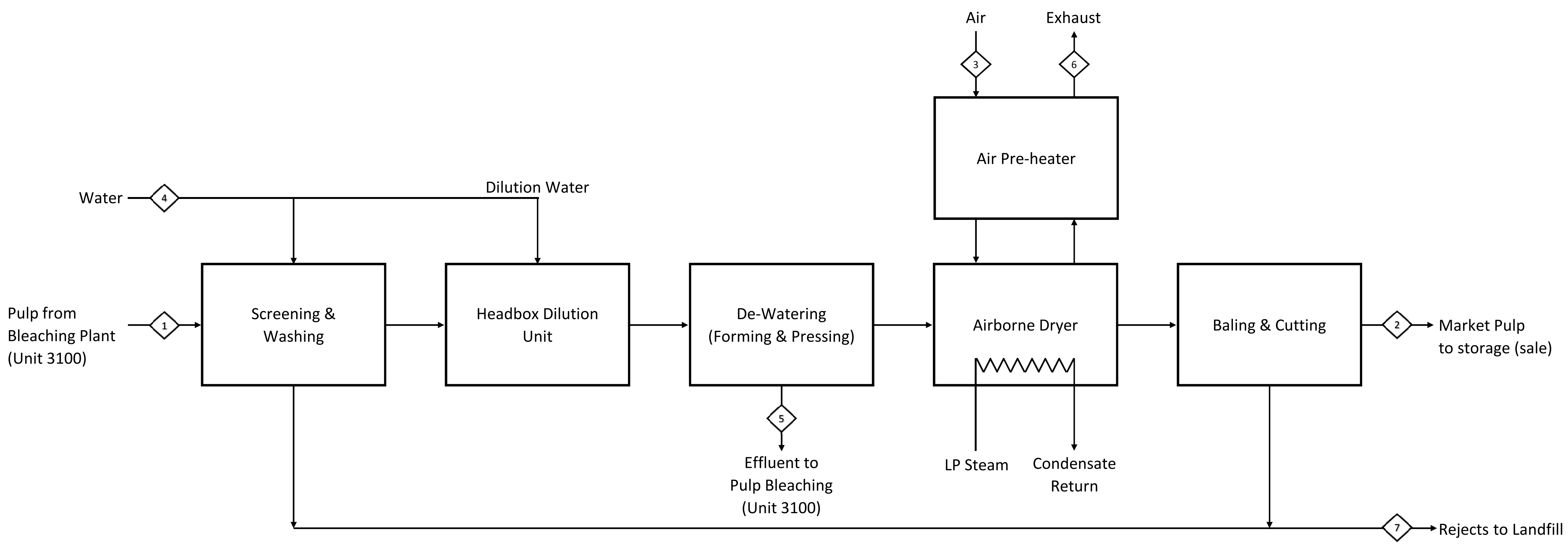
Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Unbleached Pulp	7467	711.1	5974
2	Out	Bleached Pulp	6584	627.0	5267
3	In	Washing Water	12264	1168.0	9811
4	Out	Acidic Effluent	8522	811.6	6818
5	Out	Alkaline Effluent	6168	587.4	4934
	In	ClO2	14.1	1.34	11.3
	In	NaOH	18.8	1.79	15.0
	In	H2O2	7.0	0.67	5.6
	In	O2	0.9	0.09	0.8
	In	MgSO4	0.5	0.05	0.4
	In	Talc	3.8	0.36	3.0
	In	MP Steam	470.0	44.76	376.0

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

CUSTOMER REPORT: VTT-CR-01312-15	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
	Unit 3200: Pulp Drying Unit	5.0	Dec-15	SS	PK	PK	6 of 15



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Bleached Pulp	6930	660.0	5544
2	Out	Market Pulp	1000	95.2	800
3	In	Air	5776	550.1	4621
4	In	Wash Water	4000	381.0	3200
5	Out	Effluent	7923	754.6	6338
6	Out	Exhaust	6576	626.3	5261
7	Out	Rejects	6.9	0.66	5.5
	In	LP Steam	1062	101.1	850

Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

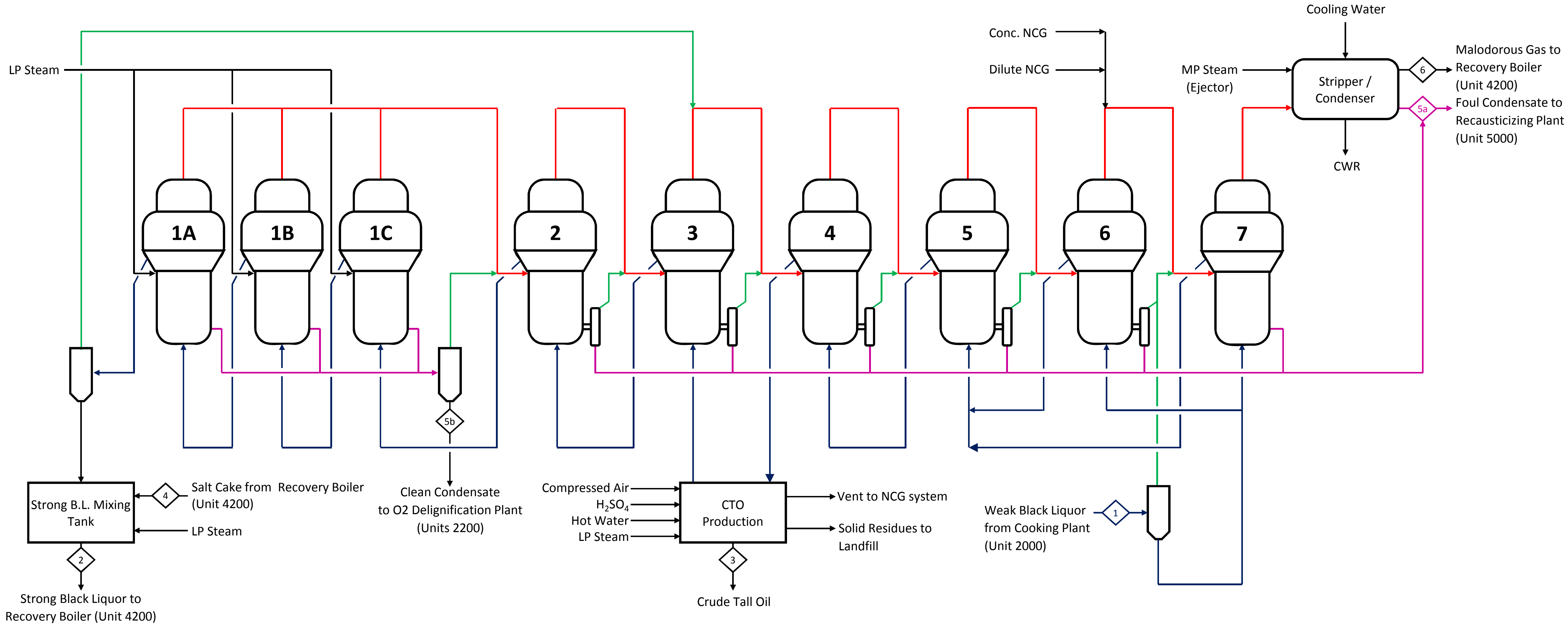
Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Bleached Pulp	6398	609.3	5118
2	Out	Market Pulp	923	87.9	738
3	In	Air	5331	507.7	4265
4	In	Wash Water	3693	351.7	2954
5	Out	Effluent	7315	696.7	5852
6	Out	Exhaust	6072	578.3	4858
7	Out	Rejects	6.4	0.61	5.1
	In	LP Steam	980	93.3	784

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

CUSTOMER REPORT: VTT-CR-01312-15

Unit 4100: Black Liquor Evaporation Unit



Base Case 1A (See Note 1)

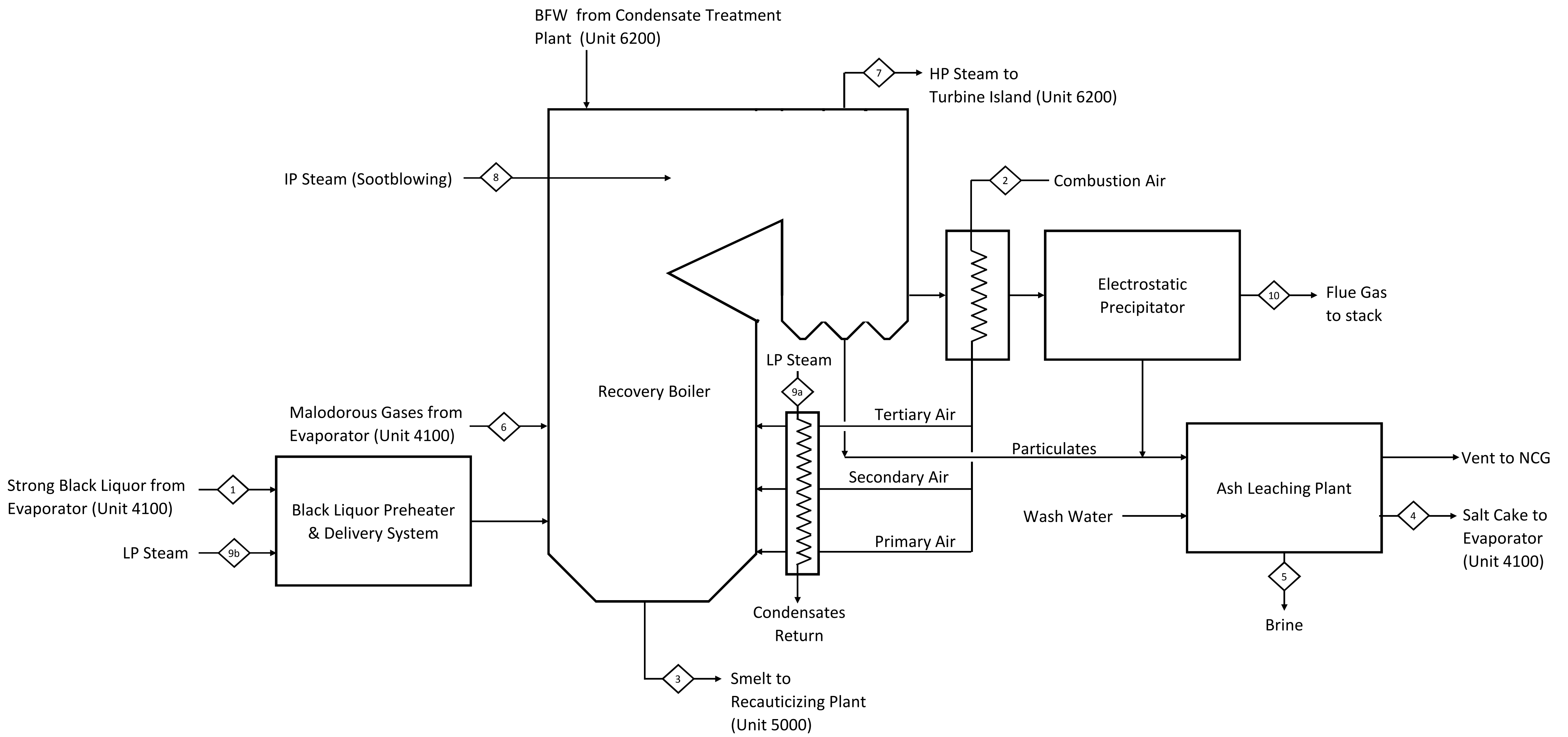
No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Weak Black Liquor	9662	920.2	7730
2	Out	Strong Black Liquor	2268	216.0	1814
3	Out	Crude Tall Oil	39.0	3.71	31.2
4	In	Salt Cake	208	19.8	166
5a	Out	Clean Condensates	2941	280.1	2353
5b	Out	Foul Concensates	3802	362.1	3042
6	Out	Malodorous Gas	10	0.95	8
	In	H2SO4	5.0	0.48	4.0
	Out	Solid Residues from CTO	0.1	0.01	0.1
	In	MP steam	318	30.3	254
	In	LP steam	910	86.7	728

Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Weak Black Liquor	9662	920.2	7730
2	Out	Strong Black Liquor	2268	216.0	1814
3	Out	Crude Tall Oil	39.0	3.71	31.2
4	In	Salt Cake	208	19.8	166
5a	Out	Clean Condensates	2941	280.1	2353
5b	Out	Foul Concensates	3802	362.1	3042
6	Out	Malodorous Gas	10	0.95	8
	In	H2SO4	5.0	0.48	4.0
	Out	Solid Residues from CTO	0.1	0.01	0.1
	In	MP steam	318	30.3	254
	In	LP steam	910	86.7	728

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Strong Black Liquor	2268	216.0	1814
2	In	Combustion Air	8877	845.4	7102
3	Out	Smelt	729	69.4	583
4	Out	Salt Cake	208	19.8	166
5	Out	Brine	29.0	2.76	23.2
6	In	Malodorous Gas	10.0	0.95	8.0
7	Out	HP Steam	6913	658.4	5530
8	In	IP Steam	193	18.4	154
9	In	LP Steam	501	47.7	401
10	Out	Flue Gas	10189	970.4	8151
	Out	CO2 Emissions (Dry)	2053	195.5	1642

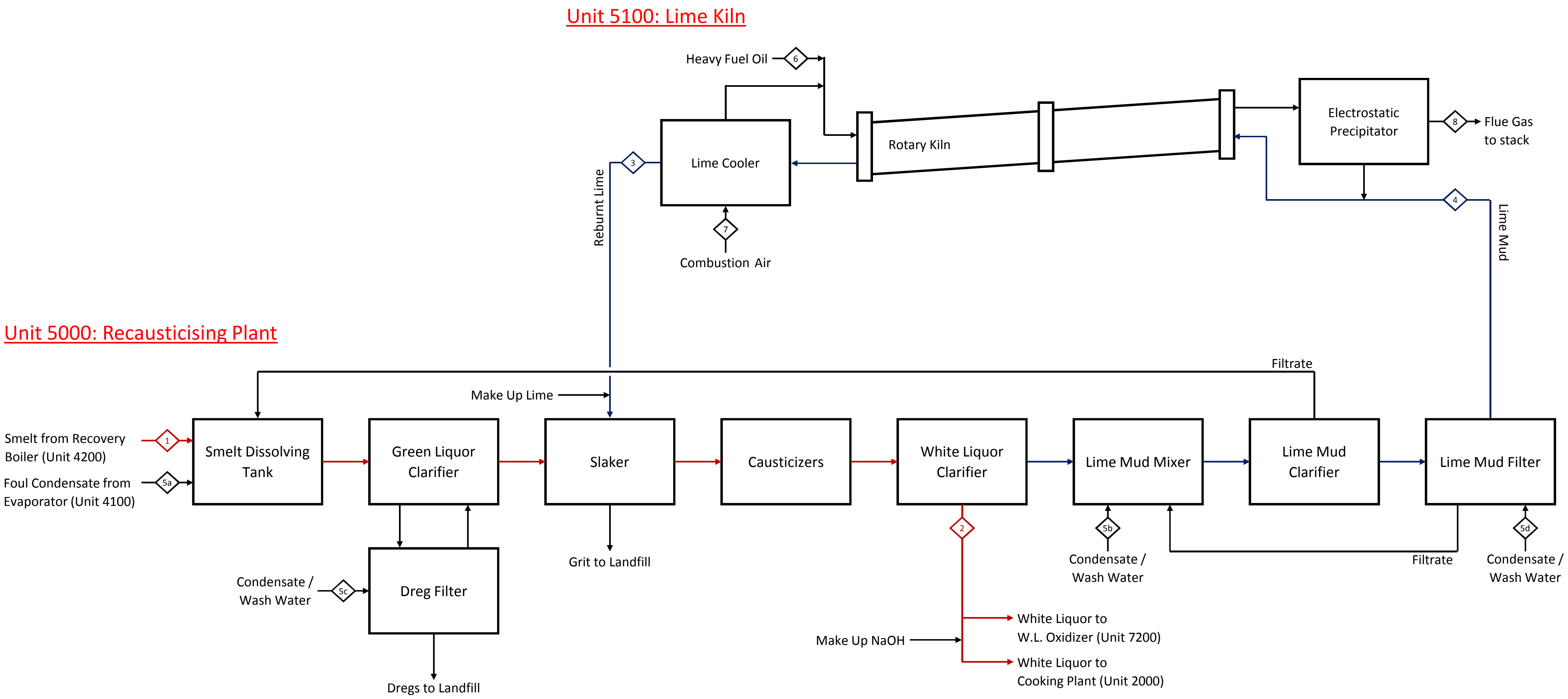
Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Strong Black Liquor	2268	216.0	1814
2	In	Combustion Air	8877	845.4	7102
3	Out	Smelt	729	69.4	583
4	Out	Salt Cake	208	19.8	166
5	Out	Brine	29.0	2.76	23.2
6	In	Malodorous Gas	10.0	0.95	8.0
7	Out	HP Steam	6913	658.4	5530
8	In	IP Steam	193	18.4	154
9	In	LP Steam	501	47.7	401
10	Out	Flue Gas	10189	970.4	8151
	Out	CO2 Emissions (Dry)	2053	195.5	1642

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

Unit 5000: Recausticizing Plant & Unit 5100: Lime Kiln



Base Case 1A (See Note 1)

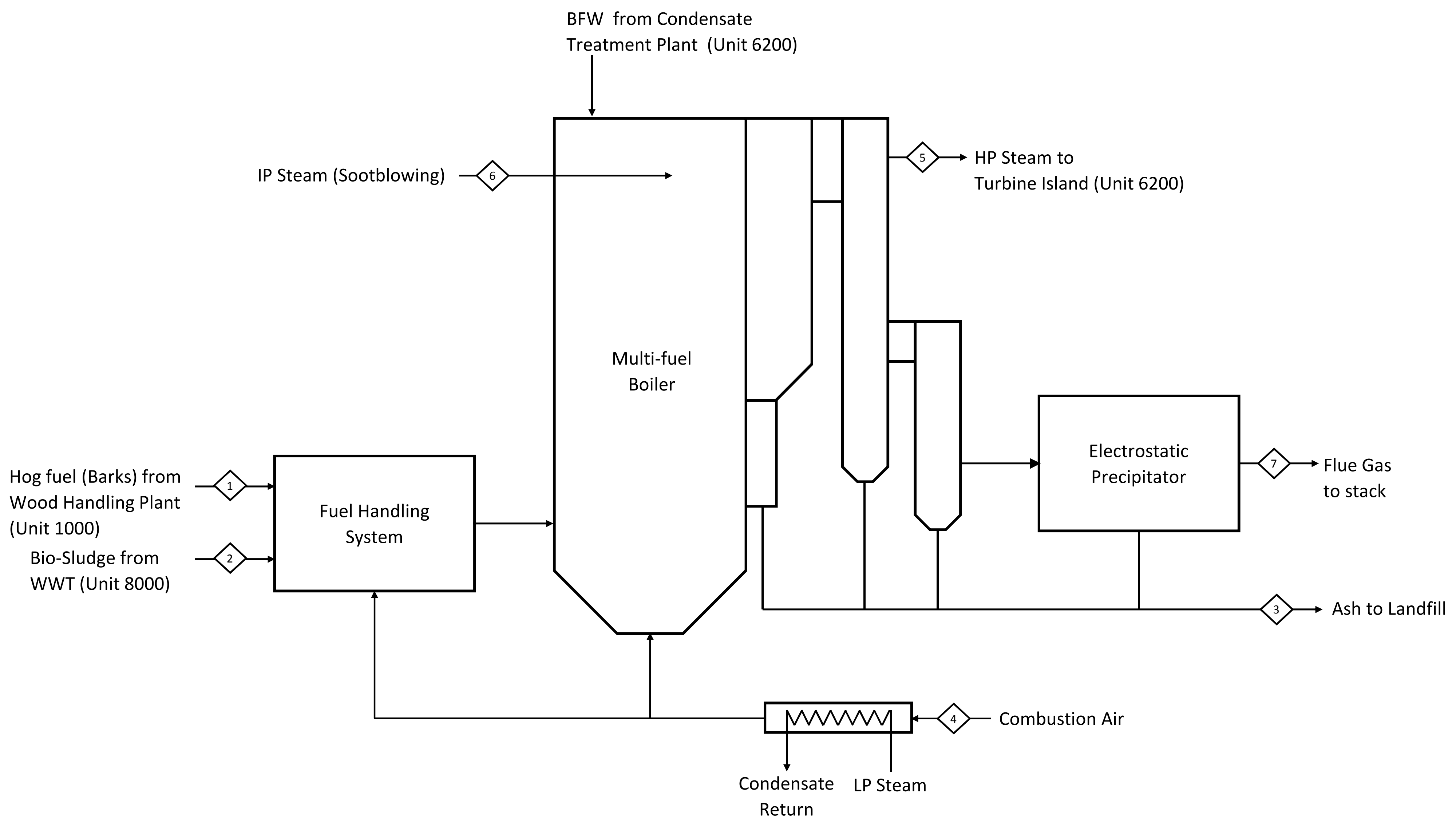
No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Smelt	729	69.4	583
2	Out	White liquor	4041	384.9	3233
3		Reburnt Lime	240	22.9	192
4		Lime Mud	592	56.4	474
5	In	Foul Condensates	3802	362.1	3042
6	In	Heavy oil	35.0	3.33	28.0
7	In	Combustion Air	524	49.9	419
	In	Make Up NaOH	17.4	1.66	13.9
	In	Make Up Lime	5.2	0.50	4.2
	Out	Dregs	1.7	0.16	1.4
	Out	Slaker Grit	7.5	0.71	6.0
8	Out	Flue Gas	856	81.5	685
	Out	CO2 Emissions (Dry)	274	26.1	219

Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Smelt	729	69.4	583
2	Out	White liquor	4041	384.9	3233
3		Reburnt Lime	240	22.9	192
4		Lime Mud	592	56.4	474
5	In	Foul Condensates	3802	362.1	3042
6	In	Heavy oil	35.0	3.33	28.0
7	In	Combustion Air	524	49.9	419
	In	Make Up NaOH	17.4	1.66	13.9
	In	Make Up Lime	5.2	0.50	4.2
	Out	Dregs	1.7	0.16	1.4
	Out	Slaker Grit	7.5	0.71	6.0
8	Out	Flue Gas	856	81.5	685
	Out	CO2 Emissions (Dry)	274	26.1	219

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Hog Fuel	481	45.8	385
2	In	Sludge	25.0	2.38	20.0
3	Out	Bottom & Fly Ash	5.0	0.48	4.0
4	In	Combustion Air	1313	125.0	1050
5	Out	HP Steam	1015	96.7	812
6	In	IP Steam	21.0	2.00	16.8
	In	LP Steam	55.0	5.24	44.0
7	Out	Flue Gas	1885	179.5	1508
	Out	CO2 Emissions (Dry)	376	35.8	301

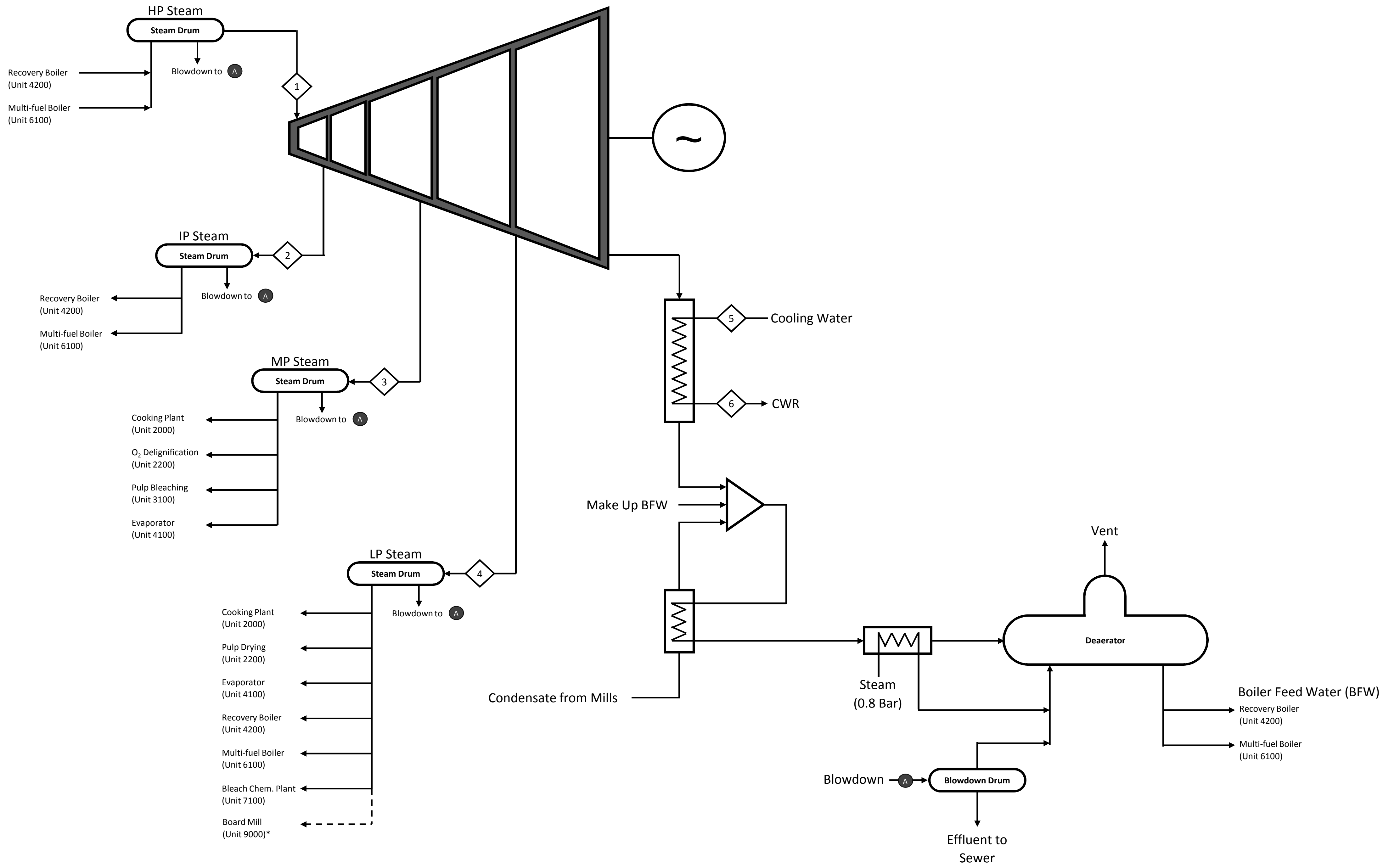
Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Hog Fuel	481	45.8	385
2	In	Sludge	25.0	2.38	20.0
3	Out	Bottom & Fly Ash	5.0	0.48	4.0
4	In	Combustion Air	1313	125.0	1050
5	Out	HP Steam	1015	96.7	812
6	In	IP Steam	21.0	2.00	16.8
	In	LP Steam	55.0	5.24	44.0
7	Out	Flue Gas	1885	179.5	1508
	Out	CO2 Emissions (Dry)	376	35.8	301

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

Unit 6200: Steam Turbine Island



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	HP Steam (103.0 Bar/505oC)	7928	755.0	6342
2	Out	IP Steam (30.0 Bar/352oC)	214	20.4	171
3	Out	MP Steam (13.0 Bar/200oC)	1796	171.0	1437
4	Out	LP Steam (4.2 Bar/154oC)	2680	255.2	2144
5	In	Cooling Water In	124866	11892.0	99893
6	Out	Cooling Water Return	124866	11892.0	99893

No.		Stream	[kWh/adt pulp]	[MWh]	[GWh]
	Out	Gross Electricity	1767	168.3	1414
	Out	Net Electricity to Grid	1127	107.3	902

Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

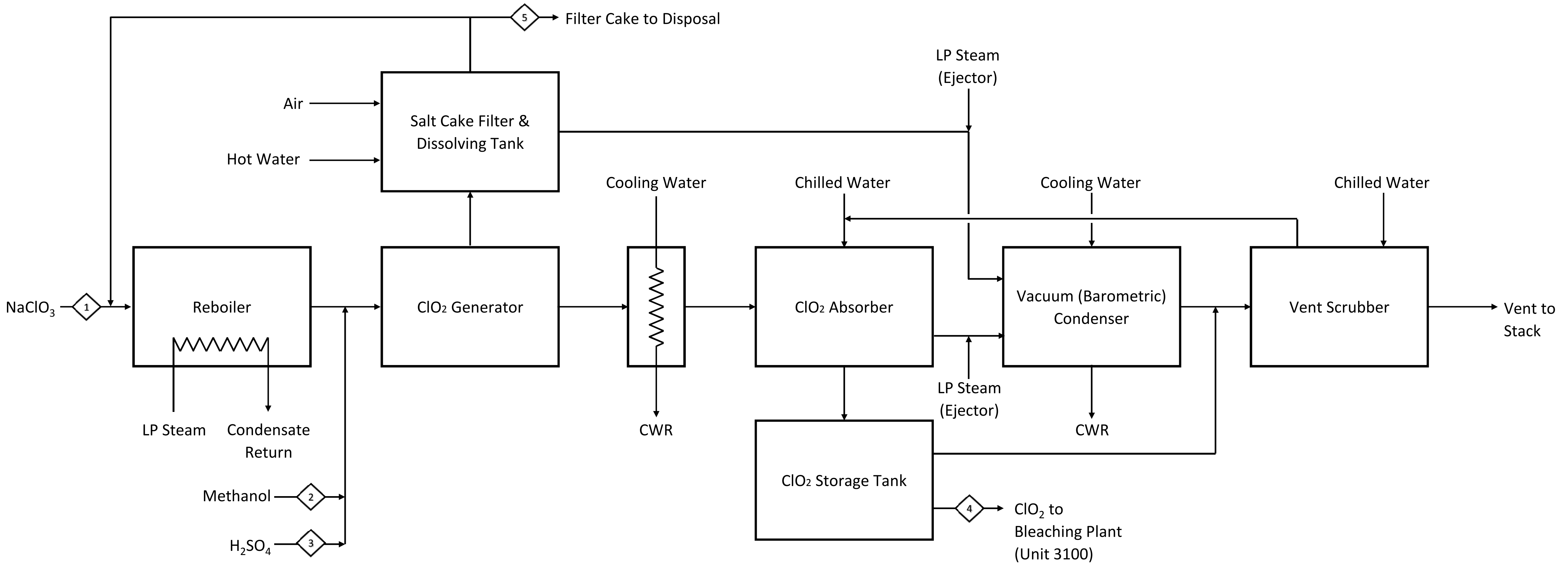
Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	HP Steam (103.0 Bar/505oC)	7928	755.0	6342
2	Out	IP Steam (30.0 Bar/352oC)	214	20.4	171
3	Out	MP Steam (13.0 Bar/200oC)	1758	167.4	1406
4	In	LP Steam (4.2 Bar/154oC)	3694	351.8	2955
5	In	Cooling Water In	90174	8588.0	72139
6	Out	Cooling Water Return	90174	8588.0	72139

No.		Stream	[kg/adt pulp]	[MWh]	[GWh]
	Out	Gross Electricity	1656	157.7	1325
	Out	Net Electricity to Grid	666	63.4	533

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

Unit 7100: Bleach Chemical Preparation Plant



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	NaClO3	24.5	2.33	19.6
2	In	Methanol	2.5	0.24	2.0
3	In	H2SO4	15.0	1.43	12.0
4	Out	ClO2	14.8	1.41	11.9
5	Out	Filter Cake (Solids Residue)	19.0	1.81	15.2
	In	Cooling water	4449	423.7	3559
	Out	Cooling Water Return	4449	423.7	3559
	In	LP Steam	80.9	7.70	64.7

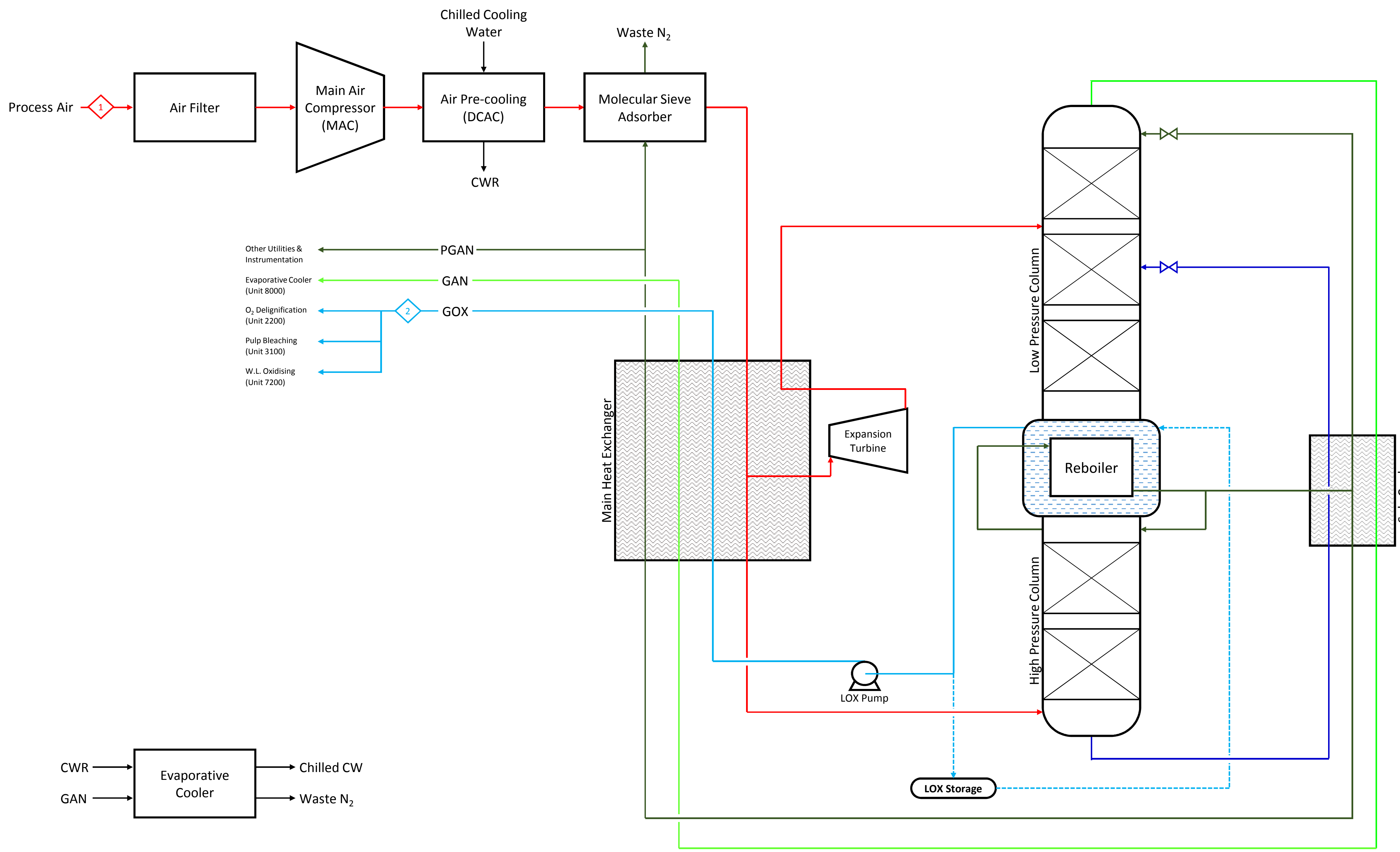
Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	NaClO3	23.3	2.22	18.6
2	In	Methanol	2.4	0.23	1.9
3	In	H2SO4	14.3	1.36	11.4
4	Out	ClO2	14.1	1.34	11.3
5	Out	Filter Cake (Solids Residue)	17.5	1.66	14.0
	In	Cooling water	4226	402.5	3381
	Out	Cooling Water Return	4226	402.5	3381
	In	LP Steam	76.8	7.32	61.4

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

Unit 7300: Air Separation Unit



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Process Air	140	13.3	112
2	Out	O2	28.0	2.67	22.4
	Out	N2	110	10.5	88
	Out	Ar and other Losses	2.0	0.19	1.6
	In	MP Steam	1.0	0.10	0.8

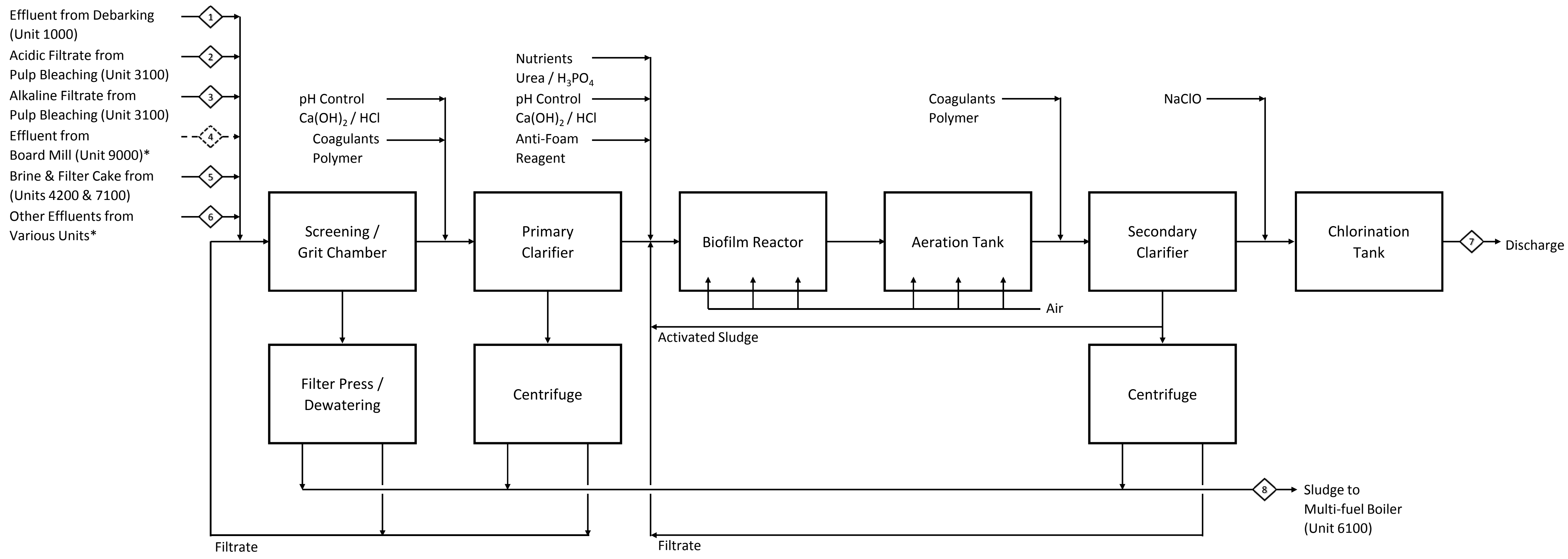
Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Process Air	140	13.3	112
2	Out	O2	27.9	2.66	22.4
	Out	N2	110	10.5	88
	Out	Ar and other Losses	2.0	0.19	1.6
	In	MP Steam	1.0	0.10	0.8

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
Unit 8000: Waste Water Treatment Plant	5.0	Dec-15	SS	PK	PK	14 of 15



Base Case 1A (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Acidic Filtrate	8980	855.2	7184
2	In	Alkaline Filtrate	6499	619.0	5199
3	In	Effluent from Debarking	1036	98.7	829
5	In	Brine and Salt Cake	48.0	4.57	38.4
6	In	Others	1200	114.3	960
7	Out	Discharge	17763	1691.7	14210
8	Out	Sludge	100	9.5	80
	In	HCl	0.10	0.01	0.08
	In	Polymer	0.10	0.01	0.08
	In	Defoamer	0.50	0.05	0.40
	In	Ca(OH)2	0.10	0.01	0.08
	In	Urea	0.50	0.05	0.40
	In	H3PO4	0.10	0.01	0.08

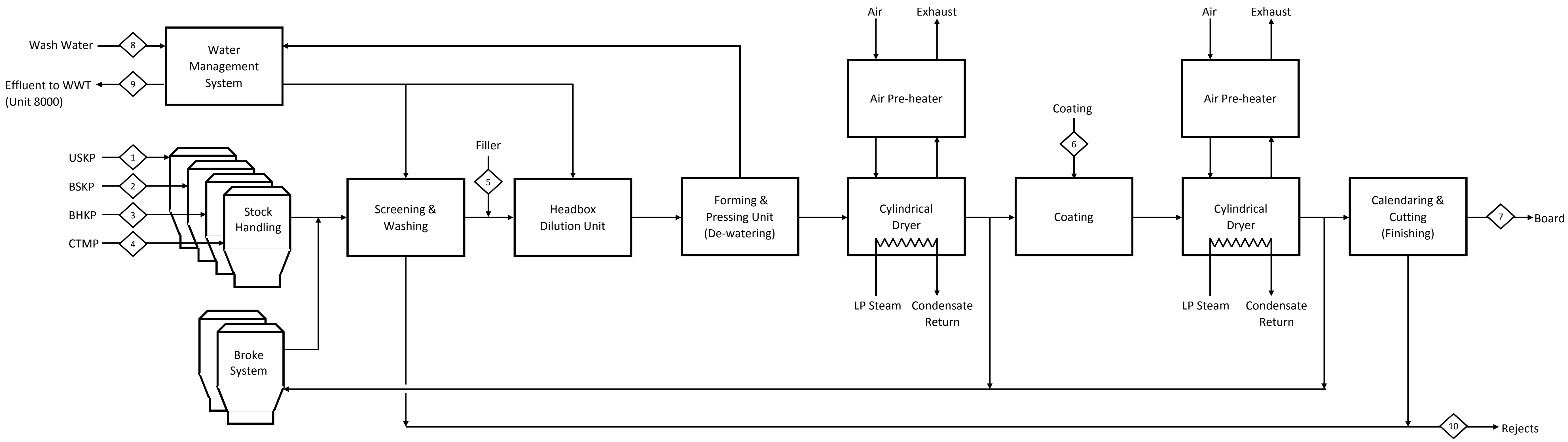
Note 1: "kg/adt" is calculated based on the production of bleached pulp = 800,000 adt/y

Base Case 1B (See Note 2)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Acidic Filtrate	8522	811.6	6818
2	In	Alkaline Filtrate	6168	587.4	4934
3	In	Effluent from Debarking	1036	98.7	829
4	In	Effluent from Board Mill	4100	390.5	3280.0
5	In	Brine and Salt Cake	46.5	4.43	37.2
6	In	Others	1200	114.3	960
7	Out	Discharge	21072	2006.9	16858
8	Out	Sludge	100	9.5	80
	In	HCl	0.12	0.01	0.09
	In	Polymer	0.12	0.01	0.09
	In	Defoamer	0.59	0.06	0.47
	In	Ca(OH)2	0.12	0.01	0.09
	In	Urea	0.59	0.06	0.47
	In	H3PO4	0.12	0.01	0.09

Note 2: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
Unit 9000: Board Mill	5.0	Dec-15	SS	PK	PK	15 of 15



Base Case 1B (See Note 1)

No.		Stream	[kg/adt pulp]	[t/h]	[kt/y]
1	In	Unbleached SW Kraft Pulp (USKP)	393	37.4	314
2	In	Bleached SW Kraft Pulp (BSKP)	186	17.7	148
3	In	Bleached HW Kraft Pulp (BHKP)	106	10.1	85
4	In	Chemi-Thermo Mech. Pulp (CTMP)	291	27.7	232
5	In	Filler	24.0	2.29	19.2
6	In	Coating	40.0	3.81	32.0
7	Out	Board	500	47.6	400
8	In	Wash Water	4550	433.3	3640
9	Out	Effluent	4100	390.5	3280
10	Out	Rejects	5.0	0.48	4.0
	In	LP Steam	1100	104.8	880

Note 1: "kg/adt" is calculated based on the production of pulp = 800,000 adt/y

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Annex III: Description and Performance of the Steam Turbine (Base Case 1A and 1B)

PERFORMANCE REPORT - ANNEX III

1 Turbine specifications

1.1 Steam turbine specification – Base cases 1A and 1B

Turbine configuration, see Figure 1:

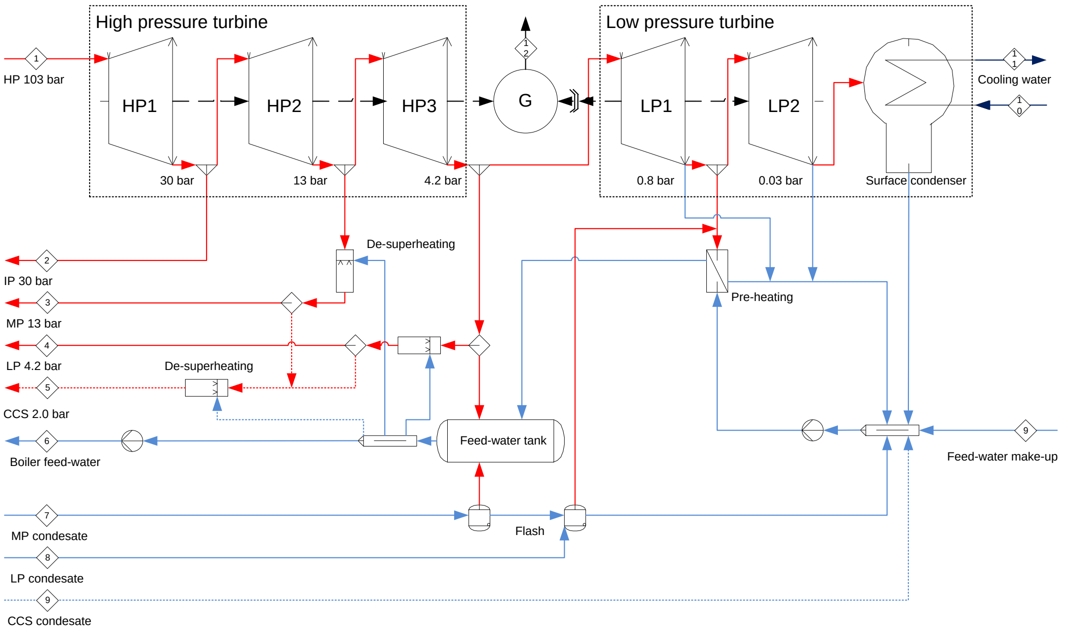

Figure 1. Steam turbine configuration and extraction points. Base cases 1A and 1B illustrated with solid lines; CCS cases marked with dashed lines.

- Turbine consists of two casings: 1) HP turbine 2) LP turbine
- Generator is located between the HP and LP casings
- A clutch between LP turbine and generator allows disconnecting the LP turbine if needed. Thus no cooling steam for LP end is needed.
- Incoming HP steam parameters are 103 bara, 505 °C. Steam is extracted at different levels
    - 30 bara / 13 bara / 4.2 bara - Pulp and paper processes
    - 0.8 bara – Preheating boiler feed water
    - 0.03 bara – Condenser pressure. Temperature of incoming cooling water is 10°C and outgoing 20°C.
- The extraction lines are equipped with controlling valves.
- Steam line between the HP and LP turbine is equipped with controlling and shut-off valves.
- Desuperheating for the extracted steams (water from the feed water tank).

- Isentropic efficiencies of turbine sections are:
  - HP1: 85%
  - HP2: 90%
  - HP3: 90%
  - LP1: 80%
  - LP2: 75%
  - (Generator: 99%)
  - Constant isentropic efficiencies assumed while partial loads of turbine are evaluated

1.2 Steam turbine specification – Cases 1A and 1B with CCS

- HP steam and steam extraction pressures are unchanged compared to the base case (103 bara / 30 bara / 13 bara / 4.2 bara / 0.8 bara / 0.03 bara)
- CCS process requires steam at 2 bara. Amount of steam varies depending on amount of flue gas that is treated (recovery boiler, multi-fuel boiler and/or lime kiln).
- Steam for the CCS process is supplied by:
  1) Extraction from the 4.2 bara line
  2) Extraction from the 13 bara line (if the 4,2 line can't supply all the steam that is needed). Amount of available 13 bara steam is limited by the pulp mill LP steam demand and the total mill electricity demand. The mill is assumed to generate its own auxiliary power consumption in all of the CCS cases.
  3) Extra 2 bara steam is generated with an additional boiler to supply all the needed steam for the CCS process.
- It is assumed that amount of extracted steam at 13 bara and 4.2 bara is flexible. Thus larger extraction is possible without any modification to the steam turbine.
- It is possible to disconnect LP turbine from the generator with a clutch if required. Thus no additional cooling steam is required for the LP turbine.
- The additional boiler is fueled with forest residues and wood-chips that are supplied by fuel suppliers. Typical cost of wood-chips are 20 EUR/MWh delivered to the site.

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Annex IV: Understanding the Biogenic Nature of the CO_2 Emissions from the Lime Kiln within the Pulp Mill

Understanding the Biogenic Nature of the CO_2 Emissions from the Lime Kiln within the Pulp Mill

1. BACKGROUND

Lime (CaO) is an important feedstock / chemicals used in the production of steel, pulp, sugar refining and many other applications. Lime is produced from the calcination of limestone ($CaCO_3$) in a lime kiln.

CO_2 Emissions from the lime kiln are generally classified as (a.) combustion related CO_2 emissions and (b.) process related CO_2 emissions. Typically, between 25 and 40% of the total emissions from the lime kiln is combustion related CO_2 emissions and the rest are process related CO_2 emissions.

Under the EU ETS accounting, the combustion related CO_2 emissions could be considered as fossil and non-fossil. Whilst, the process related CO_2 emissions are considered fossil.

Unlike the cement kiln, the use of non-fossil fuel (such as biomass, waste and other indigenous fuels) in the lime kiln are limited or with restriction due to the product (lime) quality requirements. As such, it is typical to use gaseous fuel, heavy fuel oil or petcoke/coke as fuel (with strict fuel quality requirements – i.e. low sulphur content). Thus, this is generally the main source of fossil CO_2 emissions within the pulp mill.

On the other hand, the process related CO_2 emissions are produced from the calcination of the limestone. In other industries, limestone is generally mined/sourced from quarries. As such, the chemically bound CO_2 in the limestone released during the calcination process is considered as fossil CO_2 emissions. But, this should not be the case when accounting for the process related CO_2 emissions from the lime kiln used in the Kraft Pulp Mill.

The limestone is derived from the chemical recovery cycle of the Kraft pulping process. As such, any process related CO_2 emissions should not be classified as fossil CO_2 emissions. In fact, this should be classified as biogenic CO_2 emissions and could be considered as "CO_2 neutral" if the pulp production is operated in sustainable manner.

In the pulp mill, lime is used as the re-causticizing agent to recover the chemicals (white liquor) used in the Kraft pulping process. This is illustrated in Figure A4-1 below.

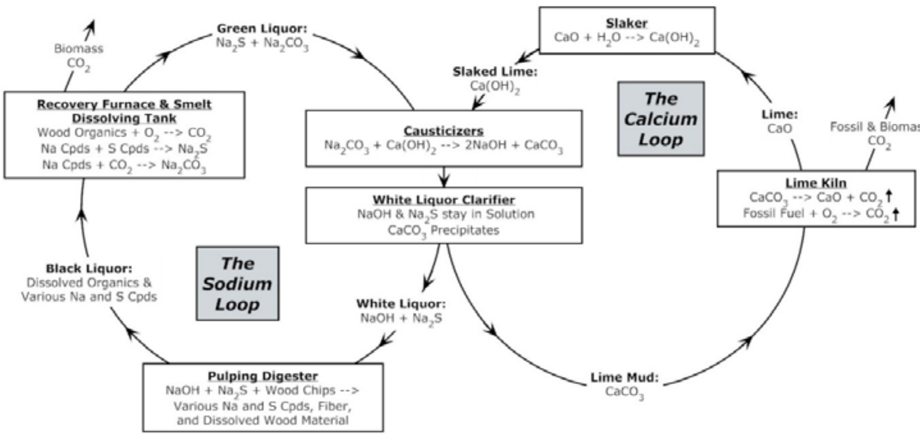


Figure A4-1: ***Calcium and sodium loops in a typical kraft pulp mill (National Council for Air and Stream Improvement, Inc. (NCASI). 2011. Greenhouse gas and non-renewable energy benefits of black liquor recovery. Technical Bulletin No. 984. Research Triangle Park, N.C.: National Council for Air and Stream Improvement, Inc.)***

2. CALCIUM LOOP (LIME CYCLE)

The calcium loop or lime cycle within the pulp mill mainly includes the processes involved in the re-causticizing unit, the slaker and the lime kiln.

The lime kiln is used to calcine the limestone ($CaCO_3$) derived from the re-causticizing unit. Typically, heavy fuel oil or gaseous fuel is used as fuel to provide the heat and energy required by the calcination process. This is the main source of fossil CO_2 emissions.

On the other hand, the carbon bound to the limestone originates from the pulping process. As such, the process related CO_2 emissions should not be classified as fossil CO_2 emissions and should be considered biogenic CO_2 emissions. This is shown in Figure A4-1 and explained below.

<u>Origin of the Limestone ($CaCO_3$) during the Pulp Production</u>

To produce the pulp, wood is treated with the Kraft Chemical or White Liquor (mainly consist of NaOH, Na_2S) to extract the lignin and hemi-cellulose. This produces the fibre (which is separated) and the black liquor (mainly consists of various Na and S compounds, and dissolved organic matters).

$$Wood + White\ Liquor \rightarrow Fibre + Black\ Liquor \qquad \text{(R1)}$$

To recover the Kraft Chemicals (White Liquor), the black liquor is concentrated in the Evaporator and burned in the Kraft Recovery Boiler. Any organic matters is burned with air to produce the combustion products (as shown in R2) and the smelts. In this process, significant amount of CO_2 produced during combustion is then absorbed in the smelt to produce the soda ash (Na_2CO_3) – as shown in R3. Around 2/3 of the Na content in the smelt is converted to Na_2CO_3.

$$organic\ matters\ in\ Black\ Liquor + O_2 \rightarrow CO_2 + H_2O \qquad \text{(R2)}$$

$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O \qquad \text{(R3)}$$

<u>Recovery of the Kraft Chemicals (White Liquor)</u>

Generally, the smelts from the Recovery Boiler is recovered and quenched to produce the Green Liquor. To recover the white liquor, the soda ash (Na_2CO_3) in the green liquor is reacted with hydrated lime in the recausticizing unit (see Reaction R4) to produce the white liquor and the "lime mud" (mainly consist of $CaCO_3$).

$$Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3 \qquad \text{(R4)}$$

The process (R1 to R4) is called the sodium loop (Kraft Chemical Recovery Cycle) of the pulp mill.

<u>Recovery of the Lime (CaO) in the Lime Kiln</u>

The lime mud is partially dried and sent to the lime kiln where the limestone in the "lime mud" is calcined (as shown in R5) to recover the lime (CaO). The quick lime (CaO) produced from the lime kiln is then sent to the Slaker Unit to be hydrated with water (as shown in R6).

$$CaCO_3 \rightarrow CaO + CO_2 \qquad \text{(R5)}$$

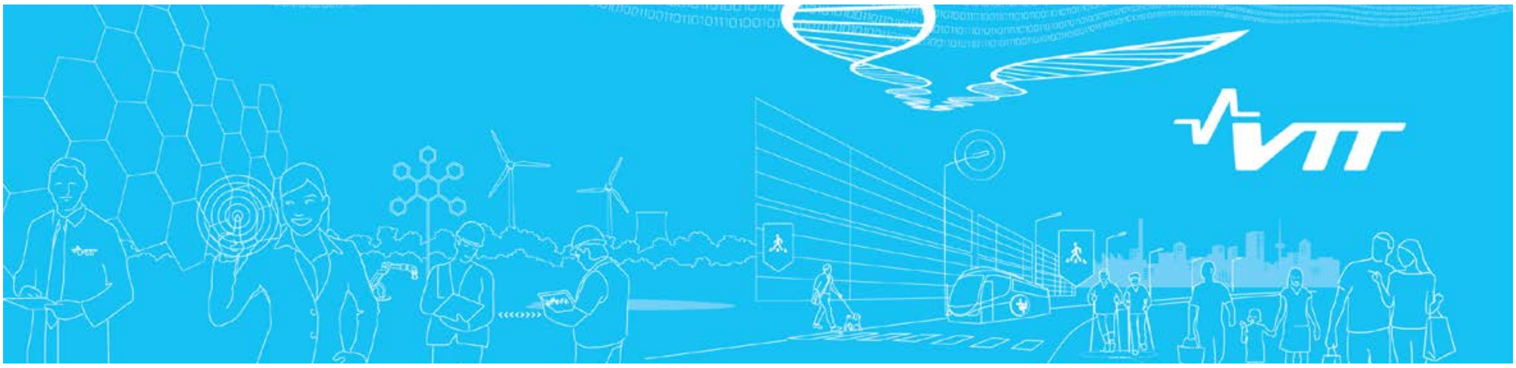
$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad \text{(R6)}$$

The process (R4-R6) is called the calcium loop (lime cycle) of the pulp mill.

3. SUMMARY

- This annex explains the origin of the limestone ($CaCO_3$) used in the lime kiln of the pulp mill. The sodium and the calcium cycles of the pulp mill clearly indicate that the carbon bound in the $CaCO_3$ is derived from the CO_2 emitted during the combustion of the organic matters in the Recovery Boiler.

- The material balance of the reference mill evaluated in this study illustrated that ~60% of the lime kiln CO_2 emissions originates from the dissolved wood combusted in the recovery boiler (R1-R6) and ~40% of the CO_2 emissions are fossil based due to the combustion of the heavy fuel oil in the lime kiln. The fossil CO_2 emissions due to the make-up lime is only ~1% of total emissions.



CUSTOMER REPORT

VTT-CR-01312-15 | 23.2.2017

CCS in P&P Industry – Reference Plants: Economic Evaluation

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Confidentiality: Final version 1.6

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CCS in P&P industry – Reference Plants: Economic Evaluation	
Customer, contact person, address IEA Greenhouse Gas R&D Programme and ÅF Consult Oy	**Order reference**
Project name CCSP&P	**Project number/Short name** 102035

Summary

This report presents the economic evaluation of two typical Finnish pulp and board mills: (i) a market (standalone) pulp mill producing 800 000 adt of bleached softwood Kraft pulp annually and (ii) an integrated pulp and board mill producing 740 000 adt of bleached softwood Kraft pulp and 400 000 adt of 3-ply folding box board annually.

The reference mills are assumed to be commissioned in 2005. Variable and fixed production costs are estimated based on the performance of the mill. A discounted cash flow analysis based on a lifetime of 25 years was conducted in order to evaluate the breakeven prices for pulp and board on EBITDA basis. The breakeven price of air dried tonne of Kraft pulp, BSKP, is 523 EUR. Correspondingly, the breakeven price of board (calculated using the breakeven price of BSKP) is 679 EUR/adt.

A sensitivity analysis shows that the breakeven price of the pulp and board is most sensitive to the fluctuation of wood price, discount rate and total plant cost (TPC). The electricity price has a less pronounced effect on the breakeven price of the board, given the fact that surplus electricity sold to the grid is less for an integrated pulp and board mill compared to a pulp mill.

This study also evaluated the potential impact of the CO_2 emission tax. Four different scenarios were assessed. It could be concluded that the recognition of the biogenic CO_2 (and how these are accounted for) and the renewable electricity credit awarded to the mill as additional incentives are some of the important factors that could affect the breakeven price of the pulp and board.

Espoo 9.1.2017

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Table of Contents

1. Background

This report is part of a larger study focusing on assessing the possibilities of deploying a retrofit CO_2 capture and storage process in the pulp and paper industry. An economic evaluation of two reference pulp and board mills is presented;

(i) Kraft pulp mill producing 800 000 adt of bleached softwood Kraft pulp (BSKP) annually (**Base case 1A**)

(ii) Integrated pulp and board mill producing 740 000 adt of bleached softwood Kraft pulp and 400 000 adt of 3-ply folding box board annually (**Base case 1B**)

The reference mills are located in western Finland. The costs of raw materials, chemicals, utilities and waste handling are presented based on typical values reported for the Scandinavian market. Logistical costs of transporting pulp and board from Finland to customers are included as they represent a clear cost factor compared to mills located closer to the markets.

The economic evaluation was assessed based on the performance of the mill presented in the previous report '*CCS in P&P industry – Reference Plants: Performance*'. More information about the reference model used in this study can be found in [1], where the majority of the investment estimates and cost data have been reported.

The economic evaluation of the reference mills will serve as the starting point in evaluating the retrofit of CO_2 Capture and Storage (CCS) in the pulp and paper industry.

2. Methodology and key assumptions

The economic analysis of the reference mills is conducted by using a Discounted Cash Flow (DCF) analysis estimating the breakeven prices of the pulp and board based on the Earnings Before Interest, Taxes, Depreciation and Amortization (EBITDA). Calculations include fixed operating costs (labour, maintenance and others), variable operating costs (raw materials, chemicals, utilities, waste disposal and logistics), investment costs, and revenues from its products and co-products (i.e. pulp, board, crude tall-oil and electricity).

2.1 Plant location

The mills are located at the north-western coast of Finland. No specific construction requirements or constraints on delivery of equipment have been assumed. Only minimum site preparation is required.

2.2 Plant life

The economic life of the Kraft pulp mill or board machine is usually between 15 and 20 years. The technical life of the plant is around 20 – 30 years before any major reinvestment and/or revamps are required.

2.3 Design and construction period

The construction of the plant is completed within 36 months after issuance of the "Notice to Proceed".

The curve of the capital expenditures during the construction period is given in Table 1.

.

Table 1: Capital expenditure during construction period

Year	Capital expenditure (% of investment costs)	Pulp and board production capacity
-3	20 %	0 %
-2	40 %	0 %
-1	35 %	0 %
1	5 %	75 %
2-25	0 %	100 %

2.4 Commissioning

During the first year of operation the pulp and board production capacity is assumed to be 75% of the plant capacity (as shown in Table 1).

2.5 Decommissioning

Decommissioning and remediation of land by the end of plant life are excluded from the cash flow analysis. It is assumed that the residual value of the plant and land will cover all decommissioning costs.

2.6 Capital charges

The discounted cash flow analysis (DCF) is applied in the evaluation of the break-even price per air dried tonne (adt) of pulp and board. A discount rate of 8% was assumed [1].

The capital is assumed to be available according to the capital expenditure schedule given in Table 1. The interest rate during construction is assumed to be equal to the discount rate at 8%.

2.7 Recurring capital expenditure

Recurring capital expenditures are assumed to be included in the annual maintenance costs, which is defined as 4% of the original investment cost at year 2005 [1].

Typical recurring capital expenditures in the pulp mill include the relining of the lime kiln, recovery boiler and multi-fuel boiler. This needs to be done a couple of times during their operating life. However, these activities are very site specific and implementation could vary from mills to mills.

2.8 Working capital

The inventories of the raw materials, products and co-products are presented in Table 2. It is assumed that all of the required raw materials, chemicals and spare parts are purchase before commissioning and that the same amount of capital is available after decommissioning.

The trade debtors and creditors include all the account receivables and payables respectively. These are normal parts of the business activities and could vary depending on the business practice of the company. This study assumes that debtor and creditor are paid in time (i.e. 0 days or no outstanding receivables or payables).

Table 2: Working capital applied in the study

Topic	Duration (days)
Feedstock, Fuel & Other Key Raw Materials	30
Finished	15
Trade Debtors	0
Trade Creditors	0

2.9 Currency

The cost evaluation is developed in EUR at 2015. When required, the currency conversion is conducted based on the average rate of the particular year in question. In 2015 the following exchange rate is assumed: 1.0 EUR = 1.1 USD.

2.10 Inflation

Inflation assumptions were not included in this study. However, typical price trends of various raw materials and products are given in Figure 1 for background information (data presented are indexed to 2015 price).

Past investment estimates are converted to 2015 values based on the Chemical Engineering Plant Cost Index (CEPCI) [2].

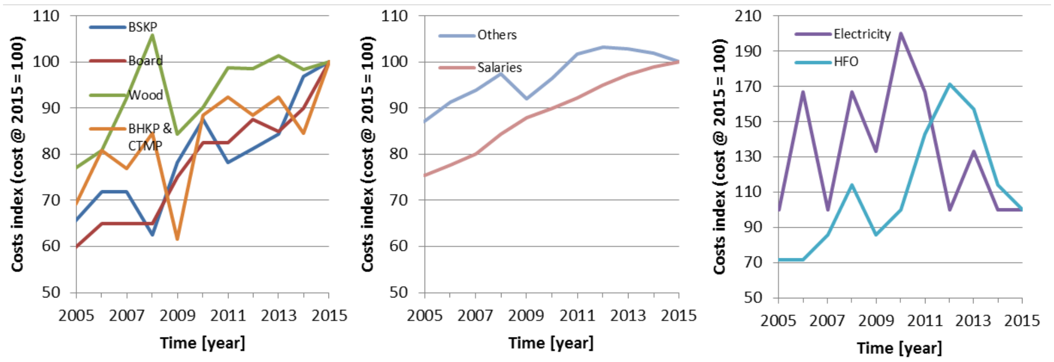

Figure 1: Price trend of wood, pulps, board, salaries, electricity HFO and others. References for the price trends are: pulps and board [Risi and Fibria], wood [Metla], energy products [Tilastokeskus], and others [Tilastokeskus].

2.11 Depreciation

In this study the depreciation is not included in the cash flow analysis as the EBITDA is used for the evaluation. However, a straight line depreciation over 20 years could be assumed for further studies resulting in an annual depreciation cost of 5% of the original investment cost in 2005.

2.12 Estimate accuracy

The accuracy of this study is ± 30%.

2.13 Overview of the cost model

The mill is considered as a single cost unit. The annual costs and revenues are calculated for the whole mill. The price/costs of internal streams or intermediates are neglected in this study. The breakeven price is calculated for the Kraft pulp in Base case 1A. When the breakeven cost of board price in Base case 1B is considered, the price of pulp is fixed based on the results reported in Base case 1A.

3. Investment cost

The reference mills were commissioned around 2005. The total plant cost (TPC), or the capital expenditure of the various major process units are presented in Table 3. The original plant cost (in 2005) and current plant cost (in 2015) are presented. The design capacities of different units are also shown in Table 3.

3.1 Contingency

The typical value of 10% contingency is applied for the calculations [1].

3.2 Total plant cost (TPC)

Capital costs of a Kraft pulp mill are obtained from [1]. Investment cost estimates of the bleaching chemical plant, white liquor oxidation, air separation unit, multi-fuel boiler and board machine are included. The capital costs reported are scaled based on the reference quoted price from the OEM on a turnkey basis and based on the ratio of reference and current capacity. A scaling factor of 0.6 is used for all cases according to Equation 1

$$(Cost_1/Cost_2)=(Capacity_1/Capacity_2)^{0.6} \qquad (1)$$

The recovery boiler, board machine, pulp drying and the cooking plant are the most capital intensive units of the reference mills. Total plant cost (TPC) were 878 MEUR for Base Case 1A and 1037 MEUR for Base case 1B.

Table 3: Total plant costs and related costs of the major process units; MEUR at 2005 (commissioning) and at 2015. Design capacities of different units shown

Unit	Description	Design capacity	Total CAPEX (MEUR 2005)	Total CAPEX (MEUR 2015)	Ref
0000	Mill infrastructure	^{A}800,000adt/y ^{B}1,140,000 adt/y	^{A}67 ^{B}82	^{A}83 ^{B}103	[1]
1000	Wood handling • Wood storage • De-icing • Debarking lines • Chipping lines • Knife grinder • Chip storage with chip piles • Screening lines • Related conveyors	943 m^3/h	53	67	
2000	Cooking plant • Chip bin • Impregnation vessel • Continuous digester • Blow line • Re-boiler • Turpentine recovery system	2,795 adt/d	107	134	[1]
2100	Brown stock handling • Diffuser washer • DD-washer • De-knotting • Screening		Included in Unit 2000	Included in Unit 2000	[1]

2200 **Oxygen delignification** • 2-stage oxygen delignification • Two DD-washers		Included in Unit 2000	Included in Unit 2000	[1]
3100 **Pulp bleaching and washing** • D_0-Eop-D_1-P stages • Four DD-washers	2,667 adt/d	^{A}49 ^{B}48	^{A}62 ^{B}60	[1]
3200 **Pulp dryer** • Screening and cleaning • Dilution head box • Twin-wire former • Combi-press with shoe-press • Airborne dryer • Cutting • Baling	^{A}2,824 adt/d ^{B}2,612 adt/d	^{A}112 ^{B}107	^{A}140 ^{B}134	[1]
4100 **Black liquor evaporation** • 7-stage evaporation • Malodorous gas collection • tall-oil plant	804 t_{H2O}/h	48	59	[1]
4200 **Kraft recovery boiler** • Recovery boiler • Electrostatic precipitators (ESP) • Flue gas stack • Boiler feed water plant • Condensate treatment • Ash leaching plant.	4,985 t_{ds}/d	160	200	[1]
5000 **recausticising plant** • Green liquor filtering • Dregs washing • Slaker • Recausticizers • White liquor filtering	11,120 m^3_{WL}/d	49	62	[1]
5100 **Lime kiln** • Lime dewatering unit • Lime mud dryer • Lime kiln • Lime cooler • ESP • Flue gas stack	t_{CaO}/d	Included in Unit 5000	Included in Unit 5000	[1]
6100 **Multi-fuel boiler** • Circulating fluidized bed boiler • Electrostatic precipitators • Flue gas stack	82MW_{th}	56	70	[3]
6200 **Turbine** • Extraction / back pressure turbine • Condensing turbine • Generator set	^{A}187 MW_e ^{B}175 MW_e	^{A}51 ^{B}49	^{A}63 ^{B}41	[1]
7100 **Bleach chemical plant** • Reactor • Heat exchanger • Absorber • Saltcake washer	^{A}34 t ClO_2/d ^{B}32 t ClO_2/d	^{A}14 ^{B}13	^{A}17 ^{B}16	[4,5]
7200 **White liquor oxidation**		Included in Unit 7100	Included in Unit 7100	

7300	**Air separation unit** • Process air filter & treatment units • Main air compressor • Cold box (incl. 2-column cryogenic distillation) • Oxygen compressor	64 t/d	8	10	[6,7]
8000	**Waste water treatment** • Fresh water plant • Mechanical & chemical treatment • Activated sludge treatment	^{A}49,000 m^3/d ^{B} 57,000 m^3/d	^{A}25 ^{B}27	^{A}31 ^{B}34	[1]
9000	**Board machine** • Water & broke systems • Screening and cleaning • Three dilution head boxes • Three formers • Press section • Drying section • Coating • Winding • Packaging	^{B}400,000 adt/y	^{B}136	^{B}170	[8]
Project Contingencies (10%)			^{A}80 / ^{B}94	^{A}100 / ^{B}118	
Total plant costs (TPC)			^{A}878 / ^{B}1037	^{A}1098 / ^{B}1298	

^{A} refers to Base case 1A (800 000 adt/y of bleached softwood Kraft pulp);
^{B} refers to Base case 1B (740 000 adt/y of bleached softwood Kraft pulp and 400 000 adt/y of folding boxboard)

3.3 Other capital expenditures

During the commissioning of the mills the following additional CAPEX are included: spare parts, start-up CAPEX, additional fuels, O&M, chemicals and others. Additionally, owner's costs ares also included in the calculations to cover pre-engineering and other preparation cost. The assumptions used to estimate these cost are presented in Table 4. The interests during construction are estimated at 8%. Working capital is calculated based on inventories of key raw materials, chemicals and fuel.

Table 4: Other capital expenditures

Cost	Value	1A	1B	Details
Spare-parts	1%	9	10	% of TPC
Start-up CAPEX	2%	18	21	% of TPC
Additional fuel	2.1%	7	7	% of annual fuel costs
O&M	25%	66	72	% of annual O&M
Chemicals and others	8.3%	2	2	% of annual chemical costs
Owner's cost	7%	61	73	% of TPC
Interest during construction	8%	263	310	Annual rate
Working capital		37	61	See Table 2
Other CAPEX		463	555	

3.4 Total capital requirement (TCR)

The schedule of the capital expenditure during construction, start-up and commissioning for Base Cases 1A and 1B are presented in Table 5. It is assumed that no renewal investments are included for the period between years 3 – 25. The annual maintenance is sufficient to keep the mill running at the same level of performance after its commissioning. After decommissioning, the same amount of working capital initially invested during year 1 is returned to the investors during year 26 (as shown in Table 5).

Table 5: Total Capital Requirement (TCR) for the Base cases 1A and 1B

Year	1A	1B
-3	190	224
-2	396	467
-1	471	549
1	181	230
2	104	122
3-25	0	0
Total	1342	1592
26	(37)	(61)

4. Annual operating and maintenance cost

The following annual operating and maintenance (O&M) costs are considered in this study:

Fixed costs:

- Labour (includes direct labour costs and indirect costs)
- Maintenance
- Other fixed costs (overheads, insurances, etc.).

Variable costs:

- Raw material (wood and purchased pulps)
- Chemicals
- Utilities
- Waste
- Logistics (extra cost for transporting products from Finland to Central Europe)

4.1 Labour

The Kraft pulp mill (Base case 1A) is operated with a personnel account of 120, including all operators at the fibre line and chemical recovery as well as management. When an integrated board machine (Base case 1B) is considered, an additional 120 workers are needed; 110 operators and an additional 10 for management duties. The average annual salary is 60 000 EUR with an additional 40% indirect costs [1]. Indirect cost covers mandatory items such as pensions, healthcare and insurances. Total annual labour costs are 10 MEUR for the kraft pulp mill (Base Case 1A) and 20 MEUR for the integrated mill (Base Case 1B), respectively, see Table 6.

Table 6: Cost of labour of reference mills

	Unit	1A	1B
Fibre line		55	55
Chemical recovery		55	55
Board machine			110
Management		10	20
Salary + indirect cost	[€/y]	60 000	60 000
Indirect costs	[% of salary]	40%	40%
Annual labour cost	[MEUR]	10.1	20.1

4.2 Maintenance

The annual maintenance costs (MC) of the reference mills are defined based on the estimated replacement value (ERV), which is based on the total plant costs (TPC). The MC/ERV ratio is defined as 6% for the recovery island as harsher environment during its operation is expected. MC/ERV is set to 3% for the fibre line and other departments while 4% is used for the board machine. Overall, the annual maintenance costs of the reference mills are around 4% of its replacement value (TPC @ 2005). This is in line with other sources [1,7,9]. Total annual maintenance costs, presented in Table 3, are 35 MEUR for the Kraft pulp mill (Base case 1A) and 42 MEUR for the integrated pulp and board mill (Base case 1B).

Table 7: Maintenance costs of reference mills

Unit	Description	Factor	1A (MEUR)	1B (MEUR)
0000	Mill infrastructure	3%	2.2	2.7
1000	Wood handling	3%	1.8	1.8
2000	Cooking plant	3%	3.6	3.6
2100	Brown stock handling	3%	See Unit 2000	See Unit 2000
2200	Oxygen delignification	3%	See Unit 2000	See Unit 2000
3100	Pulp bleaching and washing	3%	1.6	1.6
3200	Pulp dryer	3%	3.7	3.6
4100	Black liquor evaporation	6%	3.2	3.2
4200	Kraft recovery boiler	6%	10.7	10.7
5000	recausticising plant	6%	3.3	3.3
5100	Lime kiln	6%	See Unit 5000	See Unit 5000
6100	Multi-fuel boiler	3%	1.9	1.9
6200	Turbine	3%	1.7	1.6
7100	Bleach chemical plant	3%	0.5	0.4
7200	White liquor oxidation	3%	See Unit 7100	See Unit 7100
7300	Air separation unit	3%	0.3	0.3
8000	Waste water treatment	3%	0.8	0.9
9000	Board machine	4%		6.0
Annual maintenance cost			35.1	41.5

4.3 Other fixed costs

Other fixed costs include factors such as senior management, marketing, research and development, fees, local insurances, license fees, etc. As these costs can vary significantly between mills and companies, a fixed value of 25 EUR/adt is used in this study as proposed in Kangas et al. [1]. Other fixed costs, presented in Table 4, are 20 MEUR/a for the Kraft pulp mill (Base case 1A) and 28 MEUR/a for the integrated pulp and board mill (Base case 1B).

Table 8: Other fixed costs of reference mills

	Unit	1A	1B
Other fixed costs	[EUR/adt]	25	25
Production	[adt/y]	800 000	1 140 000
Annual other fixed costs	[MEUR]	20.0	28.5

4.4 Raw materials

The costs of raw material are presented in Table 9. Only a small share of the pulp produced is utilised in the integrated pulp mill (60 000 adt/y). Additional raw material is needed for the board production. Annual raw material costs for Kraft pulp production is 186 MEUR and the corresponding annual raw material costs for the integrated pulp and board production are 346 MEUR.

Table 9: Cost of raw-materials at reference mills [1,9]

	Price		Usage			Cost		
				1A	1B		1A	1B
Wood	[EUR/m^3]	40	[Mm^3/y]	4.6	4.6	[MEUR/y]	185.6	185.6
BHKP	[EUR/t]	650	[kt/y]		106	[MEUR/y]		55.2
CTMP	[EUR/t]	400	[kt/y]		232	[MEUR/y]		93.0
Filler	[EUR/t]	300	[kt/y]		19	[MEUR/y]		5.8
Coating	[EUR/t]	200	[kt/y]		32	[MEUR/y]		6.4
Raw materials cost						[MEUR/y]	185.6	345.9

BHKP refers to bleached hardwood Kraft pulp; CTMP refers to chemi-thermo-mechanical pulp.

4.5 Chemicals

Major chemicals used in the reference Kraft pulp mill are presented in Table 10. Cost data is obtained from [1,10]. The annual chemical cost for the Kraft pulp mill is 27 MEUR (Base Case 1A). Costs for the integrated mill (Base Case 1B) are slightly lower with 26 MEUR, as less pulp is bleached.

Chemicals used in water treatment are not included as they are accounted for in the lump sum cost of the wastewater treatment. Also some of the minor chemicals (retention aid, biocides, etc.) used for board making are not included. Fillers and coating used for board making are presented in Table 9 as raw material.

Table 10: Cost of chemicals at the reference mills

	Price		Usage			Cost		
				1A	1B		1A	1B
NaOH	[EUR/t]	370	[kt/y]	29.8	29.0	[MEUR/y]	11.0	10.7
H_2O_2	[EUR/t]	500	[kt/y]	5.9	5.6	[MEUR/y]	3.0	2.8
$MgSO_4$	[EUR/t]	300	[kt/y]	2.8	2.8	[MEUR/y]	0.8	0.8
CaO	[EUR/t]	120	[kt/y]	4.2	4.2	[MEUR/y]	05	0.5
H_2SO_4	[EUR/t]	50	[kt/y]	16.0	15.4	[MEUR/y]	0.8	0.8
$NaClO_3$	[EUR/t]	500	[kt/y]	19.6	18.6	[MEUR/y]	9.8	9.3
CH_3OH	[EUR/t]	350	[kt/y]	2.0	1.8	[MEUR/y]	0.7	0.7
Talc	[EUR/t]	200	[kt/y]	3.2	3.0	[MEUR/y]	0.6	0.6
Chemical cost						[MEUR/y]	27.2	26.2

4.6 Utilities

Cooling water, process water and boiler water are considered as utilities. Additionally, heavy fuel oil used by the lime kiln is classified as purchased fuel. The overall cost is applied and minor cost factors like special chemicals used in the treatment of the process water are not listed in detail. The estimates for the prices are obtained from [1]. The annual utility cost for the different types of water used by the reference mills is ~ 6 MEUR/a. Heavy fuel oil consumed by the lime kiln amounts to 11 MEUR/a. The utility costs are summarised in Table 11.

Table 11: Cost of utilities at the reference mills

	Price		Usage	1A	1B	Cost	1A	1B
Cooling water	[€/m³]	0.05	[Mm³/y]	103.5	75.6	[MEUR/y]	5.2	3.8
Process water	[€/m³]	0.1	[Mm³/y]	13.1	16.4	[MEUR/y]	1.3	1.6
Boiler water	[€/m³]	0.2	[Mm³/y]	0.8	0.8	[MEUR/y]	0.2	0.2
HFO	[€/t]	400	[kt/y]	28.0	28.0	[MEUR/y]	11.2	11.2
Utility cost						[MEur/y]	17.8	16.8

4.7 Waste disposal

Wastewater from pulp bleaching and from the board machine, ashes from the boilers, and dregs from the recausticising plant are the main waste materials discharged from the mills. Ashes and dregs are disposed to the landfill. The wastewater from the mills is treated before being discharged to the sea or sewage. The cost of wastewater treatment is assumed on a lump sum cost basis which covers the cost of required chemicals (urea, de-foamer, etc...), energy, local taxes, and others. Total costs of disposing the various wastes of the mill are in the region of around 2 MEUR/a as shown in Table 12.

Table 12: Cost of waste at the reference mills

	Price		Usage	1A	1B	Cost	1A	1B
Waste water	[EUR/m³]	0.09	[Mm³/y]	14.2	17.1	[MEUR/y]	1.28	1.52
Rejects from Brown Stock Handling	[EUR/t]	10	[kt/y]	7.2	7.2	[MEUR/y]	0.08	0.07
Residues from CTO Production	[EUR/t]	10	[kt/y]	0.1	0.1	[MEUR/y]	0.00	0.00
Bottom & Fly Ash	[EUR/t]	10	[kt/y]	4.0	4.0	[MEUR/y]	0.04	0.04
Dregs	[EUR/t]	10	[kt/y]	1.4	1.4	[MEUR/y]	0.01	0.01
Slaker grits	[EUR/t]	10	[kt/y]	6.0	6.0	[MEUR/y]	0.06	0.06
Rejects from Pulp Dryer	[EUR/t]	10	[kt/y]	5.5	5.1	[MEUR/y]	0.05	0.05
Rejects from Board Mill	[EUR/t]	10	[kt/y]	-	4.0	[MEUR/y]	-	0.04
Total						[MEUR/y]	1.5	1.8

4.8 Selling and distribution

The selling and distribution costs of pulp and board to the global market is included in the cost model. A fixed cost of 50 EUR/adt of pulp and board based on [1] is applied. Total annual logistical costs are 40 MEUR/a for the pulp mill (Base case 1A) and 57 MEUR/a for the integrated pulp and board mill (Base case 1B) as presented in Table 9.

Table 13: Cost of logistics of the reference mills

	Unit	1A	1B
Selling and distribution	[EUR/adt]	50	50
Production	[adt/y]	800 000	1 140 000
Selling and distribution	[MEUR/y]	40.0	56.9

5. Annual revenues from the co-products

5.1 Crude tall oil and electricity

Major co-products from the pulp mill are crude tall oil (CTO) and electricity. The tall oil production from pulping of softwood (pine and spruce) is approximately 40 kg/adt.

Both reference mills are energy independent, therefore producing excess electricity that could be sold to the grid, see Table 14. The price of energy products fluctuate largely as illustrated in Figure 1.

This study assumes that CTO is sold to the market at 400 EUR/t. Electricity is sold to the grid based on the average price of the Nordpool Electricity market at 40 EUR/MWh. The annual revenues from the co-product are larger in the standalone pulp mill (Base case 1A) than in the integrated mill (Base case 1B) at 52 MEUR/a and 37 MEUR/a, respectively.

Table 14: Revenues from the by-products of the reference mills

	Price		Production			Revenue		
				1A	1B		1A	1B
CTO	[EUR/t]	500	[kt/y]	31.2	31.2	[MEUR/y]	15.6	15.6
Electricity	[EUR/MWh]	40	[GWh/y]	902	533	[MEUR/y]	36.1	21.3
Total							51.7	36.9

6. Summary of annual operating and maintenance costs

The overall annual operating and maintenance (O&M) costs of a modern Nordic Kraft pulp mill (Base case 1A) and an integrated pulp and board mill (Base case 1B) is illustrated in Table 15 and Table 16. Revenues from the co-products are included in the tables. It can be seen that wood is the main cost factor in the production of pulp (Base case 1A). For the integrated pulp and board mill (Base case 1B) the wood and purchased pulps are the largest costs factors. There is significant income from the electricity and crude tall oil. The annual O&M costs for the Kraft pulp mill and for the integrated mill when operating are 246 MEUR and 444 MEUR, respectively, at their full operating capacity between year 2 and 25.

Table 15: Annual production costs (MEUR/a) of a Nordic kraft pulp mill (Base case 1A). The revenues from by-products are illustrated

Annual operating cost	Operating period -3...-1	1	2...25
Total pulp production (adt/y)		600000	800000
Fixed Cost			
Labour		10.1	10.1
Other Fixed Cost		15.0	20.0
Maintenance		35.1	35.1
Variable Cost			
Raw Materials		139.2	185.6
Chemicals		20.4	27.3
Utilities		5.0	6.6
Fuel Cost		8.4	11.2
Waste Processing & Disposal		1.1	1.5
Revenues from by-products			
Electricity Export to the Grid		(27.1)	(36.1)
CTO		(11.7)	(15.6)
O&M costs		195.6	245.8

Table 16: Annual production costs (MEUR/y) of an integrated pulp and board mill (Base case 1B). The revenues from by-products is illustrated

Annual operating cost	Operating period -3...-1	1	2...25
Total pulp production (adt/y)		554000	738000
Total board production (adt/y)		300000	400000
Fixed Cost			
Labour		20.2	20.2
Other Fixed Cost		21.3	28.5
Maintenance		41.5	41.5
Variable Cost			
Raw Materials		259.4	345.9
Chemicals		19.7	26.2
Utilities		4.2	5.6
Fuel Cost		8.4	11.2
Waste Processing & Disposal		1.3	1.8
Revenues from by-products			
Electricity Export to the Grid		(16.0)	(21.3)
CTO		(11.7)	(15.6)
O&M costs		348.3	443.9

7. Breakeven price

The breakeven price (or levelised cost) of pulp and board is calculated based on the discounted cash flow analysis. An economic lifetime of 25 years is assumed for the pulp mill with 8% discount rate. The breakeven price is calculated by setting the net present value (NPV) to zero before any consideration of interest, taxes, depreciation or amortization.

The calculated breakeven price of producing the air dried tonne of softwood Kraft pulp (BSKP) is 523 EUR (Base case 1A). The breakdown of the different cost factors are illustrated in Figure 2. The profits or additional revenues from the by-products (i.e. electricity and CTO) are also included.

When the integrated pulp and board production is evaluated (Base case 1B), the breakeven price of air dried tonne of board is 679 EUR. Figure 3 illustrates the cost breakdown of the entire integrated pulp and board mill. The pulp is considered a co-product and the value of pulp is set at the breakeven price of 523 EUR/adt (calculated in Base Case 1A).

Figure 4 illustrates the cost breakdown attributed to the board production individually. In this figure, the costs of pulp mill are subtracted from the costs of the entire mill. In summary, this figure illustrates the additional costs due to the board production.

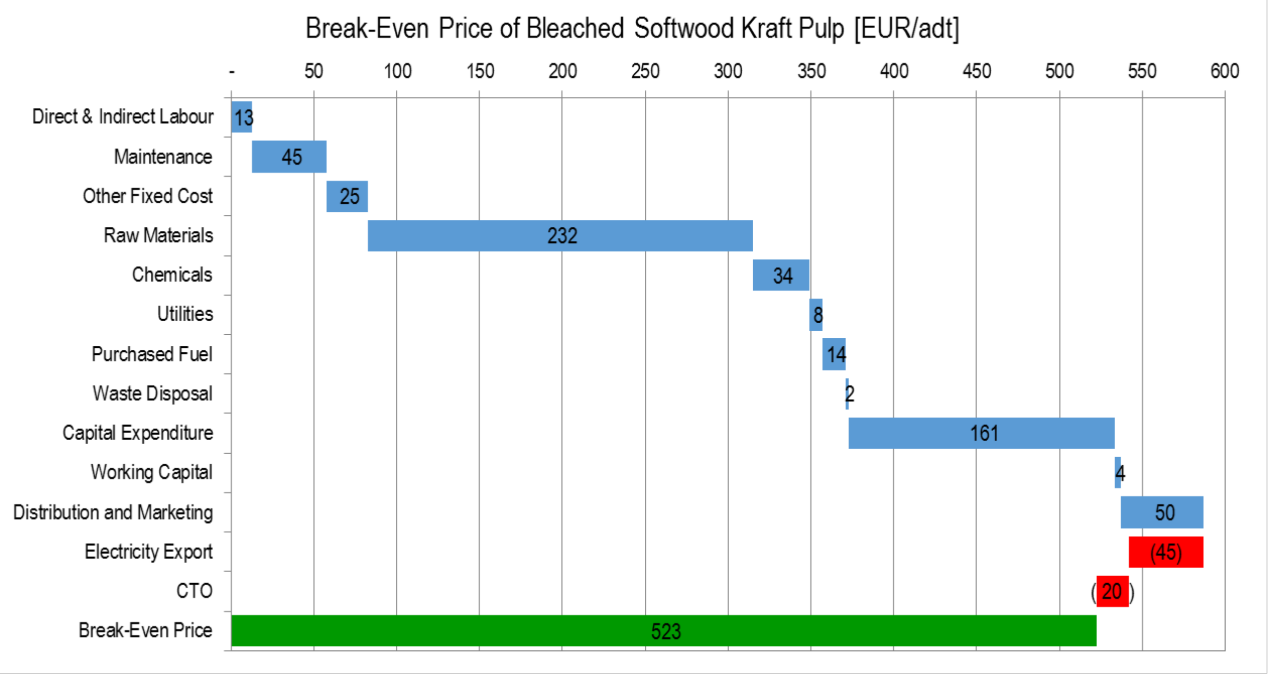

Figure 2: Break-even price per adt of softwood Kraft pulp, BSKP [EUR/adt] (Base case 1A). Different breakdown of the production cost are marked with blue, the revenues from by-products with red, and the breakeven price of the market pulp is marked with green.

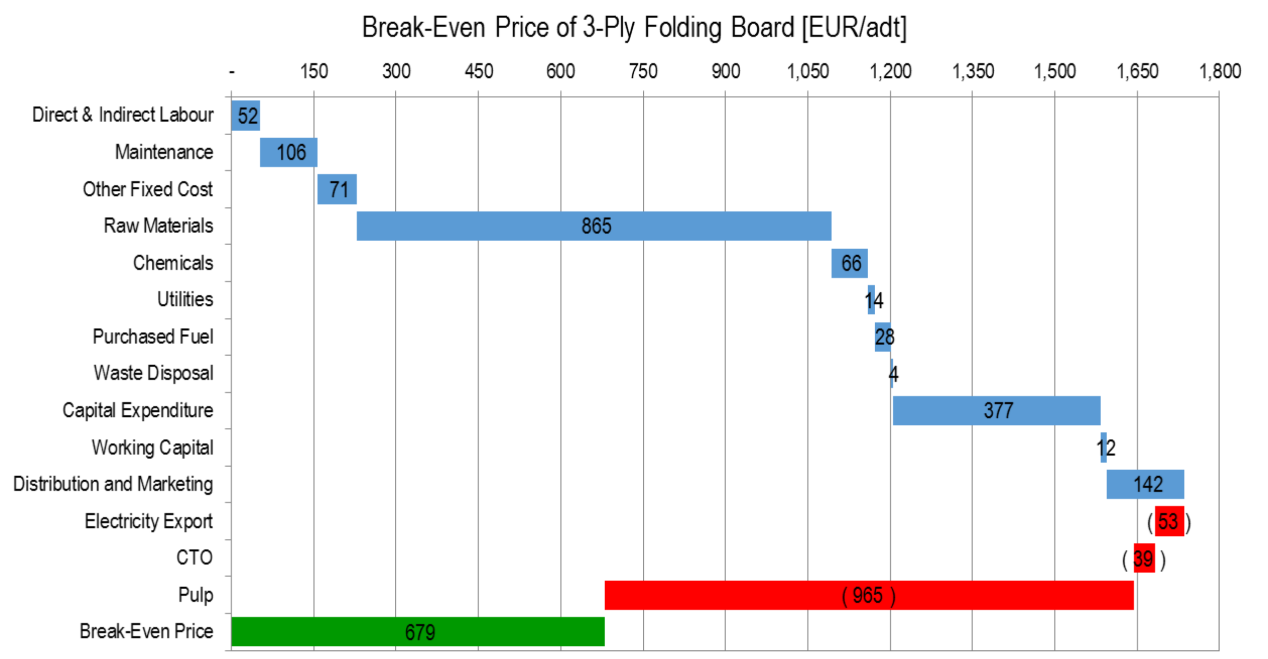

Figure 3: Breakeven price per adt of board [EUR/adt] (Base case 1B). The breakdown of the production cost is marked with blue, the revenues from the sale of by-products are marked with red and the breakeven price of the board is marked with green. The produced pulp (BSKP) is considered as co-product (also marked with red) and sold as market pulp. To calculate the break-even price of the board, the break-even price of 523 EUR/adt of BSKP (calculated in Base Case 1A) is assumed.

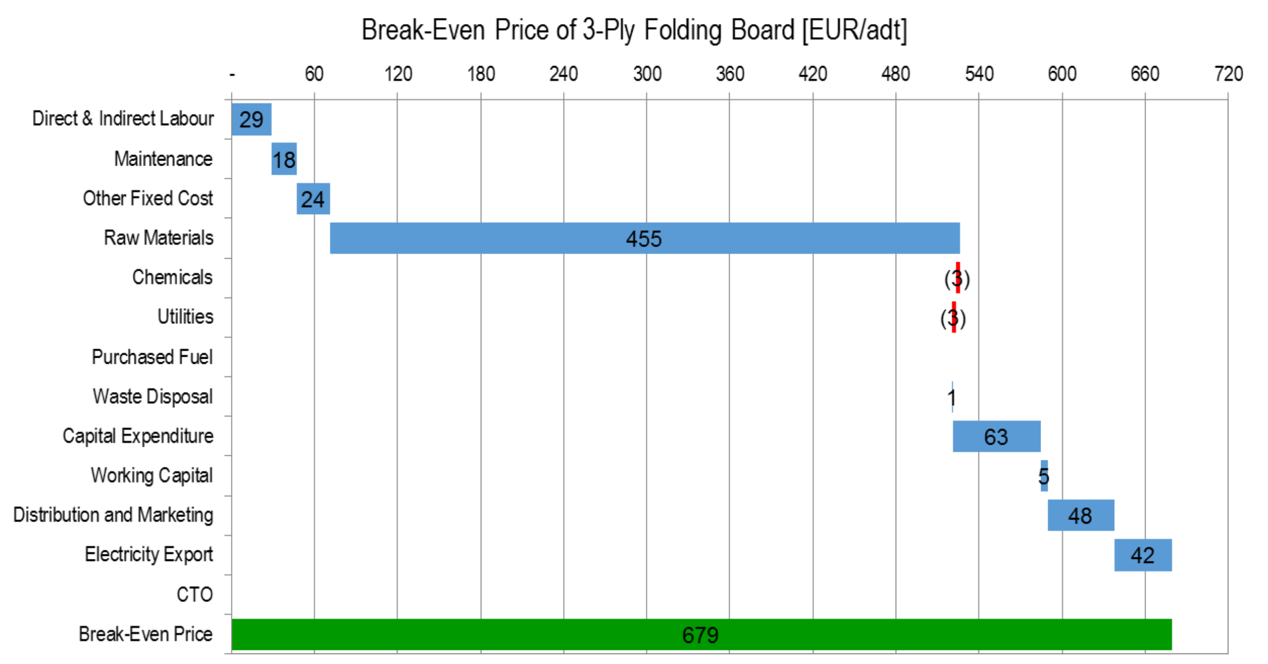

Figure 4: Breakeven price per adt of board [EUR/adt] (Base case 1B). The breakdown of the production cost are marked with blue, the break-even price of the board is marked with green. In this figure, all the costs related to pulp production are removed from the cost structure, therefore illustrating the additional cost attributed to the board production only.

7.1 Sensitivity analysis

The effect of ± 50% change in some of the major cost factors was evaluated. Selected variables are listed below and the values used in the sensitivity analysis are shown in Table 17. The results of the sensitivity analysis are presented in Figure 5.

(i) wood price
(ii) heavy fuel oil price
(iii) electricity price
(iv) discount rate
(v) total plant costs

Table 17: Variables for the sensitivity analysis

Variable		-50 %	-25 %	0 %	25 %	50 %
Wood	[EUR/m³]	20	30	40	50	60
HFO	[EUR/t]	200	300	400	500	600
Electricity	[EUR/MWh]	20	30	40	50	60
Discount rate	[%]	4%	6%	8%	10%	12%
TPC	[%]	50%	75%	100%	125%	150%

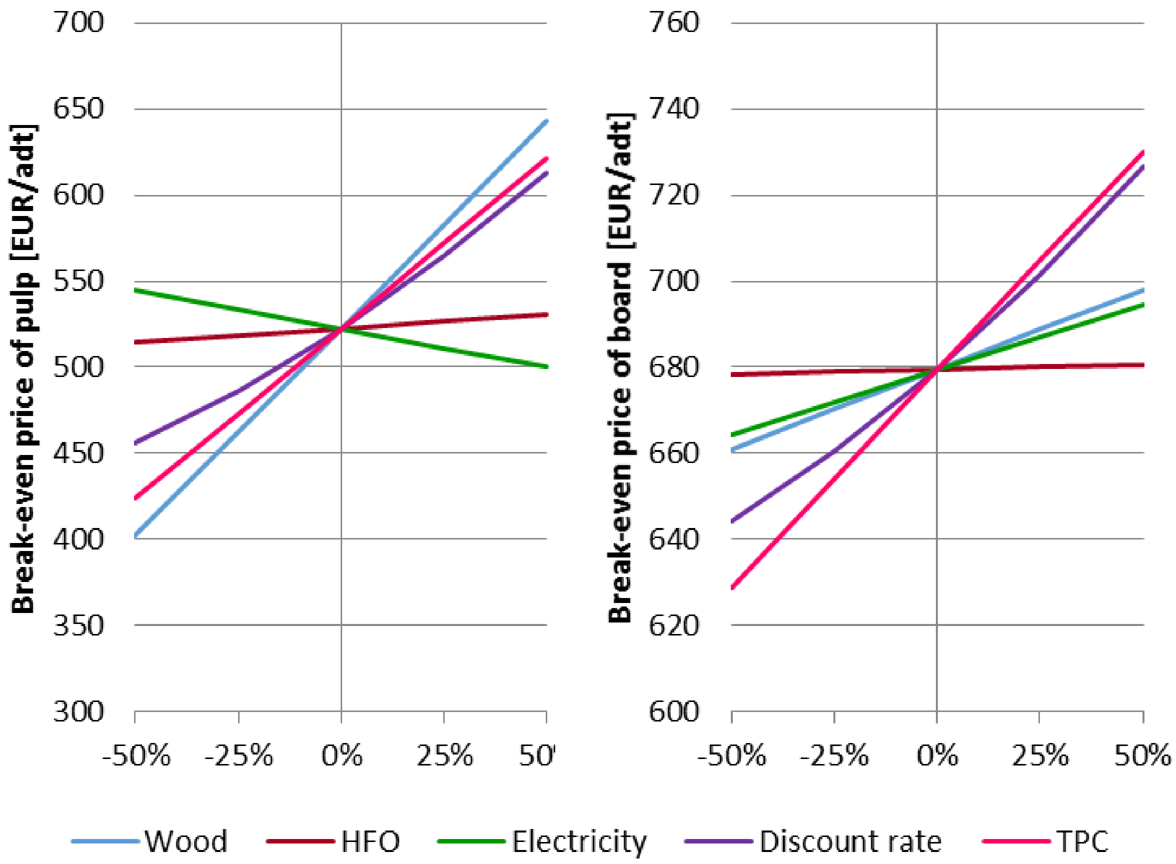

Figure 5: Sensitivity analysis of break-even price of pulp (Base case 1A) and board (Base case 1B). Effect of ± 50% changes in represented factors is illustrated.

The sensitivity analysis illustrates that the price of the wood, discount rate and TPC have the largest effect on the breakeven prices of the pulp and board. It should be noted that the breakeven price calculated in Base Case 1A set the price of the market pulp used by the board mill in Base Case 1B. (i.e. demonstrating the price setting mechanism for the market pulp applied in this study).

As demonstrated in Figure 2 and Figure 4, the price of wood is the overall largest cost factor in the production of pulp. As a consequence, an increase in wood price should also increase the breakeven price of pulp, which translates into an increase in the breakeven price of the board.

On the other hand, the increase in the overall total plant cost results in a higher breakeven price of the pulp and board. It should be noted that nearly 85% of the TPC is related to the pulp mill and the remaining balance is allocated to the board mill. Therefore, any increase in the overall TPC should lead to a higher increase in the breakeven price of pulp than in the breakeven price of the board as expected. This effect should reinforce the fact that the CAPEX component is a very small fraction of the price of the board.

The discount rate mainly reflects the impact on the cost of capital and its rate of return. Therefore, as expected, the increase in the discount rate should also increase the breakeven prices of pulp and board (i.e. to compensate for the increase in the cost of capital employed).

The sensitivity of the breakeven prices of pulp and board to the electricity price reflects the amount of surplus electricity exported to the grid. As expected, an increase in the selling price of electricity should reduce the cost of pulp production. This is not prominent when the integrated pulp and board is considered as the board mill consumes electricity on its own, therefore reducing the surplus electricity that could be exported to the grid.

8. CO_2 emission cost

The pulp mill (Base Case 1A) and the integrated pulp and board mill (Base Case 1B) as described in this study emit around 2.1 million tonnes of CO_2 annually. This consists of 1.6 million tonnes of CO_2 from the recovery boiler, 0.2 million tonnes from the lime kiln and 0.3 million tonnes from the multi-fuel boiler. Around 96% of the emissions are considered biogenic CO_2 and the rest is fossil based CO_2 (mainly originating from the combustion of the HFO in the lime kiln). Table 18 presents the breakdown between biogenic and fossil based CO_2 emissions for both reference mills (Base Case 1A and Base Case 1B).

Table 18: Breakdown of the CO_2 Emissions [MTPY] of the reference mills

	Biogenic Based CO_2 Emissions	Fossil Fuel Based CO_2 Emissions	Total Emissions
Recovery Boiler	1,642,400	-	1,642,400
Lime Kiln	132,554	86,582	219,136
Multi-fuel Boiler	300,800	-	300,800

To evaluate the sensitivity of the CO_2 emissions cost to the breakeven price of pulp or board, four different scenarios are evaluated and these are defined as follows:

- **Scenario #1:** No CO_2 emissions tax nor any incentives to the biogenic CO_2 emissions (Base number)
- **Scenario #2:** CO_2 emissions tax at €10/t and the biogenic CO_2 emitted by the mills is not recognized as CO_2 neutral (i.e. biogenic CO_2 is not exempted to the tax)

- **Scenario #3:** CO_2 emissions tax at €10/t and the biogenic CO_2 is recognized as CO_2 neutral – therefore exempting these emissions from the tax
- **Scenario #4:** CO_2 emissions tax at €10/t, the biogenic CO_2 is exempted from the tax and an additional incentive is credited to the Renewable Electricity exported to the grid at 10% of the electricity selling price (at €4 / MWh for the base number)

It should be noted that the CO_2 tax at €10/t reflects the current scenario where ETS price for CO_2 is very low. Additionally, for Scenario #4, the incentive at €4/MWh credited to the renewable electricity that is sold to the grid also reflects the current Nordic market where incentives given to the renewable electricity are slowly being withdrawn.

Nonetheless, sensitivity analysis to CO_2 emission tax and incentives to the renewable electricity are presented in the succeeding sections to demonstrate their impact to the break-even price of the pulp and board.

8.1 Break-even price of pulp and board at the different scenarios

Figure 6 and Figure *7* summarizes the results of the breakeven cost of pulp and board respectively at the given scenario.

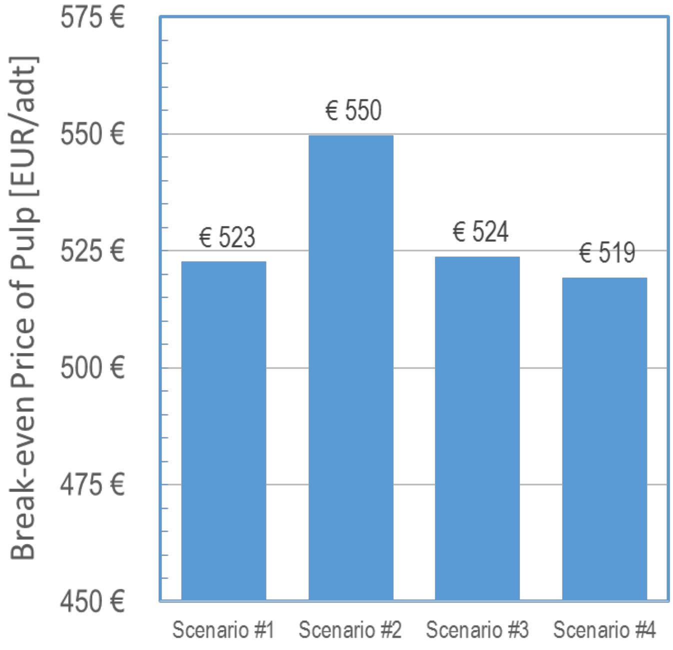

Figure 6: Impact to the breakeven cost of pulp (for Base Case 1A) vs CO_2 emissions cost as defined under the 4 different scenarios.

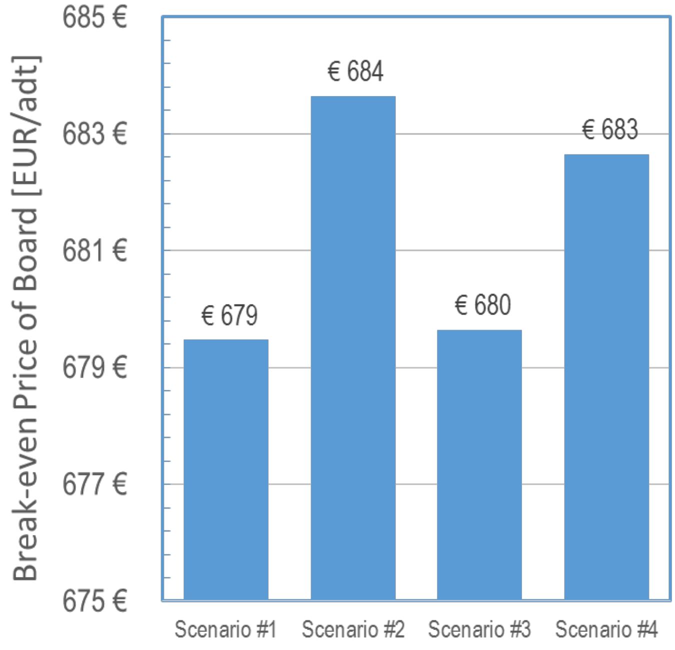

Figure 7 Impact to the breakeven cost of board[4] (for Base Case 1B) vs CO_2 emissions cost as defined under the 4 different scenarios.

[4] Breakeven price of the board is calculated using the corresponding breakeven price of the pulp of the given scenario. Likewise, this only accounts for the direct CO_2 emissions from the mill. The indirect CO_2 emissions from other raw materials (i.e. BHKP and CTMP) are not accounted.

8.2 Sensitivity to the CO_2 Emission Tax

Figure 8 presents the sensitivity of the break-even price of pulp and board to the CO_2 emission tax if the biogenic CO_2 is not given tax exemption (as defined by Scenario 2). It should be noted that this scenario only represents an extreme case where all the biogenic CO_2 emitted by the pulp mill are not recognized as "CO_2 neutral".

Figures 9 and 10 present the sensitivity to the CO_2 emission tax on the break-even price of the pulp and board when biogenic CO_2 is given tax exemption (as defined in Scenario 3) and also given a small incentive at €4/MWh for the renewable electricity exported to the grid (as defined in Scenario 4).

The results shown in Figure 9 clearly indicate that the small incentives given to the renewable electricity exported to the grid (at €4/MWh) has off-set the price of the pulp by around €4.5/adt of pulp (Scenario 3 vs Scenario 4). However, the fall in the price of pulp is not reflected in the price of the board due to the fact that there is lesser renewable electricity exported to the grid when the board mill is integrated to the pulp mill.

Figure 11 presents the sensitivity to the CO_2 emission tax on the break-even price of the pulp when only the biogenic CO_2 emissions from the Recovery Boiler and the Multi-fuel Boiler are recognized as "CO_2 neutral". This special case scenario represents the current EU ETS policy where the biogenic CO_2 from the lime kiln is not recognized as "CO_2 neutral".

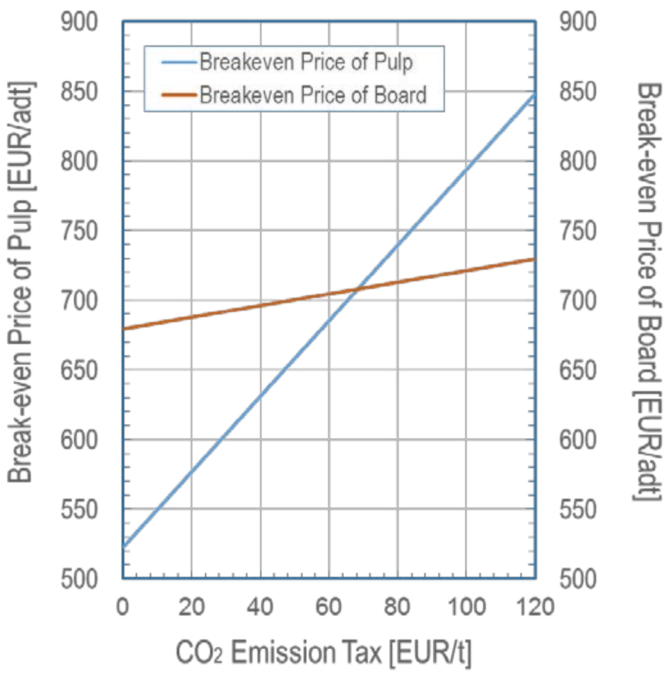

Figure 8 Sensitivity to the CO_2 emissions cost if biogenic CO_2 emission is not recognized a "CO_2 neutral" (as defined in Scenario 2).

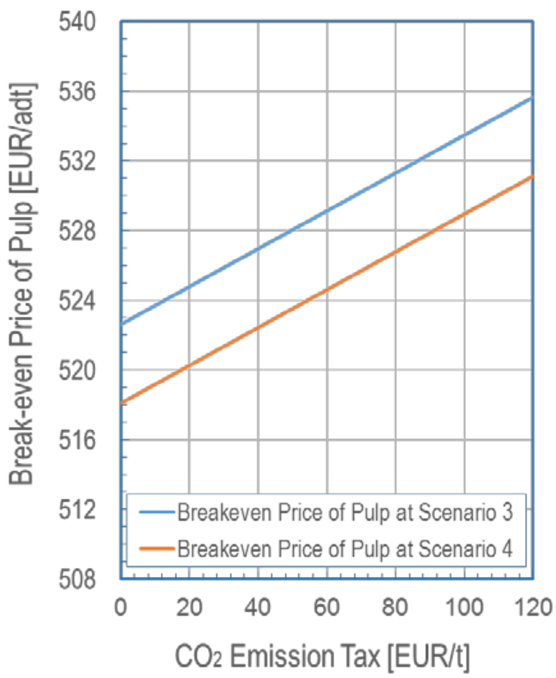

Figure 9 Sensitivity to the CO_2 emissions cost on the price of pulp if the biogenic CO_2 emission is recognized as "CO_2 neutral" (as defined in Scenario 3) and added incentive at €4/MWh is given to the Renewable Electricity exported to the grid (as in Scenario 4).

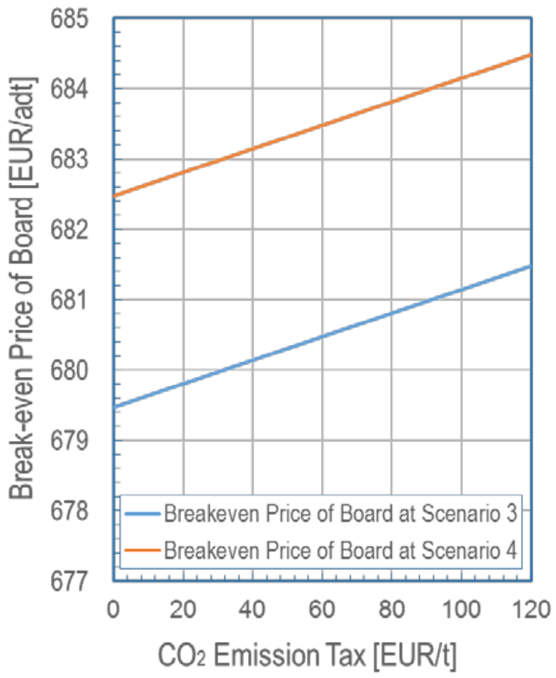

Figure 10 Sensitivity to the CO_2 emissions cost on the price of board[5] if the biogenic CO_2 emission is recognized as "CO_2 neutral" (as defined in Scenario 3) and added incentive at €4/MWh is given to the Renewable Electricity exported to the grid (as in Scenario 4).

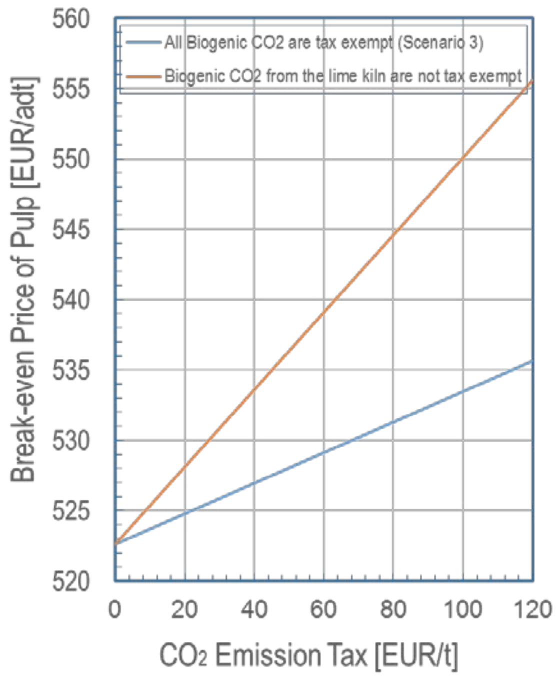

Figure 11 Sensitivity to the CO_2 emissions cost on the price of pulp if the biogenic CO_2 emission from the lime kiln is not recognized as "CO_2 neutral" – this representing the current EU ETS policy.

8.3 Sensitivity to the Renewable Electricity Credit

Figure 12 presents the sensitivity of the break-even price of the pulp to the Renewable Electricity Credit. All the prices of the pulp are calculated with an electricity selling price of €40/MWh. An additional credit to the renewable electricity exported to the grid of €4/MWh (i.e. 10% of electricity selling price) could represent the low incentive regime for renewable energy. Whilst, the additional credit of 10€ to 20€/MWh (i.e. 25 – 50% of the electricity selling price) could represent a more generous or high incentive regime.

Figure 13 illustrates the sensitivity of the break-even price of the board to the Renewable Electricity Credit. Due to the lower amount of renewable electricity exported to the grid in an integrated pulp and board mill (Base Case 1B) as compared to the standalone market pulp mill (Base Case 1A), the impact to the break-even price of the board is much less pronounced – i.e. the benefit of reducing the pulp price does not always translate to lower board price.

Figure 14 demonstrates the sensitivity to the Electricity Selling Price and Renewable Electricity Credit on break-even price of the pulp at CO_2 emission tax of €10/MWh with all the biogenic CO_2 having tax exempt status. Figure 15 illustrates only slight increase in the break-even price of pulp due to the higher CO_2 emission tax of €80/MWh as CO_2 emitted from pulp and board mill is mainly biogenic.

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[5] Breakeven price of the board is calculated using the corresponding breakeven price of the pulp of the given scenario. Likewise, this only accounts for the direct CO_2 emissions from the mill. The indirect CO_2 emissions from other key raw materials (i.e. BHKP and CTMP) are not accounted.

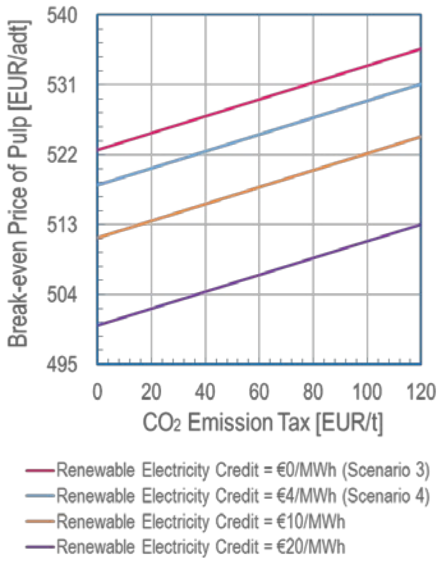

Figure 12 Sensitivity to the Renewable Electricity Credit on the break-even price of pulp. All prices are estimated based on electricity selling price of €40/MWh. This only accounts for the additional credit corresponding to the net amount of renewable electricity exported to the grid by the market pulp mill (Base Case 1A).

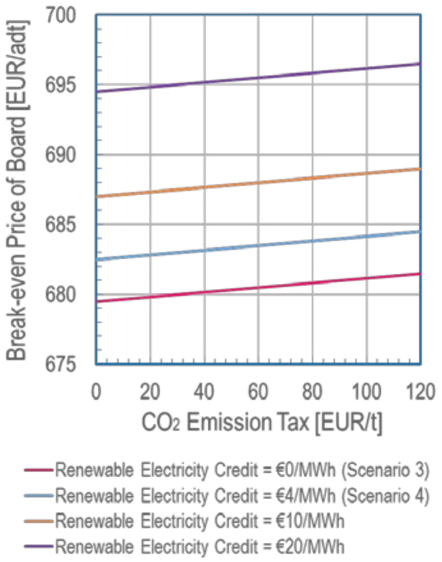

Figure 13 Sensitivity to the Renewable Electricity Credit on the break-even price of board[6]. All prices are estimated based on electricity selling price of €40/MWh. This only accounts for the additional credit corresponding to the net amount of renewable electricity exported to the grid by the integrated pulp and board mill (Base Case 1B).

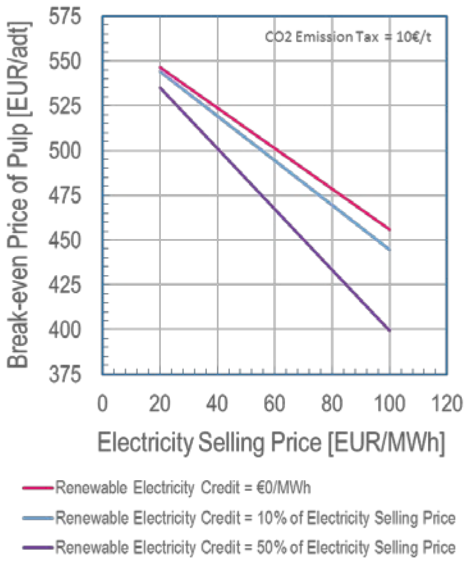

Figure 14 Sensitivity to the Electricity Selling Price and Renewable Electricity Credit on the break-even price of the pulp. All prices are estimated based on CO_2 Emission Tax of €10/t and with all the Biogenic CO_2 given tax exemption. This only accounts for the additional credit corresponding to the net amount of renewable electricity exported to the grid by the standalone market pulp mill (Base Case 1A).

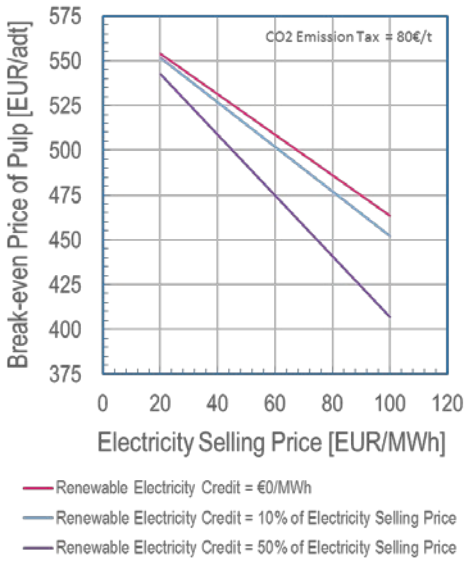

Figure 15 Sensitivity to the Electricity Selling Price and Renewable Electricity Credit on the break-even price of the pulp. All prices are estimated based on CO_2 Emission Tax of €80/t and with all the Biogenic CO_2 given tax exemption. This only accounts for the additional credit corresponding to the net amount of renewable electricity exported to the grid by the standalone market pulp mill (Base Case 1A).

[6] Breakeven price of the board is calculated using the corresponding breakeven price of the pulp of the given scenario. Likewise, this only accounts for the direct CO_2 emissions from the mill. The indirect CO_2 emissions from other key raw materials (i.e. BHKP and CTMP) are not accounted.

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Annexes

1. Annual Cash Flow
2. Annual Operating Expenditure

CCS in P&P Industry
Annex I: Annual Cash Flow

- Annex I-1: Base case 1A – Kraft pulp mill
- Annex I-2: Base case 1B – Integrated pulp and board mill

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill
Base Case 1A

				2005											
Period	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12
Sales				352.32	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76
Selling and Distribution Expenses				-30.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00
Net Sales Revenue (€ milion)				***322.32***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***
Variable Costs				-174.16	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22
GHG Emissions Cost															
CO2 Transport & Storage Cost															
Gross Margin (€ milion)				***148.16***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***
Fixed Costs				-60.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22
Net Margin (€ milion)				***87.94***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***
Residual Value - Capital Expenditure															
Capital Expenditure	-189.72	-395.94	-470.57	-143.84	-104.30										
Working Capital				-37.12											
Recurring Capital															
EBITDA (€ Million)	***-189.72***	***-395.94***	***-470.57***	***-93.03***	***28.02***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***

Period	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Sales	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	
Selling and Distribution Expenses	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	
Net Sales Revenue (€ milion)	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	
Variable Costs	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	
GHG Emissions Cost														
CO2 Transport & Storage Cost														
Gross Margin (€ milion)	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	
Fixed Costs	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	
Net Margin (€ milion)	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	
Residual Value - Capital Expenditure														
Capital Expenditure														
Working Capital														37.12
Recurring Capital														
EBITDA (€ Million)	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***37.12***

Internal Rate of Return (IRR)	**8.00%**
Discount Rate	**8.00%**
Net Present Value (NPV) - € Million	**(€ 0.00)**
Levelised Cost of Market Pulp	**€ 522.62**

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp and Board Mill
Base Case 1B

Period	-3	-2	-1	2005 1	2	3	4	5	6	7	8	9	10	11	12
Sales				520.95	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60
Selling and Distribution Expenses				-42.69	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92
Net Sales Revenue (€ milion)				***478.26***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***
Variable Costs				-293.03	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70
GHG Emissions Cost															
CO2 Transport & Storage Cost															
Gross Margin (€ milion)				***185.23***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***
Fixed Costs				-82.98	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10
Net Margin (€ milion)				***102.25***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***
Residual Value - Capital Expenditure															
Capital Expenditure	-223.96	-467.39	-548.51	-168.83	-122.43										
Working Capital				-61.04											
Recurring Capital															
EBITDA (€ Million)	***-223.96***	***-467.39***	***-548.51***	***-127.62***	***34.45***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***

Period	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Sales	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	
Selling and Distribution Expenses	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	
Net Sales Revenue (€ milion)	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	
Variable Costs	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	
GHG Emissions Cost														
CO2 Transport & Storage Cost														
Gross Margin (€ milion)	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	
Fixed Costs	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	
Net Margin (€ milion)	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	
Residual Value - Capital Expenditure														
Capital Expenditure														
Working Capital														61.04
Recurring Capital														
EBITDA (€ Million)	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***61.04***

Internal Rate of Return (IRR)	**8.00%**
Discount Rate	**8.00%**
Net Present Value (NPV) - € Million	**(€ 0.00)**
Levelised Cost of Board	**€ 679.47**
Levelised Cost of Pulp (Base Case 1A)	**€ 522.62**

CCS in P&P Industry
Annex II: Annual Operating Expenditures

- Annex II-1: Base case 1A – Kraft pulp mill
- Annex II-2: Base case 1B – Integrated pulp and board mill

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill
Base Case 1A

	Base Number €'000/y	Period -3	-2	-1	1	2	3	4	5	6	7	8
1. Fixed Cost ('000)												
1a. Direct Labour	€ 7,200.00				7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00
1b. Indirect Labour Cost	€ 2,880.00				2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 20,000.00				15,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00
1d. Maintenance	€ 35,139.50				35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50
Total (Fixed O&M Cost)					€ 60,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50
2. Variable Cost ('000)												
2a. Raw Materials	€ 185,600.00											
Wood	185,600.00				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	-											
CTMP	-											
Filler	-											
Coating	-											
2b. Chemicals	€ 27,250.40											
NaOH	11,011.20				8,258.40	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20
H_2O_2	2,960.00				2,220.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
$MgSO_4$	840.00				630.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	499.20				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H_2SO_4	800.00				600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
$NaClO_3$	9,800.00				7,350.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	700.00				525.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	640.00				480.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
2c. Utilities	€ 6,646.07											
Cooling Water	5,177.23				3,882.92	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23
Process Water	1,308.69				981.52	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69
Boiler Feed Water Make Up	160.14				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14
2d. Fuel Cost	€ 11,200.00											
HFO	11,200.00				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	€ 1,521.92											
Rejects from Brown Stock Handling	72.00				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	55.44				41.58	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill	-											
Waste Water Effluent Discharge	1,280.08				960.06	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08
Total (Variable O&M Cost)					€ 174,163.80	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40
3. Revenues ('000)												
3a. Board	€ -											
3b. Electrcity Export (Import) to the Grid	€ 36,068.80				27,051.60	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80
3c. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)					€ 38,751.60	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80
4. GHG Emissions Cost ('000)												
4a. CO_2 Emission Tax	€ -											
4b. CO_2 Emission Tax Credit	€ -											
4c. Renewable Energy Credit	€ -											
Total (GHG Emissions Cost)												
5. CO_2 Transport & Storage ('000)												
5a. CO_2 Transport & Storage	€ -											
Total (CO_2 Transport & Storage)												

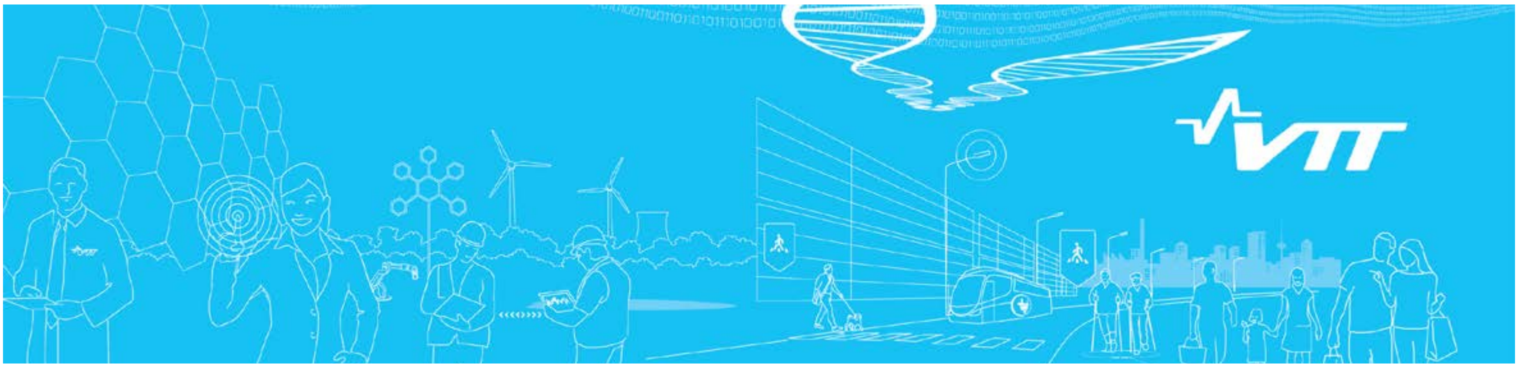
	9	10	11	12	13	14	15	16	17
1. Fixed Cost ('000)									
1a. Direct Labour	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00
1b. Indirect Labour Cost	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00
1d. Maintenance	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50
Total (Fixed O&M Cost)	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50
2. Variable Cost ('000)									
2a. Raw Materials									
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP									
CTMP									
Filler									
Coating									
2b. Chemicals									
NaOH	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20
H_2O_2	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
$MgSO_4$	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H_2SO_4	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
$NaClO_3$	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
2c. Utilities									
Cooling Water	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23
Process Water	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69
Boiler Feed Water Make Up	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14
2d. Fuel Cost									
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal									
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill									
Waste Water Effluent Discharge	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08
Total (Variable O&M Cost)	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40
3. Revenues ('000)									
3a. Board									
3b. Electrcity Export (Import) to the Grid	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80
3c. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80

	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)								
1a. Direct Labour	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00
1b. Indirect Labour Cost	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00
1d. Maintenance	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50
Total (Fixed O&M Cost)	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50
2. Variable Cost ('000)								
2a. Raw Materials								
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP								
CTMP								
Filler								
Coating								
2b. Chemicals								
NaOH	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20
H_2O_2	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
$MgSO_4$	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H_2SO_4	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
$NaClO_3$	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
2c. Utilities								
Cooling Water	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23
Process Water	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69
Boiler Feed Water Make Up	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14
2d. Fuel Cost								
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal								
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill								
Waste Water Effluent Discharge	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08
Total (Variable O&M Cost)	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40
3. Revenues ('000)								
3a. Board								
3b. Electrcity Export (Import) to the Grid	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80
3c. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp and Board Mill
Base Case 1B

	Base Number €'000/y	Period -3	-2	-1	2005 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
1. Fixed Cost ('000)																													
1a. Direct Labour	€ 14,400.00				14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00
1b. Indirect Labour	€ 5,760.00				5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 28,460.00				21,345.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00
1d. Maintenance	€ 41,478.80				41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80
	Total (Fixed O&M Cost)				**€ 82,983.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**
2. Variable Cost ('000)																													
2a. Raw Materials	***€ 345,915.56***																												
Wood	*185,600.00*				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	*55,177.78*				41,383.33	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	*92,977.78*				69,733.33	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	*5,760.00*				4,320.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	*6,400.00*				4,800.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals	***€ 26,206.78***																												
NaOH	*10,712.30*				8,034.22	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30
H2O2	*2,809.04*				2,106.78	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	*833.88*				625.41	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	*499.20*				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	*770.00*				577.50	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	*9,310.00*				6,982.50	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	*665.00*				498.75	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	*607.36*				455.52	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
2c. Utilities	***€ 5,583.75***																												
Cooling Water (m3)	*3,779.40*				2,834.55	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40
Process Water (m3)	*1,644.35*				1,233.26	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35
Boiler Feed Water Make Up (m3)	*160.00*				120.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
2d. Fuel Cost	***€ 11,200.00***																												
HFO	*11,200.00*				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	***€ 1,796.13***																												
Rejects from Brown Stock Handling	*72.00*				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	*0.80*				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	*40.00*				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	*13.60*				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	*60.00*				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	*51.18*				38.39	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	*40.00*				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Waste Water Effluent Discharge	*1,518.55*				1,138.91	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55
	Total (Variable O&M Cost)				**€ 293,026.67**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**	**€ 390,702.22**
3. Revenues ('000)																													
3a. Electrcity Export (Import) to the Grid	€ 21,312.00				15,984.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
	Total (Additional Revenues)				**€ 27,684.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**
4. GHG Emissions Cost ('000)																													
4a. CO2 Emission Tax	€ -																												
4b. CO2 Emission Tax Credit	€ -																												
4c. Renewable Energy Credit	€ -																												
	Total (GHC Emission Cost)																												
5. CO2 Transport & Storage ('000)																													
5a. CO2 Transport & Storage	€ -																												
	Total (CO2 Transport & Storage)																												



CUSTOMER REPORT

VTT-CR-01051-16 | 25.2.2017

CCS in P&P Industry – Mills with CCS: Performance

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Report's title

CCS in P&P industry – Mills with CCS: Performance

Customer, contact person, address	**Order reference**
IEA Greenhouse Gas R&D Programme and ÅF Consult Oy	
Project name	**Project number/Short name**
CCSP&P	102035

Summary

The performance of a Nordic Kraft pulp mill retrofitted with CO_2 capture is presented in this report. This study evaluated the retrofit of CCS on two reference mills: (i) Standalone pulp mill producing 800 000 air dried tonne (adt) of softwood Kraft pulp annually - Base Case 1A, and (ii) Integrated pulp and board mill producing 740 000 adt of softwood Kraft pulp and 400 000 3-ply folding boxboard annually - Base Case 1B.

Different combination of CO_2 capture options have been assessed:

- Capture of CO_2 from flue gas of the Kraft recovery boiler (REC)
- Capture of CO_2 from flue gas of the multi-fuel boiler (MFB)
- Capture of CO_2 from flue gas of the lime kiln (LK)
- Capture of CO_2 from flue gases of both REC and MFB
- Capture of CO_2 from flue gases of both REC and LK
- Capture of CO_2 from flue gases of REC, MFB and LK

The evaluation is based on the Kraft pulp mill performance reported by Kangas et al. [5] using WINGEM process simulation to calculate the mill's mass and energy balances. The CO_2 capture and compression plant is based on a post-combustion CO_2 capture technology using MEA as solvent, using Aspen process simulation to calculate its mass and energy balances. The consumption of raw materials, chemicals and utilities of the mills with CCS are evaluated and discussed in this report.

Both reference mills are considered energy independent. Excess electricity produced by the mills is exported to the grid. However, the addition of CCS could reduce the amount excess electricity that could be exported. In some cases, where CCS is retrofitted to an integrated pulp and board mill, an auxiliary boiler is needed to supplement the steam supply to the CO_2 capture plant.

The overall CO_2 emission from the reference mills is around 2.1 million MTPY. The addition of CCS could avoid around 8 to 90% of the CO_2 emitted annually depending on the CCS cases evaluated.

Tampere 9.1.2017

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List of abbreviations

adt	air dried tonne
bar(a)	bar absolute
BFW	boiler feed water
BFB	bubbling fluidized bed
CCS	CO_2 capture and storage
COD	chemical oxygen demand
CW	cooling water
CWR	cooling water return
CWS	cooling water system
DCC	direct contact cooler
ESP	electrostatic precipitator
G	generator
h	hour
HP	high pressure
HSS	heat stable salts
HX	heat exchanger
HWWS	hot and warm water system
IEA	International Energy Agency
IEAGHG	IEA Greenhouse Gas R&D Programme
IP	intermediate pressure
kg	kilogram
kt	metric kilo tonne
kW	kilowatt
L/G	liquid/gas
LK	lime kiln
LP	low pressure
m	meter
M	million/mega
m^3	cubic meter
MEA	monoethanolamine
MFB	multi-fuel boiler
MJ	megajoule
MP	medium pressure
MTPY	metric tonne per year
MW	megawatt
NPE	non-process elements
PM	particulate matter
ppm	parts per million
REC	recovery boiler
s	second
t	metric tonne
ULP	ultra-low pressure
v	volume
vol.	volume
wt.	weight

1. Background

Emission of anthropogenic CO_2 to the atmosphere and the resulting effect on global climate change has been a major concern during the last decades. As the time frame to avoid the rise of global temperature of 1.5°C to 2°C is narrowing, the cost expected to achieve these objectives is also rising. Recent studies suggest that in order to avoid a 2°C global temperature increase, the global net carbon emissions will need to be cut dramatically by 2050 [1]. This calls for deployment of technologies that can remove carbon from the atmosphere [2]. In order to deliver the required carbon removal capacity by the end of this century, the deployment of these technologies needs to start promptly [3].

The recent IEA CCS roadmap [4] has identified the pulp and paper industry as one of the major industries where CO_2 capture and storage (CCS) could be potentially deployed outside the power generation industry. The pulp and paper industry is an energy intensive industry and the largest producers and users of renewable energy in Europe [6,7]. The pulp and paper industry predominantly utilizes biomass as raw material for production of electricity and steam by-products. Capturing and storing CO_2 deriving from combustion of biogenic material (Bio-CCS) has the potential to extract CO_2 from the atmosphere and thus create carbon sinks in the form of negative CO_2 emissions.

The main types of fuel used by the pulp mills are black liquor or residual organic materials from the wood cooking process, and bark residues from the debarking of round wood used in pulping. Only a small share of the CO_2 emissions in a modern Kraft pulp and paper mill is of fossil origin.

Deploying CO_2 capture process to a pulp mill will increase the on-site energy demand of the integrated mill. The additional steam and electricity demand can partly be met by the surplus energy produced within the mill. However, in cases where the onsite energy production is not sufficient to cover the requirement for a CO_2 capture plant, additional energy production is required. This could be covered by installing additional auxiliary boiler fueled with other bio-based by-products (such as forest residues, bio-sludge, etc.) from the forest industry.

The purpose of this evaluation is to assess the feasibility of retrofitting an amine-based post-combustion CO_2 capture process to a) a standalone pulp mill and b) an integrated pulp and board mill. This study evaluates the implications of the CO_2 capture facility on the mill's process performance in terms of fuel balance and utilities such as steam, electricity and water (process water, cooling water and wastewater).

2. Methodology

2.1 Case studies

The study involves the evaluation of retrofitting a CO_2 capture plant into two different types of reference mills:

a) Base Case 1A – a standalone Kraft pulp mill producing 800 000 adt of bleached softwood Kraft pulp annually

b) Base Case 1B – an integrated Kraft pulp and board mill producing 740 000 adt bleached softwood Kraft pulp and 400 000 adt of 3-ply folding box board annually

The performance of both reference mills was evaluated by modelling the mass and energy balances based on a typical modern Nordic Kraft pulp mill.

Six CO_2 capture cases were identified and evaluated for each reference case, with a total of twelve different CO_2 capture cases evaluated:

- Cases 2A-1 & 2B-1: Capture of CO_2 from flue gas of the recovery boiler (REC) only
- Cases 2A-2 & 2B-2: Capture of CO_2 from flue gas of the multi-fuel boiler (MFB) only
- Cases 2A-3 & 2B-3: Capture of CO_2 from flue gas of the lime kiln (LK) only
- Cases 2A-4 & 2B-4: Capture of CO_2 from flue gases of both REC and MFB
- Cases 2A-5 & 2B-5: Capture of CO_2 from flue gases of both REC and LK
- Cases 2A-6 & 2B-6: Capture of CO_2 from flue gases of all the three sources.

2.2 Process modelling

The performance of the reference pulp (and board) mills was evaluated using WinGems 5.3 process simulator and is described in detail by Kangas et al. [5]. The performance of the CO_2 capture plant was modelled using Aspen Plus Rate-based Distillation, providing the mass and energy balances.

The amine-based CO_2 capture process is a non-ideal process consisting of very reactive systems with interacting polar components. In order to model this system optimally, the Rate-Base Distillation Electrolyte model is used instead of the Aspen Plus Equilibrium Model[3]. The electrolyte model takes into account the effects of kinetics and mass transfer including the limitations associated to these parameters. This is of specific importance because the CO_2 absorption is limited by mass and heat transfer rather than reaching equilibrium. This gives a more realistic flux of CO_2 moving between vapor and liquid phases in the modelled system. The properties of the MEA was modelled using the ELECNRTL property method.

2.3 Evaluation boundaries

The system boundaries applied for evaluating CCS in the pulp and paper industry were drawn around the actual mills. Input to the system boundary consists of raw material and chemicals, while system output over the boundaries consists of products and waste.

The study assumes that wood raw material utilized is grown and harvested sustainably, which is mainly the case in Europe. The CO_2 emissions arising from growing, harvesting and transporting raw material, including direct and indirect land use changes, have not been taken into consideration.

Some fossil CO_2 must be expected also from the recovery boiler and the multi-fuel boiler for start-up and shutdown. The amount is very minor compared to total CO_2 emissions during normal operation and has for the sake of simplicity been omitted from this study.

3. Process description

This study evaluates post-combustion capture of CO_2 from the three main CO_2 emission sources within the pulp mill (i.e. recovery boiler, multi-fuel boiler and lime kiln).

For all the cases evaluated, the capture of CO_2 is based on chemical absorption technology with a split flow configuration using a conventional 30 wt-% monoethanolamine (MEA) (see

[3] Aspen Plus Equilibrium model assumes that liquid and vapor phases leaving each stage is completely mixed and in phase and thermal equilibrium.

section 3.2.2). The conventional 30 wt-% MEA was chosen in order for this study to be comparable to similar studies from the past that have used state-of-the-art MEA absorption technology. A split flow configuration was adapted in order to reduce the energy demand for amine regeneration. Tailored amine solvents exist that can further drive down the regeneration energy demand, but it was decided to apply the conventional MEA technology as it will result in more conservative results for the study. The CO_2 capture rate of 90% was applied in all the cases. The overall CO_2 capture rate of the site varies depending on how many of the flue gas sources are treated (this is illustrated in section 4, sheet 15).

The wet CO_2 product from the CO_2 capture plant is dried and compressed to 110 bar(a), ready for transport and storage.

The battery limit for the CO_2 capture and compression plant consists of the following units:

- Unit 10100 Direct contact cooler (DCC)
- Unit 10200 CO_2 absorber and associated equipment
- Unit 10300 CO_2 stripper, reboiler and condenser
- Unit 10400 Amine reclaimer unit
- Unit 11000 CO_2 compression and drying unit

The block flow diagrams and corresponding mass balances of the CO_2 capture plant and the CO_2 compression and drying unit are presented in section 4, sheets 1 to 5. Annexes I and II present the overall block flow diagram of the mills with the CO_2 capture and compression plant for all the cases evaluated.

3.1 Sources of flue gas

The main sources of CO_2 emissions of both the market pulp mill (Base Case 1A) and the integrated pulp and board mill (Base Case 1B) are from the recovery boiler, from the lime kiln and from the multi-fuel boiler.

The pulp mills in both reference cases are identical and emit about 2.1 million metric tonnes CO_2 annually (MTPY). This is summarized in Table 1 below.

Table 1: CO_2 point sources at the reference mills in MTPY [5]

	Biogenic Based CO_2 Emissions	Fossil Fuel Based CO_2 Emissions	Total Emissions	CO_2 Concentration in the Flue Gas
Recovery Boiler	1.642.400	-	1.642.400	20.0 wt-% (wet)
Lime Kiln	132.554	86.582	219.136	32.0 wt-% (wet)
Multi-fuel Boiler	300.800	-	300.800	20.0 wt-% (wet)

3.1.1 Classification of the CO_2 emissions from the pulp mill

The CO_2 emissions from the recovery boiler originate from the combustion of organic matters in the black liquor. The CO_2 emitted originates from biomass and is classified as 100% biogenic. Emissions from the multi-fuel boiler originate from the combustion of bark (obtained from the wood handling plant) and bio-sludge (derived from the wastewater treatment plant). The CO_2 emitted from the multi-fuel boiler is also classified as 100% biogenic. In cases where an auxiliary boiler is deployed, the CO_2 emitted from this boiler originates from the combustion of forest residues or wood waste and is considered 100% biogenic.

The emissions from the lime kiln originate both from the combustion of fuel in the kiln and from the calcination reaction. For this reason, the CO_2 partial pressure is typically higher in the flue gas of the lime kiln. In this study, the fuel used in the lime kiln is heavy fuel oil. As a consequence, all of the emissions derived from the combustion of fuel are classified as fossil CO_2 emissions. Emissions from the calcination reaction are classified as biogenic CO_2. The reasoning behind this is that the CO_2 from the calcination process originates from the black liquor recovery process where part of the CO_2 produced during the black liquor combustion is captured by the smelts as Na_2CO_3. These processes are described in more detail in Annex IV of the report presented by Kangas et al [5].

3.1.2 Quality of the Flue Gas and Amine Degradation

One of the major considerations when integrating a post-combustion CO_2 capture process to an industrial process is the quality of the flue gases to be treated. The MEA solvent is sensitive to nitrogen dioxide (NO_2), oxygen (O_2), sulfur oxides (SO_x) and dust. These components can cause solvent degradation, equipment corrosion, foaming and formation of heat stable salts (HSS).

Flue gases from the recovery boiler, lime kiln and multi-fuel boiler typically have impurities that are much lower compared to the conventional coal-fired power plants. However, it should be noted that in the flue gas of the recovery boiler, a certain amount of sodium and sulfur compounds could be included in the particulate matters.

Table 2 summarizes the typical concentration of SO_x, NO_x and dust in the different flue gases to be treated by the CO_2 capture plant. These are based on estimates typical for pulp mills operating in accordance to the EC Directives on industrial emissions. These estimates are measured in the plant using continuous measuring devices as described in the Holcim Emission and Monitoring Guideline [6].

Table 2: Typical impurities in the flue gases (reported @ 6% O_2, dry)

Impurities		Recovery boiler	Multi-fuel boiler	Lime kiln	Typical Limit for MEA application	Ref.
SO_X	[ppm]	60	40	50	10-35	[8,9,10]
Dust/PM	[ppm]	30[1]	15	30[2]		
NO_2	[ppm]	11.0	14.1	16.9	20	[9,10]

[1] Fly ash could contain Na_2SO_4, Na_2CO_3 [2] Fly ash could contain CaO, $CaCO_3$

<u>Dust and particulate matters</u>

Dust and particulate matters can cause amine degradation and solvent foaming. It could also contribute to plugging and scaling of process equipment.

Flue gases from the recovery boiler, the multi-fuel boiler and the lime kiln go through electrostatic precipitators (ESP) for dust removal prior to CO_2 capture. It is assumed that the majority of the particulate matter (> 99%) is removed by the ESP. Most of the residual particulate matter is removed in the direct contact cooler (DCC).

<u>Sulfur dioxide (SO_2) and sulfur trioxide (SO_3)</u>

SO_2 and SO_3 are formed during the combustion of fuel containing sulfur. The main combustion product is SO_2, typically around 1 to 3% of SO_2 is converted to SO_3. Sulfur oxides (mainly SO_2 and SO_3) react with amine to form heat stable salts (HSS).

The SO_2 concentration in flue gases from the recovery boiler and the multi-fuel boiler is typically low compared to the SO_2 content of the flue gas derived from a coal-fired power plant, and the concentrations are generally below the emissions limit as required by the EC Large Combustion Plant directive.

The level of SO_2 in the flue gas of the recovery boiler is partly dependent on how the strong odorous gases from the pulp mill are handled on site. Strong odorous gases (which could also include methanol and turpentine) can be burned in the lime kiln, recovery boiler or in a dedicated odorous gas incinerator. In this study it is assumed that strong odorous gases are burned in the recovery boiler together with turpentine and methanol.

The SO_2 concentration in the flue gas of the lime kiln is dependent on the sulfur content of the heavy fuel oil (or other fuel) used. Due to the lime quality requirements, low sulfur fuel oil is preferred in order to reduce the amount of non-process elements (NPE) within the lime cycle of the pulp mill.

The implementation of a flue gas desulfurization (FGD) plant prior to the CO_2 capture plant may be required if the sulfur content of the flue gases is high. Alternatively, the DCC can be operated with dosing of alkali solution to scrub out sulfur components. One study suggested that it will be more feasible to invest in the flue gas desulfurization to achieve SO_2 concentration below 10 ppm than to incur the cost due to amine loss associated with higher SO_2 concentrations. This decision is a tradeoff depending on the cost of the amine solvent used versus the investment cost of the flue gas desulfurization plant or the additional operating of alkali dosing in the DCC [10,12].

For this evaluation, it was concluded that the SO_2 concentration in the flue gases was so low that it will not be feasible to invest in a flue gas desulfurization unit within the life time expected from the reference plant. Instead, the formation of HSS and degradation of amine by SO_2 was covered by the amine reclaimer unit and additional amine makeup as replacement for degraded amine.

SO_3 is soluble in water and it is expected that most of the SO_3 will be removed in the DCC. To prevent any carry over as H_2SO_4 mist from the DCC to the absorber, the cooled flue gases pass through a demister prior to the CO_2 absorber column.

Nitrogen dioxide (NO_2)

Nitrogen oxide (NO_x) in the form of nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are formed during combustion processes. The amount of NO_x in the flue gas is mainly dependent on the nitrogen content of the fuel and the combustion conditions. Typically less than 10% of the NO_x in the flue gas consists of NO_2.

NO_2 also reacts with amines to form amine degradation products such as nitrosamines and heat stable salts (HSS). NO in the flue gas is considered an inert and will not degrade the solvent [11-14].

Studies have also indicated that it is more feasible to replace the degraded amine than to invest in de-NOx equipment [10], but also this is a tradeoff between the investment costs of a de-NO_x unit and the additional cost for amine makeup.

In this study the level of NO_2 is below the recommended limit of 20 ppm NO_2 and there was no need for any additional de-NOx process.

Oxygen (O_2)

Oxygen promotes oxidative degradation of amine to form by-products such as acetates, oxalates, glycolates, bicines, formates and dithiocarbamates. Amine lost to oxidative degradation is not necessarily recoverable in the amine reclaimer [15]. In addition to degrading the amine solvent oxidative degradation also increases the risk of corrosion to the process equipment.

Adding inhibitors to the amine solvent can reduce the degradation rate of the solvent and minimize corrosion, especially in the case of high oxygen levels. In this study, it was assumed that degraded amine would be fully replaced.

Thermal degradation

Subjecting the amine to excessive temperature conditions could cause thermal degradation of the solvent and reduce its absorption efficiency. To reduce the impact of high temperature on the solvent the direct contact cooler reduces the temperature of the incoming flue gases to 40ºC before entering the absorber column. Additionally, the lean amine and the semi-lean amine are also cooled to 40ºC in order to compensate for the temperature rise during the absorption process. Intercoolers could also be applied to control the temperature in the CO_2 absorber during the absorption process. Intercooler configurations were not applied in this study. Due to the challenge with thermal degradation of the amine the maximum temperature in the stripper is limited, preferably to below 130°C [10,13,16].

3.2 CO_2 capture plant

3.2.1 Direct contact cooler (Unit 10100)

Prior to entering the CO_2 absorber, the flue gases are cooled and condensed in the direct contact cooler (DCC). This is also employed to remove any residual dust and soluble acidic components in the flue gas.

Flue gas from the recovery boiler and multi-fuel boiler are delivered at around 180 – 200ºC, and flue gas from the lime kiln is delivered at 230 – 250ºC. The flue gases are cooled prior to entering the DCC in a gas-gas heat exchanger where the heat from the flue gases is used to reheat the vent gas exiting the absorber. Flue gases are then further cooled down to 40ºC in the DCC. To compensate for the pressure drop across the DCC, the heat exchangers and the absorber column flue gas booster fans are installed at each flue gas source.

The DCC consists of a packed bed water spray column. This could be dosed with NaOH or other alkali solutions for the removal of SO_x as a polishing step if needed. This option was not taken in this study due to very low SO_x content in the flue gases.

The flue gases enter the DCC in the bottom and flows upwards, contacting with cooling water that is sprayed into a packed column from the top. The water is collected from the bottom of the DCC column, cooled and recirculated back to the DCC. Excess water (due to the condensation of water in flue gas) of the DCC is bled and sent to the wastewater treatment plant. This is to prevent any accumulation of dust and acidic components. The make-up water is derived from the bleed of the water wash section of the absorber column. This reduces the amount of make-up water required by the CO_2 capture plant.

The DCC is equipped with a demister to reduce the amount of mist carried over to the absorber by the cooled flue gas.

The overall mass balance for the DCC is presented in section 4, sheet 2, and the key parameters used in the modelling of the DCC is presented in Table 3.

Table 3: DCC parameters (Unit 10100)

Parameter	Stream No.	Unit	Value
Exit temperature - vent gas (from absorber and after the gas-gas heater)	5	[°C]	120
Booster fan pressure		[bar]	1.11
Cooled flue gas temperature	2	[°C]	40

3.2.2 CO_2 absorber and associated equipment (Unit 10200)

The flue gas from the DCC is fed into the bottom stage of a countercurrent packed bed absorption tower. The absorption column is divided into two sections with the amine scrubbing section in the lower part and the water wash section at the top. The amine solvent is fed into the absorber at the top and mid-stages of the scrubber section. Rich amine, saturated with CO_2, is withdrawn from the bottom of the absorber column and pumped through a lean-rich amine heat exchanger before being fed to the solvent regenerator. The vent gas exiting the absorber is reheated using the incoming flue gas prior to the DCC to avoid condensation in the stack and plume formation (see section 4, sheet 1).

The water wash section of the absorber column serves two purposes: a) closing the water balance of the CO_2 capture system and b) scrubbing out any degraded amine products. Washing water is recirculated in the water wash column. A part of the wash water is bled in order not to accumulate any degraded amine products and to maintain the water balance. This water bleed is cooled and used as make-up water in the DCC column.

Split flow configuration

The split flow configuration applied in this study is a variant of the conventional amine-based CO_2 absorption process. The main purpose of the split flow configuration is to reduce the overall energy consumption of the CO_2 capture plant. Several variations of the split flow configuration are reported in literature [17-21].

The main idea with the split flow configuration is to regenerate only a part of the amine solvent used in the absorption process by withdrawing a portion of the amine from the mid-section of the stripper column. In some cases, a portion of the rich amine is regenerated partially in a separate flash column.

Rich amine is fed to the top of the stripper section in the regenerator. As the saturated amine solvent flows downwards the temperature increases and CO_2 is released from the solvent. Lean amine, which is almost fully stripped of CO_2, is collected from the stripper bottom and returned to the absorber. Extracting a side stream of the amine solvent from the stripper mid-stages reduces the flow rate to the bottom of the stripper. This translates into lower steam demand in the reboiler. The amine solvent in this side stream has not been fully regenerated, but still holds capacity to absorb CO_2 in the absorber. This is then introduced in the mid-section of the absorber column. The partially regenerated amine is known as the semi-lean amine.

One major advantage of the split flow configuration is the reduction in thermodynamic losses due to the reduced driving force in the absorption column [17,22]. Additionally, the semi-lean amine could also act as an inhibitor to MEA degradation by minimizing the interaction between the amine with the SO_2 and O_2 in the flue gases (i.e. reducing the driving force of reaction between amine and these species).

A disadvantage of using split flow configuration is the requirement of higher flow rate of solvent recirculation in order to achieve a similar CO_2 recovery rate compared with the conventional configuration. Another drawback of using semi-lean amine is the higher risk of corrosion that it poses to the different process equipment due to the higher concentration of MEA components in the solvent [15]. Capital investments for a split flow configuration are higher as this requires larger absorber columns and additional equipment such as additional heat exchangers, pumps and additional piping for the semi-lean amine solvent.

In this study, a simple split flow configuration has been implemented. This is illustrated in section 4, sheet 1. In this configuration, the semi-lean amine is withdrawn from the mid stages of the stripper section and fed into the mid stages of the absorber column. The stage where the semi-lean amine is withdrawn from the stripper column is dependent on the temperature profile in the columns and how the individual absorption process is optimized. The split flow configuration lowered the specific heat demand in the regenerator reboiler from 3.6 MJ/kg captured CO_2 for the conventional amine circulation system to 3.1 – 3.2 MJ/kg CO_2.

Key parameters

The overall mass balance around the absorber column is summarized in section 4, sheet 2. The key parameters used in the modelling of the absorber column and some of the key results are presented in Tables 4 and 5.

Table 4: Key operating parameters of the absorber (Unit 10200)

No.	Stream		2A-1 & 2B-1^{CO2MP}	2A-2 & 2B-2	2A-3 & 2B-3	2A-4 & 2B-4^{CO2MP}	2A-5 & 2B-5^{CO2MP}	2A-6^{MP} & 2B-1^{CO2MP}
2	Flue gas from DCC	[kg/s]	250.8	40.2	18.1	291.3	268.9	309.4
	Temperature	[°C]	40	40	40	40	40	40
	CO_2 concentration	[mol-%]	14.7	16.8	27.6	15.0	15.5	15.7
6	Lean amine	[kg/s]	746.6	136.7	87.4	869.9	840.8	984.9
	Temperature	[°C]	40	40	40	40	40	40
	Loading	[mol/mol]	0.23	0.23	0.23	0.23	0.23	0.23
7	Semi-lean amine	[kg/s]	550.0	60.0	65.0	640.0	600.0	750.0
	Temperature	[°C]	40.0	40.0	40.0	40.0	40.0	40.0
	Loading	[mol/mol]	0.45	0.42	0.41	0.45	0.45	0.45
8	Rich amine	[kg/s]	1345.5	205.0	158.4	1567.6	1496.0	1801.3
	Temperature	[°C]	49.3	51.2	56.2	48.8	49.5	51.2
	Loading	[mol/mol]	0.49	0.50	0.50	0.50	0.50	0.49

Table 5: Key design parameters of the amine absorber (Unit 10200)

Parameter		2A-1 & 2B-1^{CO2MP}	2A-2 & 2B-2	2A-3 & 2B-3	2A-4 & 2B-4^{CO2MP}	2A-5 & 2B-5^{CO2MP}	2A-6^{MP} & 2B-1^{CO2MP}
Absorber diameter	[m]	13.2	5.4	3.9	14.5	14.0	14.9
Estimated height of the column	[m]	35	30	25	45	45	50
CO_2 recovery	[%]	90.0	90.0	90.0	90.0	90.0	90.0
Gas velocity	[m/s]	1.4	1.4	1.1	1.4	1.4	1.4
L/G ratio		5.1	5.1	8.5	5.3	5.5	5.7

* Including water wash section

3.2.3 CO_2 stripper (Unit 10300)

The CO_2 stripper is a countercurrent packed bed distillation column equipped with a condenser and reboiler. The stripper is divided into two sections with the amine regeneration in the lower section and the water wash section on top of the column.

Rich amine withdrawn from the CO_2 absorber is pre-heated in the rich-lean amine heat exchanger to around 99°C before being fed into the top of the stripper section. Due to the higher temperature, the bond between the CO_2 and the amine solvent is broken, releasing CO_2 from the amine solvent. Heat for regeneration in the stripper column is provided by the reboiler. The reboiler is heated with steam.

Semi-lean amine is withdrawn from the mid-section of the stripper column at around 98 – 107°C. The lean amine is withdrawn from the bottom of the column at 120°C. Both solvent streams are used to pre-heat the incoming rich amine in the rich-lean amine heat exchanger. The lean and semi-lean amine solvents are then further cooled to 40°C before being fed into the absorber column (illustrated in section 4, sheet 1).

The water wash section, also equipped with a demister, minimizes any carryover of the amine in the captured CO_2 product. The captured CO_2 contains a significant amount of water. This is removed in the condenser and the condensate is collected and recycled back to the water wash section.

The reboiler used in providing the heat required by the CO_2 stripper is a kettle type reboiler. Ultra-low pressure (ULP) steam required by the reboiler is mainly supplied from the de-superheated low pressure (LP) steam obtained from the steam turbine of the pulp mill. In cases where excess steam from the pulp mill is not sufficient to cover the requirements of the CO_2 capture plant, medium pressure (MP) steam could be supplied by an auxiliary boiler fired with waste wood. In cases where the CO_2 compressor is driven by a steam turbine, most of the ULP steam will be derived from this unit.

Results of steam requirement for the different cases are presented in section 4, sheets 6 and 7, and described in section 5.

The overall mass balance around the stripper column is summarized in section 4, sheet 2. The parameters used for modelling the stripper column are presented in Table 6.

Table 6: Key parameters of the CO_2 stripper (Unit 10300)

Parameter		2A-1 & 2B-1^{CO2MP}	2A-2 & 2B-2	2A-3 & 2B-3	2A-4 & 2B-4^{CO2MP}	2A-5 & 2B-5^{CO2MP}	2A-6^{MP} & 2B-1^{CO2MP}
Wet CO_2 product*	[kg/s]	49.0	9.0	6.2	57.9	55.2	64.2
Product CO_2 concentration*	[wt-%]	99.72	99.73	99.73	99.72	99.72	99.72
Stripper diameter	[m]	7.6	3.3	2.9	7.3	8.5	9.2
Estimated height of the column	[m]	30	25	20	35	35	40
Steam demand	[MWth]	156.4	27.7	19.0	176.9	173.8	205.1
Specific steam demand	[MJ/kg CO_2]	3.2	3.1	3.1	3.1	3.2	3.2
Steam pressure	[bar]	2.0	2.0	2.0	2.0	2.0	2.0
Reboiler temperature	[°C]	120	120	120	120	120	120
Reboiler pressure	[bar]	1.8	1.8	1.8	1.8	1.8	1.8

* CO_2 after the condenser (going to the CO_2 compressor) and ** including water wash section

3.2.4 Amine reclaimer (Unit 10400)

The amine reclaimer unit plays an important part in reducing foaming, corrosion and fouling of the equipment in the CO_2 capture plant. It also restores amine capture capacity by removing high-boiling and non-volatile components such as heat stable salts, volatile acids and solids.

A typical reclaimer process is a semi-continuous batch distillation process in a heated vessel, usually a kettle type heat exchanger). A side stream of 1 – 5% of the circulating solvent is withdrawn from the bottom of the regenerator and diverted to the reclaimer unit.

The reclaimer is initially filled with caustic soda and then the amine solvent is added until the heating elements are fully immersed. At this point the feed is shut off and the vessel is heated to its operating temperature. Once the solution reaches its boiling point the liquid level in the reclaimer is maintained by incremental addition of fresh MEA solvent. The vapor phase (mainly steam) is returned to the regenerator. Once equilibrium is achieved and if the solution is not contaminated, the boiling point temperature should remain constant. Otherwise, the boiling point temperature should continue to rise allowing the contaminants to concentrate in the residual liquid phase to form the sludge. The reclaiming cycle is over by shutting off the feed once it reaches a temperature of around 140 – 160^{o}C. The remaining bottom thick sludge is discarded by flushing with water.

Soda ash or caustic soda (around 0.3 wt-% of the solution) is added during the initial filling of the reclaimer to neutralize any volatile acids or heat stable salts.

In this study, it was assumed that around 5% of the total amine solvent (including both lean and semi-lean amine) is diverted to the reclaimer and that around 1.2 kg MEA/t CO_2 captured is lost. This assumption is made based on the current levels of SO_2 in the flue gas and without the use of NaOH in the DCC (as polishing SO_x removal step).

De-superheated low pressure (LP) steam at 4.2 bar(a) and 140^{o}C is used as heating medium in the amine reclaimer unit. NaOH is used as neutralizing agent. This study assumed that around 0.13 kg NaOH/t CO_2 captured is consumed in the reclaimer [23,24].

Details of the steam demand and NaOH consumption for all the cases are presented in section 4, sheets 2 and 6.

3.3 CO_2 compression and drying unit (Unit 11000)

CO_2 leaving the stripper column is saturated with water. Most of the water is removed in the condenser before the CO_2 is delivered to the compression and drying unit. The CO_2 is compressed to liquid CO_2 at 110 bar(a) (33^{o}C).

The compression train consists of four compression stages equipped with inter-coolers, and a liquid CO_2 pump for the final pressurization. The key parameters used in the modelling of the CO_2 compression and dehydration are presented in Table 7. The block flow diagram and the overall mass balance around the CO_2 compression unit are presented in section 4, sheets 3 to 5.

In between compression stages (i.e. stages 1 to 3), the water is removed from the bulk gas in the knock-out drums. After stage 3, the CO_2 product is fed into a molecular sieve where the gas is finally dried to below 10 ppmv. The regeneration of the molecular sieve is done by recirculating a portion of the dried CO_2. The recycled CO_2 is heated by an electric heater to 230°C. Table 8 presents the specification of the product CO_2 after drying.

Table 7: Key parameters of the CO_2 compression and drying (Unit 11000)

Parameter		Value
Compressor stage 1	[bar]	4
Compressor stage 2	[bar]	14
Compressor stage 3	[bar]	35
Compressor stage 4	[bar]	75
Liquid CO_2 pump	[bar]	110
Molecular sieve regeneration flow	[%]	12.5
Compressor isentropic efficiency	[%]	72

Table 8: Product CO_2 specification

Parameter		2A-1 & 2B-1^{CO2MP}	2A-2 & 2B-2	2A-3 & 2B-3	2A-4 & 2B-4^{CO2MP}	2A-5 & 2B-5^{CO2MP}	2A-6^{MP} & 2B-1^{CO2MP}
CO_2	[vol-%]	99.99	99.98	99.98	99.97	99.97	99.97
Temperature	[°C]	33	33	33	33	33	33
Pressure	[bar]	110	110	110	110	110	110
H_2O	[ppm$_V$]	8.75	9.46	8.68	9.99	9.09	9.02

In this study, the type of drivers to be used for the CO_2 compressor has been selected based on the availability of surplus steam and electricity on site. Electric motor driven compressors are used in all cases except for cases 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP} and 2B-6^{CO2MP} (base case 1B, integrated pulp and board mill). In these cases, a back pressure steam turbine is used instead of the electric motor. This is described in more detail in section 5.2.

3.4 Utilities

3.4.1 Steam

The steam required by the CO_2 capture plant and the CO_2 compression and drying unit consists of:

- MP steam (13.0 bar(a) at 200°C)

  MP steam is used by the back pressure steam turbine driving the CO_2 compressor for cases 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP} and 2B-6^{CO2MP}. MP steam is supplied from the steam turbine island and from an auxiliary boiler (see sections 5.2 and 5.3).

- LP steam (4.2 bar(a) at 154°C)

  LP steam is used by the amine reclaimer (Unit 10400).

- ULP steam (2.0 bar(a) at 120°C)

  ULP steam is used by the reboiler in the CO_2 stripper (Unit 10320). ULP steam is obtained by de-superheating LP or MP steam. In cases where there is a deficit in steam production from the pulp mill an auxiliary boiler provides the additional MP steam required (described in sections 5.2 and 5.3).

The steam demand of the CO_2 capture plant and the CO_2 compression and drying unit is summarized in section 4, sheet 6. The steam supplied by the steam turbine island and the auxiliary boiler are summarized in section 4, sheet 7.

3.4.2 Electricity

Both reference mills evaluated in this study (Base Case 1A and Base Case 1B) produce surplus electricity that is exported to the grid. When retrofitting the reference cases with CO_2 capture, the mills have sufficient electricity to be able to cover the additional demand by the CO_2 capture and compression plant in most of the cases evaluated.

The electricity demand for the CO_2 capture and compression is summarized in section 4, sheets 8. The electricity supplied by the steam turbine island is summarized in section 4, sheet 9.

3.4.3 Process water and boiler feed water

Demineralized process water is used by the CO_2 capture plant in the following processes:

- Make up water for the water wash column of the absorber
- Make up water for the amine solvent
- Wash water for the reclaimer unit

Water utilization has been minimized by recycling and re-use as much as possible within the integrated plant.

Additional boiler feed water will be needed for Cases 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP} and 2B-6^{CO2MP} where an auxiliary boiler is required to provide the additional steam required by the CO_2 capture plant. The additional process water and boiler feed water required by the mill with CCS is summarized in section 4, sheet 10.

3.4.4 Cooling water

The additional cooling water required by the CO_2 capture and compression plant was mainly serviced by adding a new circuit of once through seawater cooling. The use of seawater cooling versus cooling tower system is dependent on site specific conditions. Regulations could limit the withdrawal and/or return of the cooling water from/into the receiving body of water (i.e. sea or river). In these cases, a cooling tower system or air cooling systems could be used. In this study, there is no limitation assumed in the volume of seawater that could be withdrawn, but the maximum temperature difference between extracted and returned cooling water was limited to 10°C. This study assumed a typical average temperature of the seawater (in the coastal region of Finland) of 10^{o}C. As a result, the maximum discharge temperature of the cooling water back to the sea was limited to 20^{o}C.

Integrating the cooling water system of the CO_2 capture and compression unit to the hot and warm water system (HWWS) of the pulp mill is also possible. Also this solution is a very site specific condition. Additionally, if the pulp mill also provides district heating (typical for Nordic pulp mills), waste heat from the CO_2 capture plant or CO_2 compression could also be recovered. This study has not evaluated these options.

The additional cooling water required by the mill with integrated CCS is summarized in section 4, sheet 11.

3.4.5 Wastewater

Wastewater from the CO_2 capture plant originates from the direct contact cooler (DCC) and from the CO_2 compression and drying unit.

Wastewater from the capture facility contains soluble acids and part of the particulate matters (dust) generated during the combustion processes. This study has not evaluated the quality of wastewater from the capture plant. A typical pulp mill handles large volumes of wastewater and it is expected that the wastewater from the CO_2 capture facility could also be handled in the existing wastewater treatment plant of the reference mills.

The amount of additional wastewater to be treated depends on the size of the capture plant. For cases where capture of CO_2 from the recovery boiler is included, the additional amount of wastewater generated is significant, and an expansion of the existing wastewater treatment facility must be expected.

The additional wastewater to be treated by the mill with CCS is summarized in section 4, sheet 12.

3.4.6 Solid waste

MEA sludge produced by the amine reclaimer is the main solid waste derived from the CO_2 capture plant. This is typically handled by an external company specializing in hazardous waste for safe disposal.

In cases where an auxiliary boiler is installed, additional bottom and fly ash must be expected.

Section 4, sheet 13 presents the amount of additional waste to be handle by the mill when CCS is retrofitted.

4. Summary of results – CO_2 capture and compression plant

This section summarizes the key information and results relevant to the retrofit of CO_2 capture plant (Unit 10000) and the CO_2 compression and drying unit (Unit 11000) to the reference mills.

The information presented in this section includes:

- Sheet 1: Schematic block flow diagram of the CO_2 capture plant
- Sheet 2: Overall mass balance of the CO_2 capture plant
- Sheet 3: Schematic block flow diagram of the CO_2 compression and drying unit (with electric motor drive)
- Sheet 4: Schematic block flow diagram of the CO_2 compression and drying unit (with back pressure steam turbine drive)
- Sheet 5: Overall mass balance of the CO_2 compression and drying unit
- Sheet 6: Steam demand of the reference mill without and with CCS
- Sheet 7: Steam supply of the reference mill without and with CCS
- Sheet 8: Electricity demand of the reference mill without and with CCS
- Sheet 9: Electricity demand of the reference mill without and with CCS
- Sheet 10: Utilities – process water and boiler feed water
- Sheet 11: Utilities – once through seawater cooling
- Sheet 12: Utilities – wastewater
- Sheet 13: Solid waste
- Sheet 14: CO_2 balance
- Sheet 15: Overall CO_2 capture rate and % CO_2 avoided

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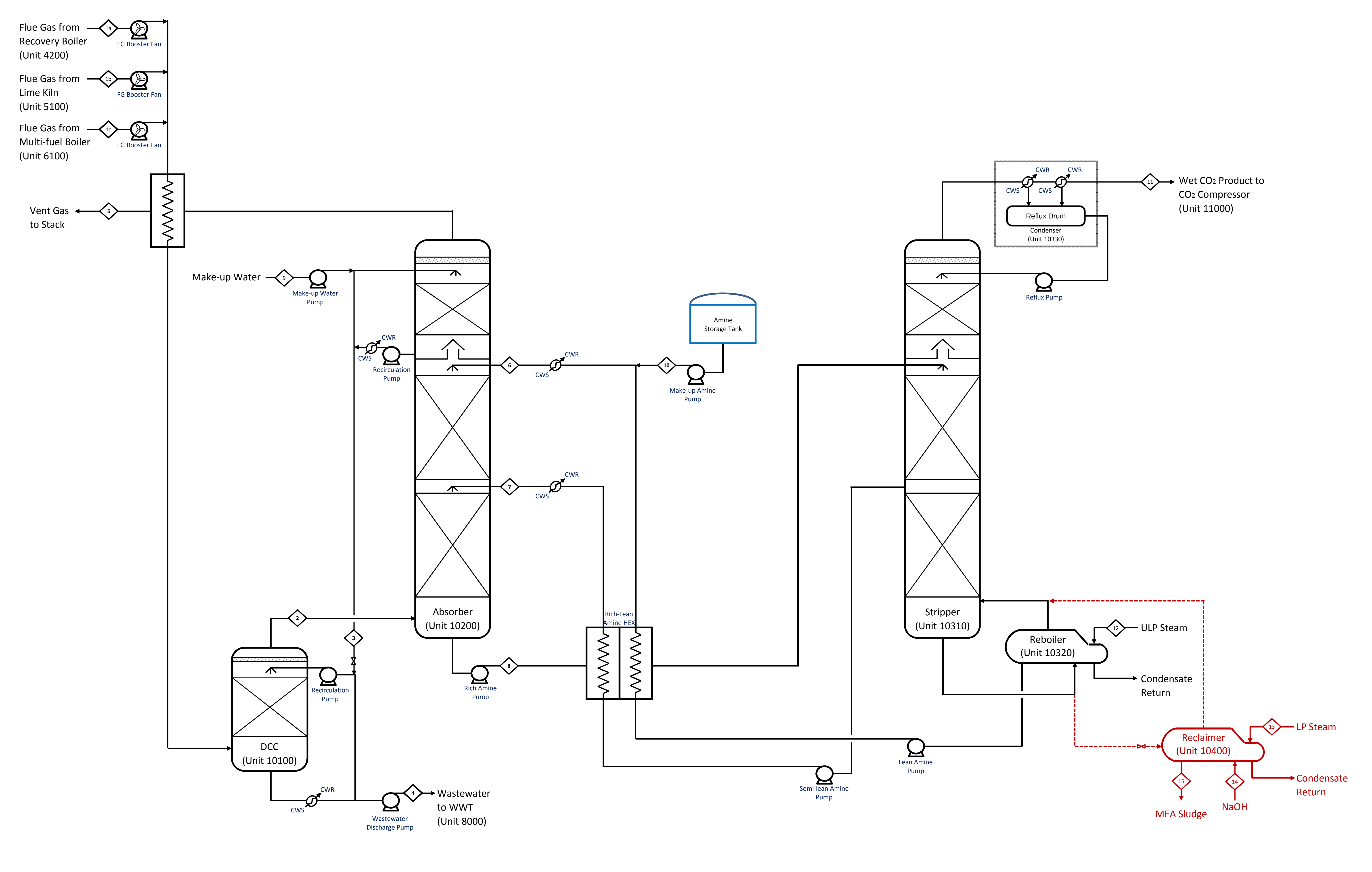
	Schematic Block Flow Diagram	REVISION	DATE	BY	CHKD	APP.	SHEET
VTT	**Unit 10000: CO_2 Capture Plant**	3.0	Dec-16	SS	KO	KO	1 of 15
CUSTOMER REPORT: VTT-CR-01312-15							



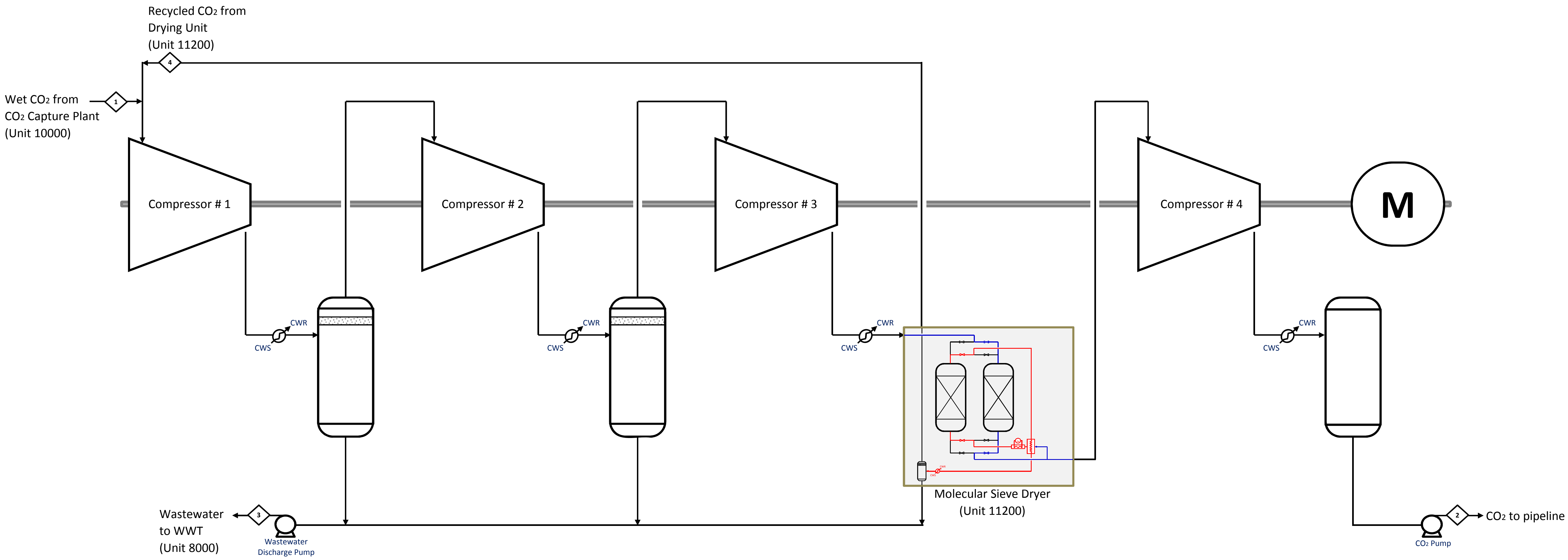
	Stream Description	Case No.					
		2A-1 & 2B-1^{CO2MP}	2A-2 & 2B-2	2A-3 & 2B-3	2A-4 & 2B-4^{CO2MP}	2A-5 & 2B-5^{CO2MP}	2A-6^{MP} & 2B-6^{CO2MP}
		[kg/s]					
1a	Flue gas from recovery boiler (Unit 4200)	269.6	-	-	269.6	268.6	268.6
1b	Flue gas from lime kiln (Unit 5100)	-	-	22.6	-	22.6	22.6
1c	Flue gas from multi-fuel boiler (Unit 6100)	-	49.8	-	49.8	-	49.8
2	Cooled flue gas from DCC (Unit 10100)	250.8	40.20	18.10	291.3	268.9	309.4
3	Water bleed from water wash column	24.0	3.0	1.0	26.0	25.0	28.0
4	Wastewater to WWT (Unit 8000)	42.9	12.6	4.6	54.3	47.5	59.9
5	Vent gas from absorber (Unit 10200) to stack	200.7	31.9	12.1	233.6	213.0	243.0
6	Lean amine	746.6	136.7	87.4	869.9	840.8	984.9
7	Semi-lean amine	550.0	60.0	65.0	640.0	600.0	750.0
8	Rich amine	1345.5	205.0	158.4	1567.6	1496.0	1801.3
9	Make-up water to water wash column	24.0	3.0	1.0	26.0	25.0	28.0
10	Make-up amine	0.059	0.011	0.007	0.069	0.066	0.077
11	Wet CO2 product to CO2 compressor (Unit 10500)	49.0	9.0	6.2	58.0	55.2	64.2
12	ULP steam to reboiler (Unit 10320)	71.1	12.6	8.6	80.4	78.9	93.1
13	LP steam to reclaimer (Unit 10400)**	0.262	0.044	0.032	0.307	0.292	0.349
14	NaOH to reclaimer (Unit 10400)**	0.006	0.001	0.001	0.008	0.007	0.008
15	MEA sludge to disposal*	0.059	0.011	0.007	0.069	0.066	0.077

Note:

* The CO2 capture plant for both reference mills is identical - as this involves the same size recovery boiler, multi-fuel boiler and lime kiln of the mill producing pulp at a nominal capacity of 800,000 adt/y

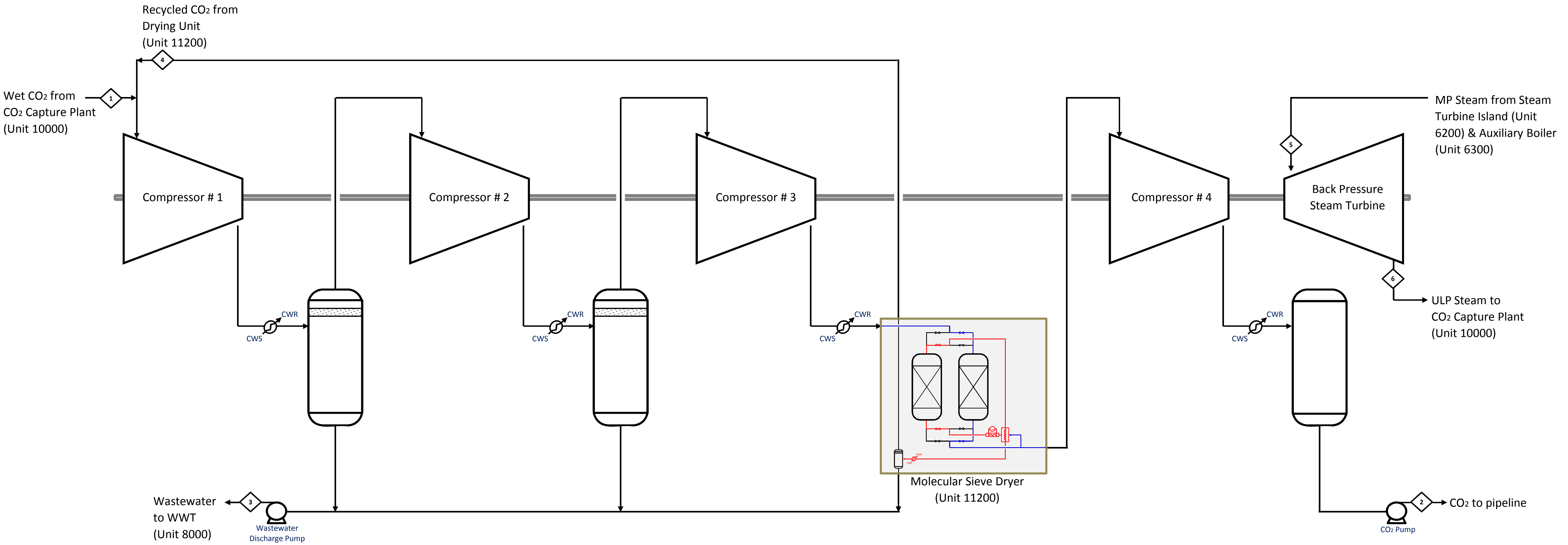
** The reclaimer unit is a batch process. Information reported in this table for this process is the average value over the annual operating hours (8400 hours)

	Schematic Block Flow Diagram	REVISION	DATE	BY	CHKD	APP.	SHEET
CUSTOMER REPORT: VTT-CR-01312-15	**Unit 11000A: CO_2 Compression and Drying Unit**	1.0	Dec-16	SS	KO	KO	3 of 15



VTT	Schematic Block Flow Diagram	REVISION	DATE	BY	CHKD	APP.	SHEET
CUSTOMER REPORT: VTT-CR-01312-15	**Unit 11000B: CO_2 Compression and Drying Unit**	1.0	Dec-16	SS	KO	KO	4 of 15

For Cases $2B\text{-}1^{CO2MP}$, $2B\text{-}4^{CO2MP}$, $2B\text{-}5^{CO2MP}$ and $2B\text{-}6^{CO2MP}$



Unit 11000: CO_2 Compression and Drying Unit

Stream Description		Case No.					
		2A-1	2A-2	2A-3	2A-4	2A-5	2A-6[MP]
		[kg/s]					
1	Wet CO_2 product from CO_2 capture plant (Unit 11000)	49.00	8.98	6.23	57.96	55.20	64.20
2	CO_2 to pipeline	48.90	8.95	6.51	57.86	55.42	64.37
3	Wastewater to WWT (Unit 8000)	0.14	0.02	0.02	0.15	0.14	0.17
4	Recycled CO_2 from Dryer (Unit 11200)	7.0	1.3	0.9	8.3	7.9	9.2

* This table should be referred to Sheet 3 - CO2 Compression for Cases using electric motor as compressor drive

Stream Description		Case No.					
		2B-1[CO2MP]	2B-2	2B-3	2B-4[CO2MP]	2B-5[CO2MP]	2B-6[CO2MP]
		[kg/s]					
1	Wet CO_2 product from CO_2 capture plant (Unit 11000)	49.00	8.98	6.23	57.96	55.20	64.20
2	CO_2 to pipeline	48.90	8.95	6.51	57.86	55.42	64.37
3	Wastewater to WWT (Unit 8000)	0.14	0.02	0.02	0.15	0.14	0.17
4	Recycled CO_2 from Dryer (Unit 11200)	7.0	1.3	0.9	8.3	7.9	9.2
5	MP steam from ST (Unit 6200) & auxiliary boiler(Unit 6300)	52.6	NA	NA	62.2	59.2	68.8
6	ULP steam to CO_2 capture plant (Unit 10000)	52.6	NA	NA	62.2	59.2	68.8

*For Cases 2B-2 and 2B-3 - should be referred to Sheet 3 - CO2 Compression using electric motor as compressor driver; & for all other cases should be referred to Sheet 4 - CO2 Compression for Cases using steam turbine as compressor driver

Steam Demand	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6^{MP}
	[t/h]						
Pulp Mill							
IP Steam (30 Bar/352°C)	20.4	20.4	20.4	20.4	20.4	20.4	20.4
MP Steam (13 Bar/200°C)	171.0	171.0	171.0	171.0	171.0	171.0	171.0
LP Steam (4.2 Bar/154°C)	255.2	255.2	255.2	255.2	255.2	255.2	255.2
CO2 Capture and Compression Plant							
LP Steam (4.2 Bar/154°C)	-	0.9	0.2	0.1	1.1	1.1	1.3
ULP Steam (2 Bar / 120°C)	-	255.8	45.2	31.0	289.3	284.2	335.3
Total - Steam Demand [t/h]	446.7	703.4	492.0	477.8	737.1	731.9	783.2

Steam Demand	Case No.						
	Base Case 1B	2B-1^{CO2MP}	2B-2	2B-3	2B-4^{CO2MP}	2B-5^{CO2MP}	2B-6^{CO2MP}
	[t/h]						
Pulp and Board Mill							
IP Steam (30 Bar/352°C)	20.4	20.4	20.4	20.4	20.4	20.4	20.4
MP Steam (13 Bar/200°C)	167.4	167.4	167.4	167.4	167.4	167.4	167.4
LP Steam (4.2 Bar/154°C)	351.8	351.8	237.1	308.4	351.8	351.8	351.8
Auxiliary Boiler							
IP Steam (30 Bar/352oC)	-	1.5	-	-	2.3	2.2	3.4
LP Steam (4.2 Bar/154°C)	-	2.8	-	-	4.3	4.1	6.5
CO2 Capture and Compression Plant							
MP Steam (13 Bar/200°C)	-	189.5	-	-	223.9	213.2	247.6
LP Steam (4.2 Bar/154°C)	-	0.9	0.2	0.1	1.1	1.1	1.3
ULP Steam (2 Bar / 120°C)	-	255.8	45.2	31.0	289.3	284.2	335.3
Total - Steam Demand [t/h]	539.6	990.1	470.3	527.4	1,060.6	1,044.3	1,133.7

Steam Supply	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6[MP]
	[t/h]						
Ex: Steam Turbine Island (Unit 6200)							
IP Steam (30 Bar/352°C)	20.4	20.4	20.4	20.4	20.4	20.4	20.4
MP Steam (13 Bar/200°C)	171.0	171.0	171.0	171.0	171.0	171.0	171.0
LP Steam (4.2 Bar/154°C)	255.2	256.2	255.4	255.3	256.3	256.3	256.5
ULP Steam (2 Bar / 120°C)	-	255.8	45.2	31.0	289.3	284.2	335.3
Total - Steam Supply [t/h]	446.7	703.4	492.0	477.8	737.1	731.9	783.2
LP Steam (4.2 Bara) to Condensing Steam Turbine (LP Section)	281.90	37.16	238.73	253.35	-	9.10	-

Steam Supply	Case No.						
	Base Case 1B	2B-1[CO2MP]	2B-2	2B-3	2B-4[CO2MP]	2B-5[CO2MP]	2B-6[CO2MP]
	[MWth]						
Ex: Steam Turbine Island (Unit 6200)							
IP Steam (30 Bar/352°C)	20.4	21.8	20.4	20.4	22.7	22.5	23.8
MP Steam (13 Bar/200°C)	167.4	292.0	167.4	167.4	290.4	285.2	263.2
LP Steam (4.2 Bar/154°C)	351.8	355.5	351.9	351.9	357.2	356.9	359.6
ULP Steam (2 Bar / 120°C)	-	66.3	45.2	31.0	65.3	71.0	87.8
Ex: Auxiliary Boiler (Unit 6300)							
MP Steam (13 Bar/200°C)	-	64.9	-	-	100.9	95.4	151.9
CO2 Compression and Drying Unit							
ULP Steam (2 Bar / 120oC) - Ex: Back Pressure ST Driver	-	189.5	-	-	224.0	213.2	247.6
Total - Steam Supply [t/h]	539.6	990.1	585.0	570.7	1,060.6	1,044.3	1,133.7
LP Steam (4.2 Bara) to Condensing Steam Turbine (LP Section)	192.21	-	149.22	162.69	-	-	-

Electricity Demand	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6^{MP}
	[MWe]						
Pulp Mill	61.0	61.0	61.0	61.0	61.0	61.0	61.0
CO2 Capture and Compression Plant							
DCC (including the flue gas booster fan)	-	4.86	1.05	0.50	6.66	6.05	7.19
CO_2 Capture Plant	-	1.02	0.14	0.11	1.02	1.02	1.26
CO_2 Compression and Drying Unit	-	17.57	3.24	2.23	20.77	19.79	22.99
Total - Electricity Demand [MWe]	61.0	84.4	65.4	63.8	89.4	87.8	92.4

Electricity Demand	Case No.						
	Base Case 1B	2B-1^{CO2MP}	2B-2	2B-3	2B-4^{CO2MP}	2B-5^{CO2MP}	2B-6^{CO2MP}
	[MWe]						
Pulp Mill	61.0	61.0	61.0	61.0	61.0	61.0	61.0
Board Mill	33.3	33.3	33.3	33.3	33.3	33.3	33.3
Auxiliary Boiler	-	1.6	-	-	2.4	2.3	3.7
CO2 Capture and Compression Plant							
DCC (including the flue gas booster fan)	-	4.86	1.05	0.50	6.66	6.05	7.19
CO_2 Capture Plant	-	1.02	0.14	0.11	1.02	1.02	1.26
CO_2 Compression and Drying Unit	-	1.88	3.24	2.23	2.22	2.12	2.46
Total - Electricity Demand [MWe]	94.3	103.6	98.7	97.1	106.6	105.8	108.9

Electricity Supply	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6[MP]
	[MWe]						
Ex: Steam Turbine Island (Unit 6200)							
HP Turbine Section (Back Pressure Steam Turbine)	130.4	130.4	130.4	130.4	130.4	130.4	113.7
LP Turbine Section (Condensing Steam Turbine)	37.9	7.7	33.0	34.7	-	4.3	-
Gross Electricity Production [MWe]	168.3	138.1	163.4	165.1	130.4	134.7	113.7
Net Electricity Exported to the Grid [MWe]	107.3	53.7	98.0	101.3	41.0	46.9	21.3

Electricity Supply	Case No.						
	Base Case 1B	2B-1[CO2MP]	2B-2	2B-3	2B-4[CO2MP]	2B-5[CO2MP]	2B-6[CO2MP]
	[MWe]						
Ex: Steam Turbine Island (Unit 6200)							
HP Turbine Section (Back Pressure Steam Turbine)	130.6	124.2	130.6	130.6	124.5	124.5	127.3
LP Turbine Section (Condensing Steam Turbine)	27.1	-	21.8	23.5	-	-	-
Gross Electricity Production [MWe]	157.7	124.2	152.4	154.1	124.5	124.5	127.3
Net Electricity Exported to the Grid [MWe]	63.4	20.6	53.7	57.0	17.9	18.7	18.4

Process Water	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6^{MP}
	[m^3/h]						
Pulp Mill	1558	1558	1558	1558	1558	1558	1558
CO2 Capture Plant & Compression Plant	-	86	13	4	94	90	101
Total - Process Water [m^3/h]	1558	1644	1571	1562	1652	1648	1659

Process Water	Case No.						
	Base Case 1B	2B-1^{CO2MP}	2B-2	2B-3	2B-4^{CO2MP}	2B-5^{CO2MP}	2B-6^{CO2MP}
	[m^3/h]						
Pulp Mill	1524	1524	1524	1524	1524	1524	1524
Board Mill	434	434	434	434	434	434	434
CO_2 Capture Plant & Compression Plant	-	86	13	4	94	90	101
Total - Process Water [m^3/h]	1958	2044	1971	1962	2052	2048	2058

Boiler Feed Water (Make-Up)	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6^{MP}
	[m^3/h]						
Pulp Mill (Recovery Boiler & Multi-fuel Boiler)	95	95	95	95	95	95	95
CO2 Capture Plant (Reboiler & Reclaimer)	-	13	2	2	15	14	17
Total - Boiler Feed Water - Make Up [m^3/h]	95	108	98	97	110	110	112

Boiler Feed Water (Make-Up)	Case No.						
	Base Case 1B	2B-1^{CO2MP}	2B-2	2B-3	2B-4^{CO2MP}	2B-5^{CO2MP}	2B-6^{CO2MP}
	[m^3/h]						
Pulp Mill (Recovery Boiler & Multi-fuel Boiler)	95	95	95	95	95	95	95
Auxiliary Boiler	-	7	-	-	11	10	16
CO2 Capture Plant (Reboiler & Reclaimer)	-	13	2	2	15	14	17
Total - Boiler Feed Water - Make Up [m^3/h]	95	115	98	97	121	120	128

Utilities - Once Through Seawater Cooling

Seawater Cooling	Case No.						
	Base Case 1A	**2A-1**	**2A-2**	**2A-3**	**2A-4**	**2A-5**	**$2A-6^{MP}$**
	[m^3/h]						
Steam Turbine Island (Unit 6200)	11,903	3,064	10,327	10,818	-	2,090	-
Bleach Chemicals Preparation Plant (Unit 7100)	424	424	424	424	424	424	424
CO2 Capture Plant (Unit 10000) & Compression Plant (Unit 11000)	-	21,497	4,430	2,692	23,372	22,134	27,665
Total - Cooling Water [m^3/h]	12,327	24,985	15,181	13,933	23,796	24,648	28,089

Seawater Cooling	Case No.						
	Base Case 1B	**$2B-1^{CO2MP}$**	**2B-2**	**2B-3**	**$2B-4^{CO2MP}$**	**$2B-5^{CO2MP}$**	**$2B-6^{CO2MP}$**
	[m^3/h]						
Steam Turbine Island (Unit 6200)	8,596	-	7,082	7,569	-	-	-
Bleach Chemicals Preparation Plant (Unit 7100)	403	403	403	403	403	403	403
CO2 Capture Plant (Unit 10000) & Compression Plant (Unit 11000)	-	21,497	4,430	2,692	23,372	22,134	27,665
Total - Cooling Water [m^3/h]	8,999	21,900	11,915	10,663	23,775	22,537	28,068

Utilities - Waste Water

Waste Water Effluent	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6^MP
	[m³/h]						
Acidic Filtrate	856.0	856.0	856.0	856.0	856.0	856.0	856.0
Alkaline Filtrate	619.5	619.5	619.5	619.5	619.5	619.5	619.5
Effluent from De-barking	98.8	98.8	98.8	98.8	98.8	98.8	98.8
Brine and Salt Cake	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Other Effluent from Pulp Mill	114.4	114.4	114.4	114.4	114.4	114.4	114.4
Effluent from Board Mill	-	-	-	-	-	-	-
Effluent from CO2 Capture and Compression Plant	-	155.2	45.6	16.7	196.3	171.7	216.5
Total - Waste Water Discharge [m³/h]	1,693.2	1,848.4	1,738.9	1,709.9	1,889.5	1,864.9	1,909.8

Waste Water Effluent	Case No.						
	Base Case 1B	2B-1^CO2MP	2B-2	2B-3	2B-4^CO2MP	2B-5^CO2MP	2B-6^CO2MP
	[m³/h]						
Acidic Filtrate	812.3	812.3	812.3	812.3	812.3	812.3	812.3
Alkaline Filtrate	587.9	587.9	587.9	587.9	587.9	587.9	587.9
Effluent from De-barking	98.8	98.8	98.8	98.8	98.8	98.8	98.8
Brine and Salt Cake	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Other Effluent from Pulp Mill	114.4	114.4	114.4	114.4	114.4	114.4	114.4
Effluent from Board Mill	390.8	390.8	390.8	390.8	390.8	390.8	390.8
Effluent from CO2 Capture and Compression Plant	-	155.2	45.6	16.7	196.3	171.7	216.5
Total - Waste Water Discharge [m³/h]	2,008.7	2,163.9	2,054.3	2,025.3	2,204.9	2,180.3	2,225.2

Solid Waste for Disposal

Solid Waste	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6[MP]
	[t/h]						
Rejects from Brown Stock Handling	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Residues from CTO Production	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Bottom & Fly Ash	0.48	0.48	0.48	0.48	0.48	0.48	0.48
Dregs	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Slaker Grit	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Rejects from Pulp Dryer	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Rejects from Board Mill	-	-	-	-	-	-	-
MEA Sludge	-	0.21	0.04	0.03	0.25	0.24	0.28
Total - Solid Waste [t/h]	2.88	3.09	2.92	2.91	3.13	3.12	3.16

Solid Waste	Case No.						
	Base Case 1B	2B-1[CO2MP]	2B-2	2B-3	2B-4[CO2MP]	2B-5[CO2MP]	2B-6[CO2MP]
	[t/h]						
Rejects from Brown Stock Handling	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Residues from CTO Production	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Bottom & Fly Ash	0.48	0.75	0.48	0.48	0.89	0.87	1.11
Dregs	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Slaker Grit	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Rejects from Pulp Dryer	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Rejects from Board Mill	0.48	0.48	0.48	0.48	0.48	0.48	0.48
MEA Sludge	-	0.21	0.04	0.03	0.25	0.24	0.28
Total - Solid Waste [t/h]	3.30	3.78	3.34	3.33	3.97	3.94	4.21

CO_2 Balance

CO2 Balance	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6^MP
	[MTPY]						
Recovery Boiler	1,642,400	163,700	1,642,400	1,642,400	163,700	163,700	163,700
Multi-fuel Boiler	300,800	300,800	30,142	300,800	29,900	300,800	29,900
Lime Kiln	219,136	219,136	219,136	22,128	219,136	21,914	22,161
Total - CO2 Emissions	2,162,336	683,636	1,891,678	1,965,328	412,736	486,414	215,761

Fossil CO2 Emissions	86,582	86,582	86,582	-	86,582	-	-
Biogenic CO2 Emissions	2,075,754	597,054	1,805,097	1,965,328	326,155	486,414	215,761
Fossil CO2 to Pipeline	-	-	-	86,582	-	86,582	86,582
Biogenic CO2 to Pipeline	-	1,478,700	270,658	110,427	1,749,600	1,589,341	1,859,993
Total - CO2 Balance	2,162,336	2,162,336	2,162,336	2,162,336	2,162,336	2,162,336	2,162,336

CO2 Balance	Case No.						
	Base Case 1B	2B-1^CO2MP	2B-2	2B-3	2B-4^CO2MP	2B-5^CO2MP	2B-6^CO2MP
	[MTPY]						
Recovery Boiler	1,642,400	163,700	1,642,400	1,642,400	163,700	163,700	163,700
Multi-fuel Boiler	300,800	300,800	30,142	300,800	29,900	300,800	29,900
Lime Kiln	219,136	219,136	219,136	22,128	219,136	21,914	21,914
Auxiliary Boiler	-	149,369	-	-	232,096	219,457	349,293
Total - CO2 Emissions	2,162,336	833,005	1,891,678	1,965,328	644,832	705,871	564,807

Fossil CO2 Emissions	86,582	86,582	86,582	-	86,582	-	-
Biogenic CO2 Emissions	2,075,754	746,423	1,805,097	1,965,328	558,251	705,871	564,807
Fossil CO2 to Pipeline	-	-	-	86,582	-	86,582	86,582
Biogenic CO2 to Pipeline	-	1,478,700	270,658	110,427	1,749,600	1,589,341	1,859,993
Total - CO2 Balance	2,162,336	2,311,705	2,162,336	2,162,336	2,394,432	2,381,793	2,511,382

Overall CO_2 Capture Rate (Whole Site) & %CO_2 Avoided

CO2 Balance	Case No.						
	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6[MP]
	MTPY						
Fossil CO2 Emissions	86,582	86,582	86,582	-	86,582	-	-
Biogenic CO2 Emissions	2,075,754	597,054	1,805,097	1,965,328	326,155	486,414	215,761
Captured Fossil CO2	-	-	-	86,582	-	86,582	86,582
Captured Biogenic CO2	-	1,478,700	270,658	110,427	1,749,600	1,589,341	1,859,993
Overall CO2 Capture Rate (Whole Site)*	-	68.4%	12.5%	9.1%	80.9%	77.5%	90.0%
% CO2 Avoided (without recognition of biogenic CO2 as neutral)**	-	68.4%	12.5%	9.1%	80.9%	77.5%	90.0%
% CO2 Avoided (with recognition of biogenic CO2 as neutral)***	-	1708%	313%	228%	2021%	1936%	2248%

CO2 Balance	Case No.						
	Base Case 1B	2B-1[CO2MP]	2B-2	2B-3	2B-4[CO2MP]	2B-5[CO2MP]	2B-6[CO2MP]
	MTPY						
Fossil CO2 Emissions	86,582	86,582	86,582	-	86,582	-	-
Biogenic CO2 Emissions	2,075,754	746,423	1,805,097	1,965,328	558,251	705,871	564,807
Captured Fossil CO2	-	-	-	86,582	-	86,582	86,582
Captured Biogenic CO2	-	1,478,700	270,658	110,427	1,749,600	1,589,341	1,859,993
Overall CO2 Capture Rate (Whole Site)*	-	64.0%	12.5%	9.1%	73.1%	70.4%	77.5%
% CO2 Avoided (without recognition of biogenic CO2 as neutral)**	-	61.5%	12.5%	9.1%	70.2%	67.4%	73.9%
% CO2 Avoided (with recognition of biogenic CO2 as neutral)***	-	1708%	313%	228%	2021%	1936%	2248%

Note:

*Overall CO2 Capture Rate = total captured CO2 / total CO2 emission - whole site x 100%

** % CO2 Avoided (without recognition of biogenic CO2 emissions) = [Total CO2 emissions (base case) - Total CO2 emissions (capture case)] / Total CO2 emissions (base case) x 100%

*** % CO2 Avoided (with recognition of biogenic CO2 emissions) = [Fossil CO2 emissions (base case) - Fossil CO2 emissions (capture case) + Captured biogenic CO2 (capture case)] / Fossil CO2 emissions (base case) x 100%

5. Integration of CCS to the pulp mill

Retrofitting a CO_2 capture plant to an existing pulp mill or pulp and board mill would require several modifications to the existing infrastructure.

Areas where considerations need to be made in analyzing the possible impact when retrofitting CCS include, but are not limited to:

- Site considerations
- Changes to the steam and electricity supply network
- Addition of auxiliary boiler
- Changes to the process water, boiler feed water and cooling water supply network
- Changes to the wastewater treatment plant

5.1 Site considerations

The site considerations for retrofitting the CO_2 capture plant made in this study has benefitted from insights gained during a visit to the Metsä Fibre's Äänekoski Mill in Finland. In the Äänekoski mill, a slip stream with 10% of the total CO_2 is captured from the lime kiln and/or from the recovery boiler. The flue gas is delivered to a neighboring facility producing chemicals (mainly carbonates and bi-carbonates).

The proximity of the different sources of flue gases (i.e. from recovery boiler, multi-fuel boiler and lime kiln) to the CO_2 capture plant and to each other is another consideration. In this study it is assumed that all the flue gas sources could be treated as one combined stream in one common absorber in cases where multiple flue gas sources are to be treated simultaneously.

Site considerations are important in any assessment of retrofitting CCS to a pulp mill. The layout of the plant could be dependent on factors such as level of integration between pulp mill and users of the pulp (such as board, paper or tissue mills). In some cases, a fully integrated pulp and paper mill could also include mechanical pulping and recycling of papers and boards. Therefore, the assumptions to be used in any techno-economic evaluation could be very site specific.

An example of a typical layout of a standalone market pulp mill is illustrated in Figure 1 below.

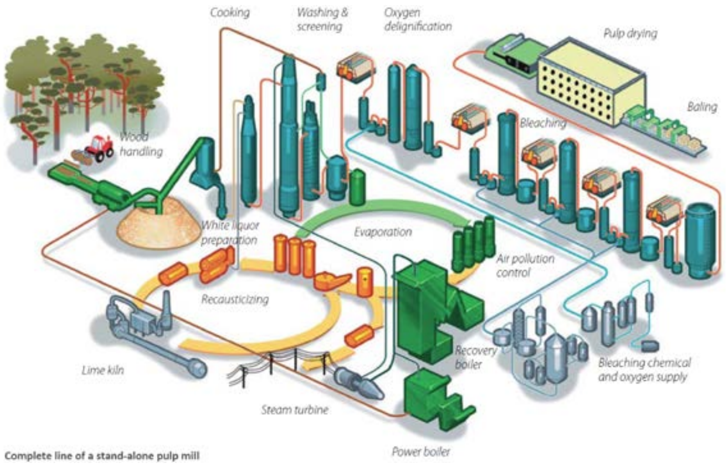


Figure 1: Typical layout of a standalone pulp mill. (Courtesy of Valmet) [25].

5.2 Modifications to the steam and electricity supply network

The CO_2 capture and compression plant would require heat and electricity. Steam is mainly used as heat supply for the reboiler and in the amine reclaimer. Electricity is mainly used by the different blowers, pumps and compressors of the CO_2 capture plant. For most of the cases evaluated, these energy demands could be covered by the excess steam and electricity produced by the reference mill (especially for all the CCS cases involving Base Case 1A, a standalone Kraft pulp mill). In other cases, where steam supply becomes a deficit, an auxiliary boiler could be added. In some cases where electricity supply becomes a deficit, this could be imported from the grid. Information about steam and electricity supply is summarized in section 4, sheets 6 to 9, and in Annex III.

When retrofitting CO_2 capture to the pulp mill, the major modifications concern changes to the existing steam turbine island and associated equipment. These changes should not impact the operation of the mill.

The steam turbine evaluated in this study consists of a back pressure turbine (HP section) and a condensing turbine (LP section) in a single shaft and dual casing arrangement. The LP section of the turbine is typically clutched to allow operational flexibility depending on the steam demand of the mill. For further details on the existing steam turbine, see Annex III of the report presented by Kangas et al. [8].

The following section presents the key points considered during the modification of an existing steam turbine to meet the demand of the CO_2 capture and compression plant. The discussion covers 1) the amount of excess steam and electricity available from the existing steam turbine island, 2) options and different configurations considered for the supply of steam and electricity required by the capture plant, and 3) the various considerations relevant to the modification of the steam turbine island and associated equipment.

5.2.1 Excess steam and electricity from the existing steam turbine

In this study most of the excess steam produced by the pulp mill is available at 4.2 bar(a). LP steam is normally sent to the LP section of the steam turbine to generate additional electricity for grid export.

The amount of excess electricity exported to the grid for Base Case 1A and Base Case 1B is 107.3 MW_e and 63.4 MW_e, respectively. Included in these numbers is the amount of electricity produced from the LP section of the steam turbine which corresponds to 37.9 MW_e and 27.1 MW_e (or 35% and 43% of the total electricity exported to the grid) for Base Case 1A and Base Case 1B, respectively (see section 4, sheet 9).

If CCS is to be retrofitted to the mill, several options could be considered of how the excess steam could be extracted from the existing steam turbine. This is described in Annex III. Typically, if LP steam will be extracted, let down and de-superheated to 2.0 bar(a), the maximum available steam is around 200 t/h for the standalone pulp mill. However, if MP steam will be extracted and de-superheated to 2.0 bar(a), the maximum available steam is around 213 t/h. This means that the LP section of the steam turbine would be halted and only the HP turbine is producing electricity of around 131 MW_e (if LP steam is extracted) and 120 MW_e (if MP steam is extracted).

5.2.2 Alternative configuration for the steam turbine

In this study, to accommodate the additional steam demand from the CO_2 capture plant, three different alternative configurations for the steam turbine were evaluated. Options are given in the assumed order of increasing investment cost. For all the cases where the excess LP steam

(4.2 bar(a)) is not sufficient to cover the additional demand required by the CO_2 capture plant configuration II and III were evaluated. These results are presented in Annex III.

Key features of configuration I:

- Excess steam is extracted from the HP section of the turbine at 4.2 bar(a). No major modifications to the extraction point are expected as most of the steam will only be diverted away from the LP section of the turbine.
- Should the steam flow be reduced to below the minimum value, the LP section of the turbine can be declutched to halt the operation of the LP turbine.
- The pressure of the extracted steam (4.2 bar(a)) is reduced to 2.0 bar(a) and de-superheated.
- The CO_2 compressor used by the capture plant is electrically driven.
- This configuration is applied to all cases except for Cases 2A-6^{MP}, 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP} and 2B-6^{CO2MP}.
- The schematic block flow diagram of the steam turbine island for this configuration is shown in Figure 2.

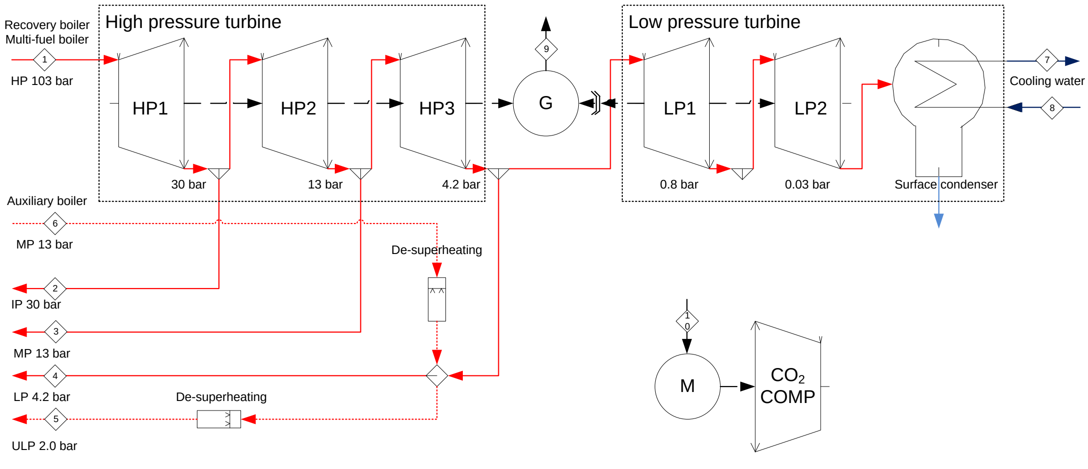


Figure 2: Configuration I – Pulp mill steam turbine.
Ultra-low pressure steam (2.0 bar(a)) to be used in the CO_2 capture plant is extracted from the low pressure (4.2 bar(a)) line. If additional steam is needed, an auxiliary boiler is installed. CO_2 compressor is electrically driven.

Key features of configuration II:

- Excess steam is extracted from the HP section of the turbine at 13.0 bar(a). Modifications to the extraction point is to be expected given that the mass flow of steam extracted from the 13.0 bar(a) line has increased. In an actual steam turbine retrofit case, the volume of the steam that can be extracted should be considered carefully. The priority is to ensure that the supply of the MP (13.0 bar(a) and the LP steam (4.2 bar(a)) needed by the pulp mill will not be affected and at the same time the extraction of the MP steam should not significantly impact the pressure control of the HP section of the steam turbine. In this case, the sizing of the auxiliary boiler should be adjusted based on the capacity of the actual steam turbine.
- The LP section of the turbine will be clutched to halt its operation if the steam flow is below the minimum values required.
- The pressure of the extracted steam (13.0 bar(a)) is reduced to 2.0 bar(a) and de-superheated.

- The CO_2 compressor is electrically driven.
- This configuration is only used in Case 2A-6[MP].
- The schematic block flow diagram of the steam turbine island for this configuration is shown in Figure 3.

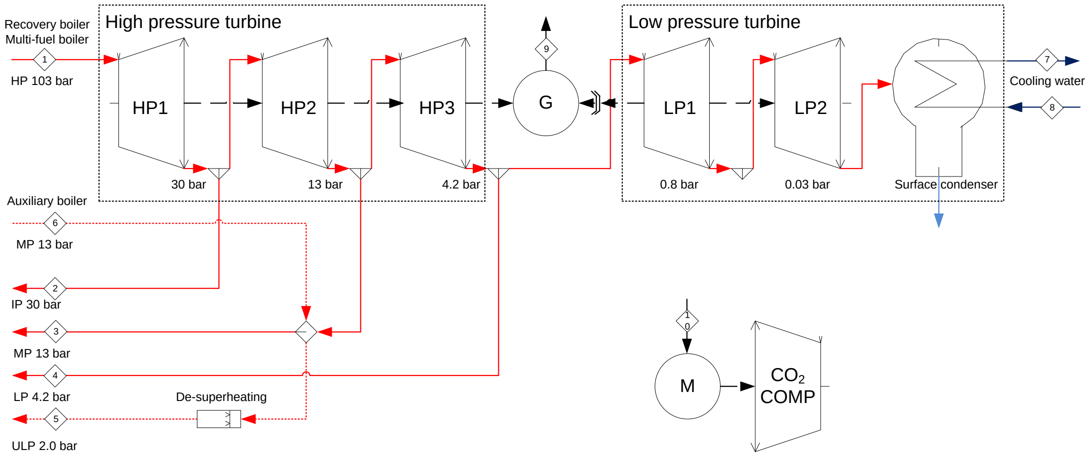


Figure 3: Configuration II – Pulp mill steam turbine.
Ultra-low pressure steam (2.0 bar(a)) to be used in the CO_2 capture plant is extracted from the medium pressure (13.0 bar(a)) line. If additional steam is needed, an auxiliary boiler is installed. CO_2 compressor is electrically driven.

Key features of configuration III:

- Excess steam is extracted from the HP section of the turbine from both 13.0 and 4.2 bar(a) lines. Some modifications to the extraction point of the 13.0 bar(a) line is to be expected as the mass flow of the steam is increased. Like in Configuration II, a case-by-case evaluation will be necessary to check how much 13.0 bar(a) steam could be extracted without affecting the supply of the 13.0 bar(a) and the 4.2 bar(a) steam needed by the mill and the pressure control of the turbine. There will be no major modification to the extraction point at the 4.2 bar(a) line given that steam is only diverted away from the LP section of the turbine.
- Similar to all other options, the LP section of the turbine will also be clutched to halt its operation if the steam flow is below the minimum value required.
- The CO_2 compressor is driven by a back pressure steam turbine using the 13.0 bar(a) steam extracted from the steam turbine and supplemented by the 13.0 bar(a)/200ºC steam produced from the auxiliary boiler. The steam parameters of the auxiliary boiler are the same as for the MP steam used in the mill.
- The steam pressure of the extracted steam from 4.2 bar(a) line is reduced to 2.0 bar(a) and de-superheated. This is then combined with the 2.0 bar(a) steam from the back pressure steam turbine driving the CO_2 compressor.
- This configuration is applied to Cases 2B-1[CO2MP], 2B-4[CO2MP], 2B-5[CO2MP] and 2B-6[CO2MP].
- The schematic block flow diagram of the steam turbine island for this configuration is shown in Figure 4.

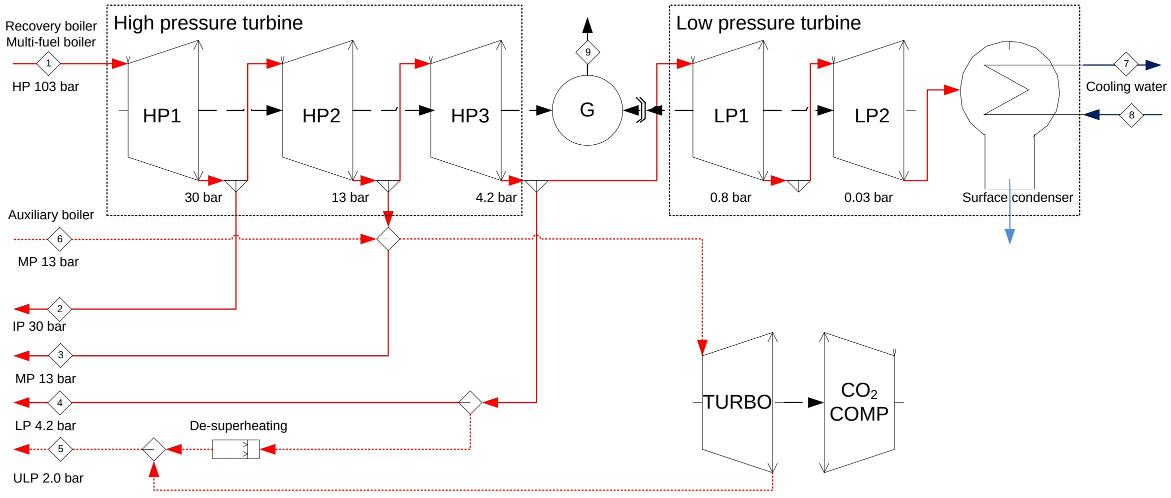


Figure 4: Configuration III – pulp mill steam turbine.
Ultra-low pressure steam (2.0 bar(a)) to be used in the CO_2 capture plant is extracted from the original steam turbine and supplemented by the steam extracted from the back pressure steam turbine driving the CO_2 compressor. If additional steam is needed, an auxiliary boiler is installed. The CO_2 compressor is steam driven.

5.2.3 Other modifications to the steam turbine island

Additional modifications associated with the different steam turbine configurations could be expected. Some of these considerations include:

- Addition of vessels and associated equipment including boiler feed water pumps for de-superheating of the steam.
- Addition or modification to the steam headers and blow down tanks (due to the additional steam from auxiliary boiler that needs to be handled).
- Addition and/or expanding of the existing steam pipeline network including any associated equipment such as valves, steam traps, etc.to accommodate the additional steam flow.
- Addition or expansion of the condensate collection network including any associated equipment such as collecting tanks, headers, pumps, valves, etc.
- Addition or expansion of the treatment facilities for the boiler feed water and returning condensate (i.e. de-aeration tanks, steam blow down equipment, etc.)

5.2.4 Key outcome

All of the results are presented in section 4, sheets 6 and 9 and in Annex III. This section summarizes the key results for all the cases evaluated.

<u>Market pulp mill with CCS (Base Case 1A with CCS)</u>

For all the cases involving Base Case 1A, the amount of excess steam and electricity produced by the pulp mill is sufficient to cover the additional demand of the CO_2 capture and compression plant.

For all of the cases except for case 2A-6^{MP} extracting excess LP steam (4.2 bar(a)) is sufficient to cover the demand of the CO_2 capture plant (using configuration I).This reduces the amount of electricity produced by the LP section of the steam turbine by 3.2 MW_e (case 2A-3) to 37.9 MW_e (case 2A-4).

For case 2A-6^{MP}, where the CO_2 is captured from all three flue gas sources, the LP steam (4.2 bar(a)) is not sufficient. In this case MP steam (13.0 bar(a)) is used instead (using configuration II). This reduces the amount of electricity produced by the HP section of the steam turbine by ~ 17 MW_e (down to a total production of 113.7 MW_e compared to 130.4 MW_e for Base Case 1A).

As a result of retrofitting the CO_2 capture and compression plant the amount of electricity exported to the grid was reduced by 6 MW_e (case 2A-3) to 86 MW_e (case 2A-6^{MP}). This corresponds to a reduction ranging between 6 and 80% of the electricity exported to the grid compared to Base Case 1A at 107.3 MW_e).

<u>Integrated pulp and board mill with CCS (Base Case 1B with CCS)</u>

When an integrated pulp and board mill is considered, less excess energy will be available for utilization in the CO_2 capture and compression plant.

Only in cases 2B-2 and 2B-3 where CO_2 is captured from the flue gases of smaller sources such as the individual lime kiln or multi-fuel boiler there is sufficient steam available from the mill to meet the additional energy demand of the CO_2 capture and compression plant.

For all other cases involving the capture of CO_2 from flue gases from the recovery boiler or the recovery boiler in combination with the lime kiln and/or multi-fuel boiler (cases 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP} and 2B-6^{CO2MP}), the available excess steam from the mill is not sufficient to cover the steam demand of the CO_2 capture and compression plant. In these cases, the use of configuration II and III were evaluated. In all of these cases, an auxiliary boiler will be needed.

In configuration II an electrically driven compressor is employed for CO_2 compression. The auxiliary boiler is smaller in capacity compared to the auxiliary boiler if configuration III is employed. However, not all the cases with configuration II will have sufficient electricity supplied by the mill, therefore requiring import of electricity from the grid, see Annex III.

In configuration III, a steam turbine driven compressor is employed. The compressor driver is based on a back pressure steam turbine using MP (13.0 bar(a)) steam obtained from the original steam turbine of the mill and supplemented by the auxiliary boiler. ULP (2.0 bar(a)) steam is extracted and sent to the reboiler of the CO_2 stripper to complement the extracted and de-superheated LP steam (4.2 bar(a)) from the steam turbine island.

To optimize the energy performance of the integrated pulp and board mill with CCS it was decided to select configuration III instead of configuration II. This maximizes the amount of electricity that is exported to the grid and at the same time meets the steam demand for both the mill and the CO_2 capture and compression plant. The auxiliary boilers employed in these cases are briefly described in section 5.3.

For cases 2B-2 and 2B-3, the amount of electricity exported to the grid has been reduced by 6 MW_e (case 2A-3) to 10 MW_e (case 2A-2). This corresponds to a reduction of 10 – 15% of the electricity exported to the grid (compared to Base Case 1B at 63.4 MW_e).

For cases 2B-1^{CO2MP} and 2B-4^{CO2MP} to 2B-6^{CO2MP}, the amount of electricity exported to the grid has been significantly reduced due to the additional demand of the CO_2 capture and compression plant and the auxiliary boiler where electricity is needed to run the auxiliary equipment (i.e. fan, blowers, pumps, etc.). This requires shutting down the LP section of the steam turbine. In all of these cases, the amount of electricity exported to the grid has been reduced by 41 MW_e (case 2B-1^{CO2MP}) to 43 MW_e (case 2B-4^{CO2MP}). This corresponds to a reduction of 65 – 68% of the electricity exported to the grid compared to Base Case 1B at 63.4 MW_e).

5.3 Auxiliary boiler

For cases 2B-1^{CO2MP} and 2B-4^{CO2MP} to 2B-6^{CO2MP} an auxiliary boiler is necessary to supplement the process steam produced by the mill to meet the additional demand of the CO_2 capture and compression plant.

The auxiliary boiler employed in these cases is a bubbling fluidized bed (BFB) boiler. The boiler is fired with forest residues that are purchased from wood fuel markets delivered to the site. The overall thermal efficiency of the boiler is around 80%. The boiler generates 13.0 bar(a) steam. This is fed to the steam turbine driver of the CO_2 compressor, supplementing the steam supplied by the steam turbine island of the mill (see Figure 4).

The auxiliary boiler would need IP steam (30.0 bar(a)) from the mill for soot blowing and LP steam (4.2 bar(a)) for pre-heating the combustion air.

The CO_2 emitted by the auxiliary boiler is not captured. These emissions are considered biogenic CO_2 emission and could be accounted as CO_2 neutral if the fuel is supplied from sustainable sources.

The boiler is equipped with a wood receiving and storage system, fuel feeding lines, boiler housing, an electrostatic precipitator (ESP), a flue gas fan, boiler feed water pumps and a stack. The fly ash collected in the ESP and the bottom ash from the boiler is collected and stored in a dry ash silo. The ash is sent to the landfill.

Key parameters and results of the auxiliary boiler used in the performance and economic evaluation are summarized in Table 9.

Table 9: Key operating parameters of the auxiliary boiler

		CO_2 capture plant integrated to pulp and board mill			
		2B-1^{CO2MP}	2B-4^{CO2MP}	2B-5^{CO2MP}	2B-6^{CO2MP}
Fuel in (50% moist.)	[t/h]	19.1	29.7	28.1	44.7
Air in	[t/h]	65.4	101.6	96.1	152.9
FG out	[t/h]	91.0	141.4	133.7	212.8
CO_2 out	[t/h]	17.8	27.6	26.1	41.6
IP steam (in)	[t/h]	1.5	2.3	2.2	3.4
MP steam (out)	[t/h]	65.0	100.9	95.4	151.9
LP steam (in)	[t/h]	2.8	4.3	4.1	6.5
Boiler feed water	[t/h]	65.0	100.9	95.4	151.9
Boiler feed water make-up	[t/h]	6.9	10.7	10.1	16.1
Ash out	[t/h]	0.3	0.4	0.4	0.6
Electricity consumption	[kW_e]	1569.0	2437.9	2305.2	3669.0

5.4 Modification to the process water, boiler feed water and cooling water supply network

5.4.1 Process water

The CO_2 capture plant would require additional process water as make-up water to the amine solvent and in the water wash column.

As shown in section 4, sheet 10 the additional process water needed by the CO_2 capture plant is not significant compared to the volume of process water needed by the mill without CCS.

For example, for Case 2A-6^{MP} the additional process water requirement is 101 m^3/h. This corresponds to an increase of around 6% compared to Base Case 1A (at 1 558 m^3/h).

Modifications to the demi-water plant due to CCS integration are minimal compared to the amount of demi-water being used by the entire pulp mill.

5.4.2 Boiler feed water

Additional boiler feed water is needed by the CO_2 capture plant to cover any loss of condensate returning from the reboiler and reclaimer, and any make-up boiler feed water needed in the de-superheating of the steam.

This study assumed 5% system loss based on the mass flow of steam to the reboiler and reclaimer. This only contributes to an increase in boiler feed water demand from 2 m^3/h (case 2A-3) to 17 m^3/h (case 2A-6^{MP}).

When an auxiliary boiler is installed (cases 2B-1^{CO2MP} and 2B-4^{CO2MP} to 2B-6^{CO2MP}), additional makeup boiler feed water is required. This results in an increase of boiler feed water ranging from 7 m^3/h (case 2B-1^{CO2MP}) to 17 m^3/h (case 2B-6^{CO2MP}).

The modifications needed in the boiler feed water and condensate system should be in line with the modifications employed to the steam turbine island.

5.4.3 Cooling water

In this study the increase in cooling water demand is between 1 600 m^3/h (case 2A-3) and 15 800 m^3/h (case 2A-6^{MP}) compared to Base Case 1A (at 12 327 m^3/h). An increase between 1 700 m^3/h (case 2B-3) and 19 100 (case 2B-6^{CO2MP}) is reported compared to Base Case 1B (at 8 999 m^3/h). This corresponds to an increase in cooling water demand ranging between 12% and 215% compared to their corresponding base cases.

Due to the substantial demand of the additional cooling water needed by the CO_2 capture and compression plant, this study assumed that a new dedicated circuit of once-through seawater cooling system will be installed.

This study recommends a more thorough assessment of heat integration with the pulp mill to reduce the volume of seawater cooling required. This is further described in section 6.2.

5.5 Modification to the wastewater treatment plant

The majority of the wastewater generated by the CO_2 capture and compression plant comes from the direct contact cooler and the compression and drying unit (see section 4, sheets 2 and 5).

The increase in the volume of wastewater generated by the CO_2 capture and compression plant is relatively minimal (a maximum of 13% increase for case 2A-6^{MP}) when compared to the original volume of wastewater being processed by the pulp mill (see section 4, sheet 12).

It is expected that the treatment of the additional wastewater from the CCS plant could be integrated into the original wastewater treatment plant of the mill. Small modifications should be expected (for example addition of settling tanks) to accommodate the additional volume of wastewater to be treated.

5.6 Solid waste from the CO_2 capture plant

The additional solid waste generated by the CO_2 capture plant mainly comes from the MEA sludge generated by the amine reclaimer. This study assumed that these waste will be collected and sent to a dedicated company specializing in dealing with hazardous waste.

6. Future considerations available to greenfield development or major revamp scenario

6.1 Steam turbine island

The energy performance of the mill with CO_2 capture could be improved for instance by a major revamp to the steam turbine island or if the development of a greenfield site is assumed. Some preliminary considerations have been made to look at how the energy performance could be improved.

A major revamp of steam turbine would be ideal. This could be beneficial if the existing LP turbine section (condensing steam turbine) is replaced with a new back-pressure steam turbine for generation of 2.0 bar(a) steam required by the CO_2 capture plant. This could reduce the efficiency losses due to steam expansion and de-superheating that is currently assumed in all of the configurations evaluated in this study (i.e. when steam is extracted from the 4.2 bar(a) line). Expansion of the extracted steam in the new steam turbine could also increase the electricity production. An important consideration concerning this type of deployment is the assessment of the overall steam balance for both the mill and CO_2 capture plant. This is because the current configuration assessed in this study consist of substantial amount of boiler feed water used in de-superheating of the 4.2 bar(a) steam becomes a substantial contribution to the total amount of the steam supplied to the CO_2 capture plant.

Another alternative is to install an additional back-pressure steam turbine and generator set. The new back-pressure steam turbine could be fed with HP steam generated from the available steam obtained from the extraction points (30.0/13.0/4.2 bar(a)) of the existing turbine or an auxiliary boiler. In practice, the efficiency of the existing steam turbine would decrease due to lower steam volume flowing though the turbine. Consequently, this could decrease the amount of the additional power gained. However, this option may not be feasible for retrofit cases where investment cost is a constraint.

In cases where a greenfield pulp mill with CO_2 capture is considered, the design of the steam turbine and associated generator could be custom made to suit other types of configurations. For example, it is possible to install a steam turbine that would allow extraction at pressures of 30.0/13.0/4.2/2.0 bar(a). However, with this configuration, the assessment of the steam balance of the mill is essential to ensure that enough steam is generated to accommodate all of the on-site process steam users.

For a green field development option, the multi-fuel boiler could be re-sized to accommodate the combustion of additional fuel obtained off-site to ensure that the mill is able to meet the steam demand of the entire integrated mill with CO_2 capture.

6.2 Heat integration with the pulp mill

A pulp mill typically has a well-established integrated hot and warm water system (HWWS). Retrofitting a CO_2 capture and compression plant could provide opportunities where low grade heat from the capture plant could be integrated into the existing HWWS. It should be noted that this type of integration has very site specific requirements.

As an example, the temperature level of the CO_2 capture plant has a very similar profile to the temperature level of the black liquor evaporator plant. Further assessment should be made to explore whether more comprehensive process integration analyses could provide additional benefits to the energy performance of the mill. Additional considerations should be made to evaluate whether such integration could impact the availability of the evaporator or whether it would be too sensitive to any disturbance from the CO_2 capture plant.

Future considerations should also include the use of adiabatic CO_2 compressor instead of the intercooled CO_2 compressor assumed in this study. This could potentially provide higher grade heat which could be integrated into the HWWS or to be used in pre-heating condensate or boiler feed water used by the recovery boiler or the multi-fuel boiler.

In most Nordic pulp mills district heating is always part of the mill processes. If this is considered, would the retrofit of the CO_2 capture plant provide an increased capacity for district heating? Would district heating reduce the amount of cooling water demand?

6.3 Water integration

The pulp and paper industry is a major water consumer. Significant amounts of water are used in nearly every step of the manufacturing processes. As a result, pulp and paper mills produce large volumes of wastewater and residual sludge waste, presenting a number of issues in relation to wastewater treatment, discharge and sludge disposal.

The role of advanced treatment technologies including innovative strategies geared towards water reuse and resource recovery, present viable solutions for pulp and paper manufacturers in terms of wastewater and solid waste management.

Among the different types of water usage within the pulp mill and the CO_2 capture and compression plant the increase in cooling water demand is a major concern. The addition of the CO_2 capture and compression plant could represent an increase of up to 220% (case 2A-6^{MP}) of cooling water demand. Considerations should be made on how to reduce this demand when retrofitting CCS.

Future studies should look at other options that could realize a reduction of cooling water in a pulp mill with CCS. Some of these options include:

- Use of cooling tower system or air cooling system instead of once through sea water cooling system
- Integration of the cooling water system of the CO_2 capture plant to the existing HWWS network of the mill
- Integration of the cooling water system of the CO_2 capture plant to the pre-heating of condensate and boiler feed water
- Integration of the cooling water system of the CO_2 capture plant and the wastewater treatment plant (i.e. re-use of some of the treated wastewater stream as cooling medium with an aim of reducing water usage)

It should be noted that a combination of these options may be necessary to optimize and minimize the water usage when retrofitting CO_2 capture plant to a pulp mill.

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Annexes

1. Overall block flow diagram – Pulp mill with CCS
2. Overall block flow diagram – Integrated pulp and board mill with CCS
3. Steam Turbine Configurations – Performance results

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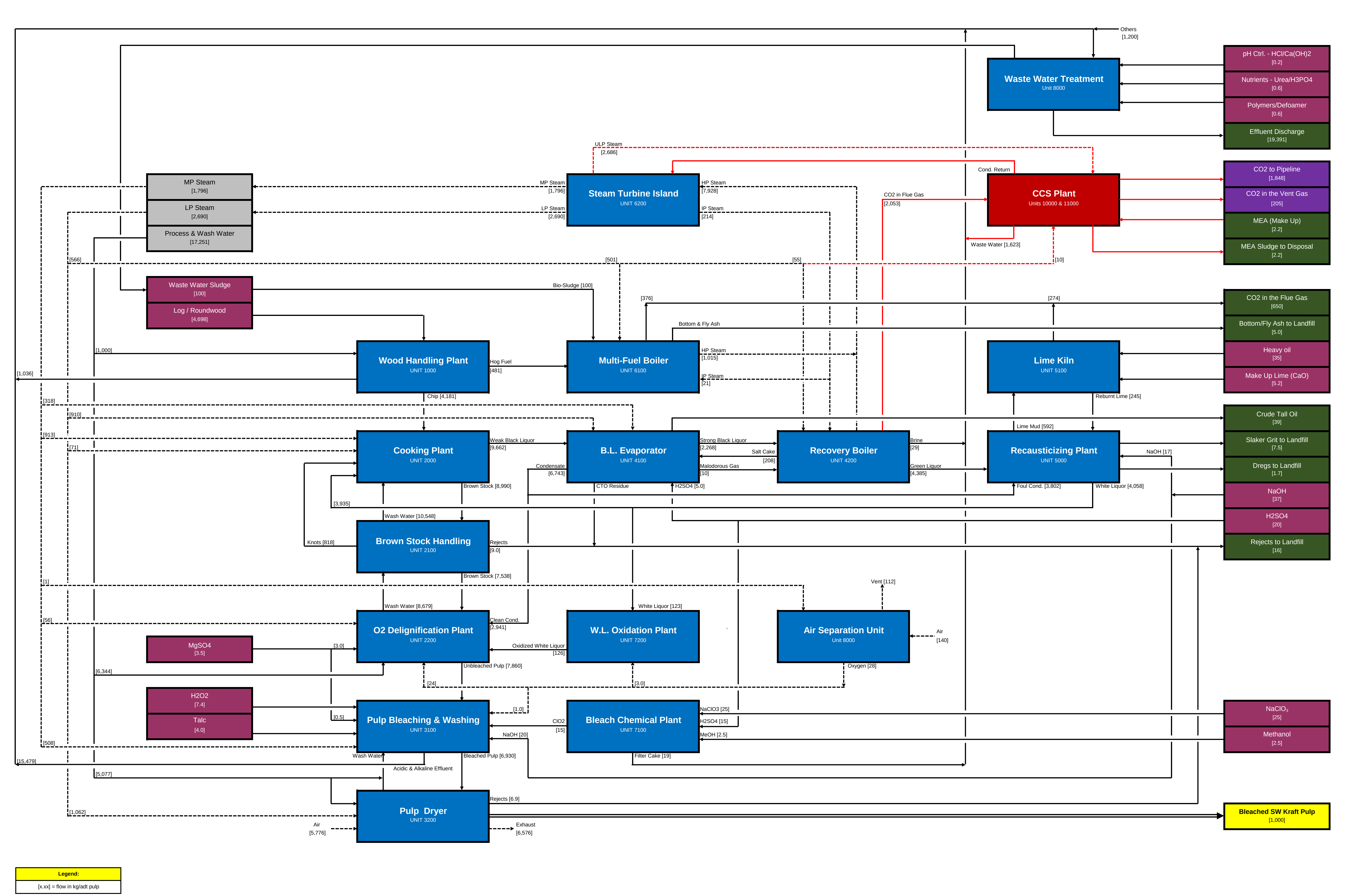
Annex I: Market Pulp Mill with CCS Overall Block Flow Diagram

- Annex I-1: Case 2A-1 – Capture of CO_2 from Flue Gas of Recovery Boiler
- Annex I-2: Case 2A-2 – Capture of CO_2 from Flue Gas of Multi-fuel Boiler
- Annex I-3: Case 2A-3 – Capture of CO_2 from Flue Gas of Lime Kiln
- Annex I-4: Case 2A-4 – Capture of CO_2 from Flue Gases of Recovery Boiler and Multi-fuel Boiler
- Annex I-5: Case 2A-5 – Capture of CO_2 from Flue Gases of Recovery Boiler and Lime Kiln
- Annex I-6: Case 2A-6^{MP} – Capture of CO_2 from Flue Gases of Recovery Boiler, Multi-fuel Boiler and Lime Kiln

CUSTOMER REPORT: VTT-CR-01312-15	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
	Case 2A-1: Market Pulp Mill with CCS (800,000 adt/y) (Capture of CO_2 from Flue Gas of the Recovery Boiler)	1.0	Dec. 16	SS	KO	KO	1 of 6



CUSTOMER REPORT: VTT-CR-01312-15

SCHEMATIC BLOCK FLOW DIAGRAM

Case 2A-2: Market Pulp Mill with CCS (800,000 adt/y)

(Capture of CO_2 from Flue Gas of the Multi-fuel Boiler)

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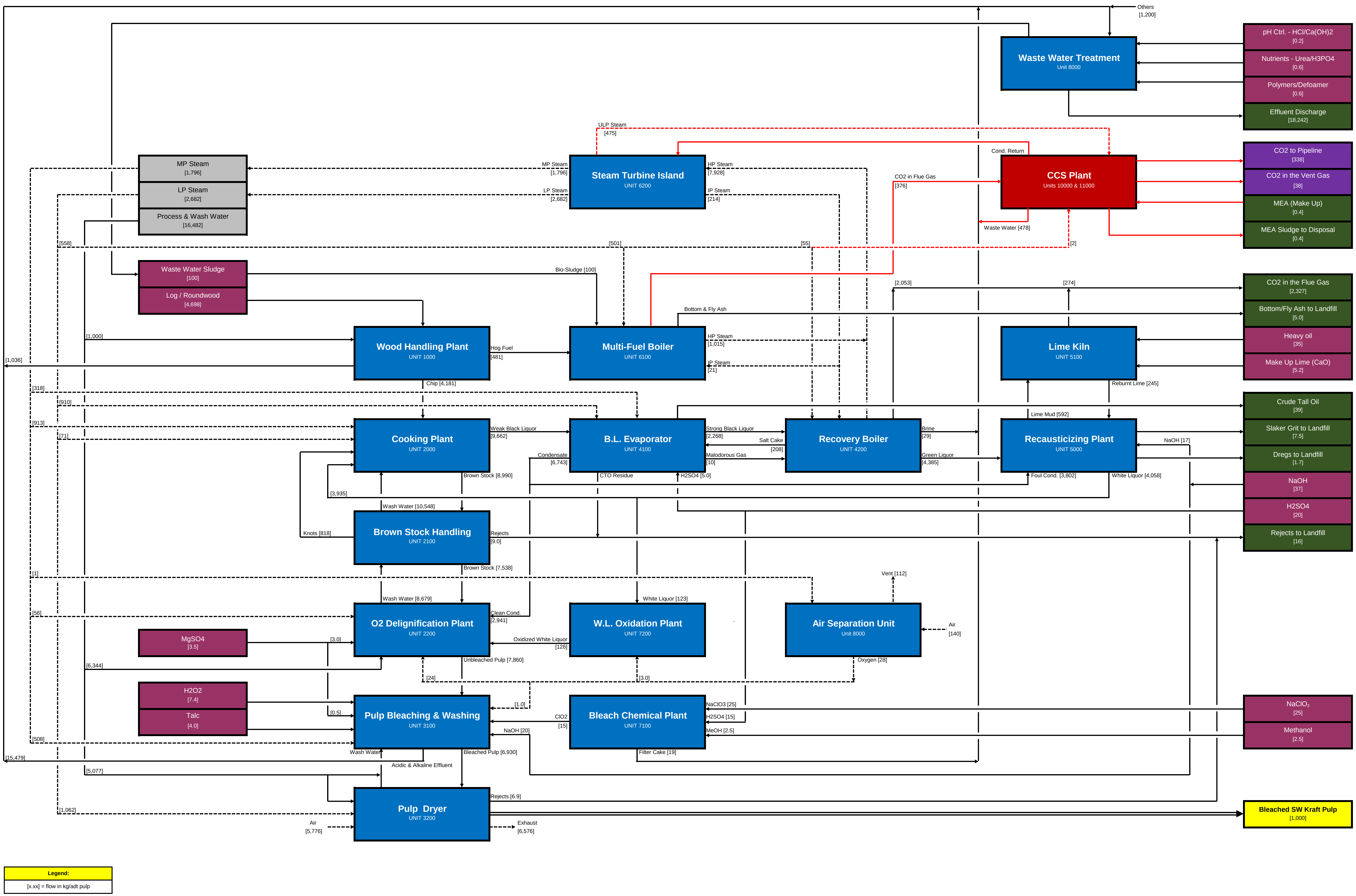


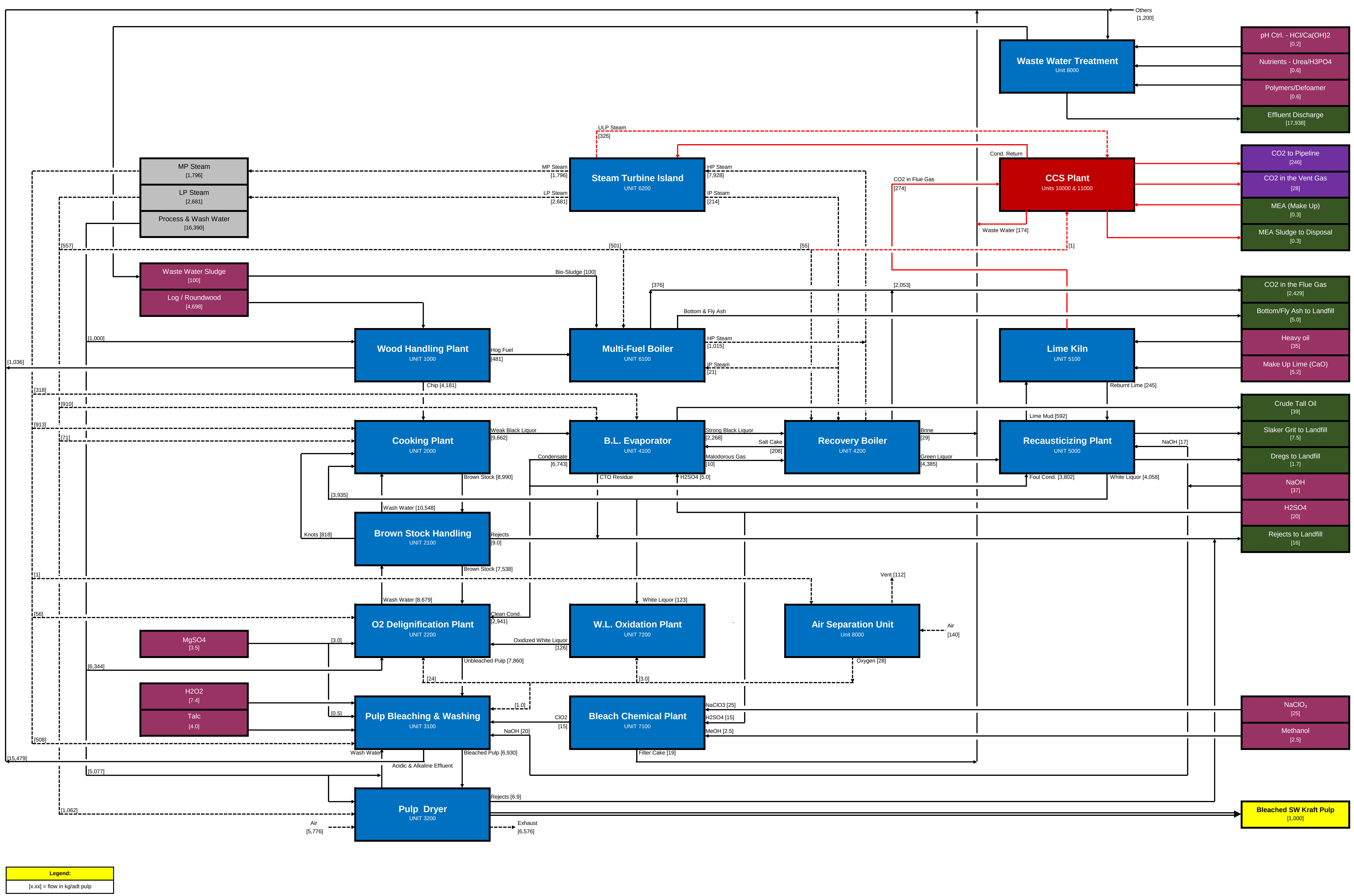
CUSTOMER REPORT: VTT-CR-01312-15

SCHEMATIC BLOCK FLOW DIAGRAM

Case 2A-3: Market Pulp Mill with CCS (800,000 adt/y)

(Capture of CO_2 from Flue Gas of the Lime Kiln)

REVISION	DATE	BY	CHKD	APP.	SHEET
1.0	Dec. 16	SS	KO	KO	3 of 6



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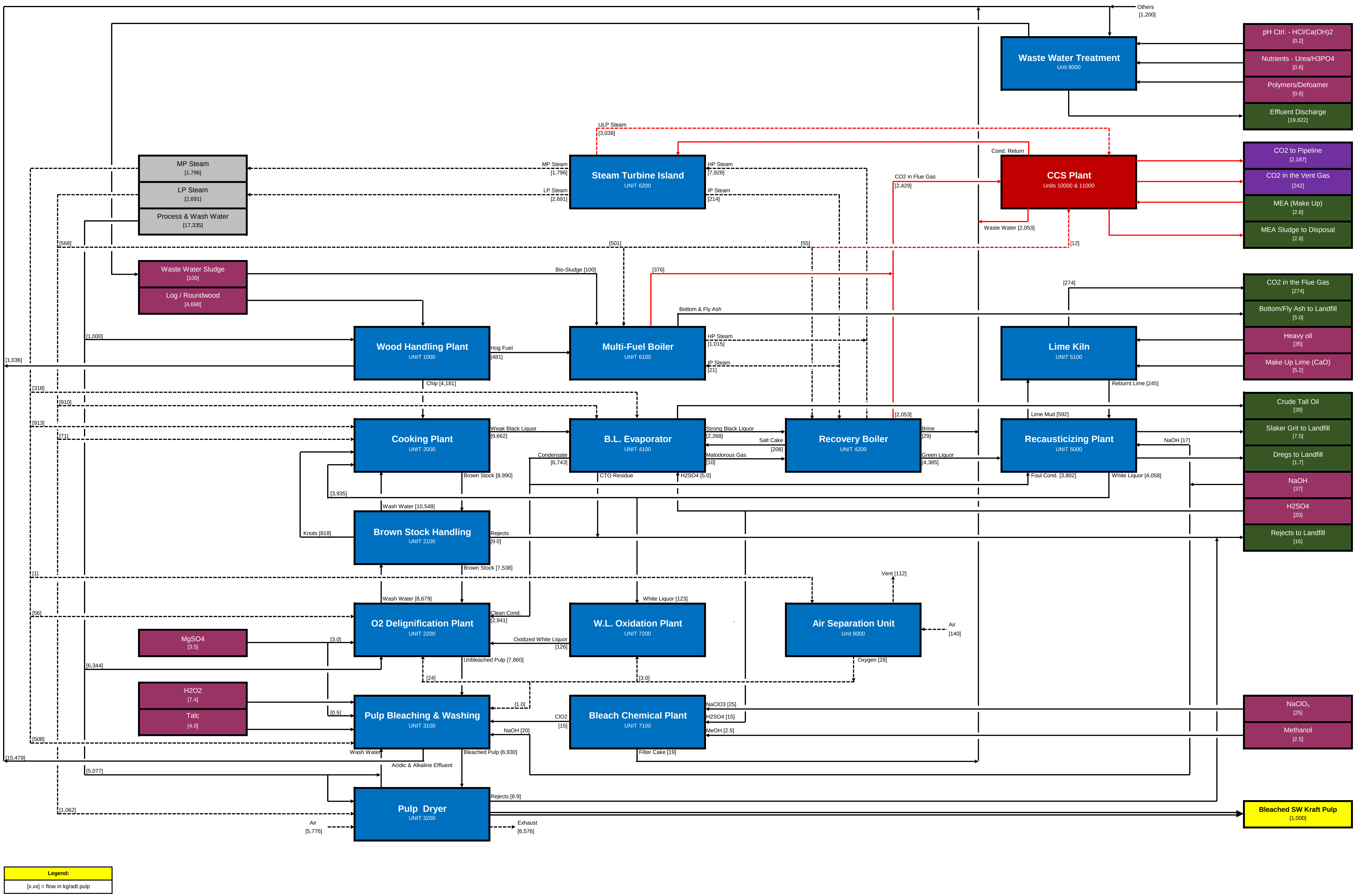
	Case 2A-4: Market Pulp Mill with CCS (800,000 adt/y) **(Capture of CO_2 from Flue Gases of the Recovery Boiler and Multi-fuel Boiler)**	1.0	Dec. 16	SS	KO	KO	4 of 6



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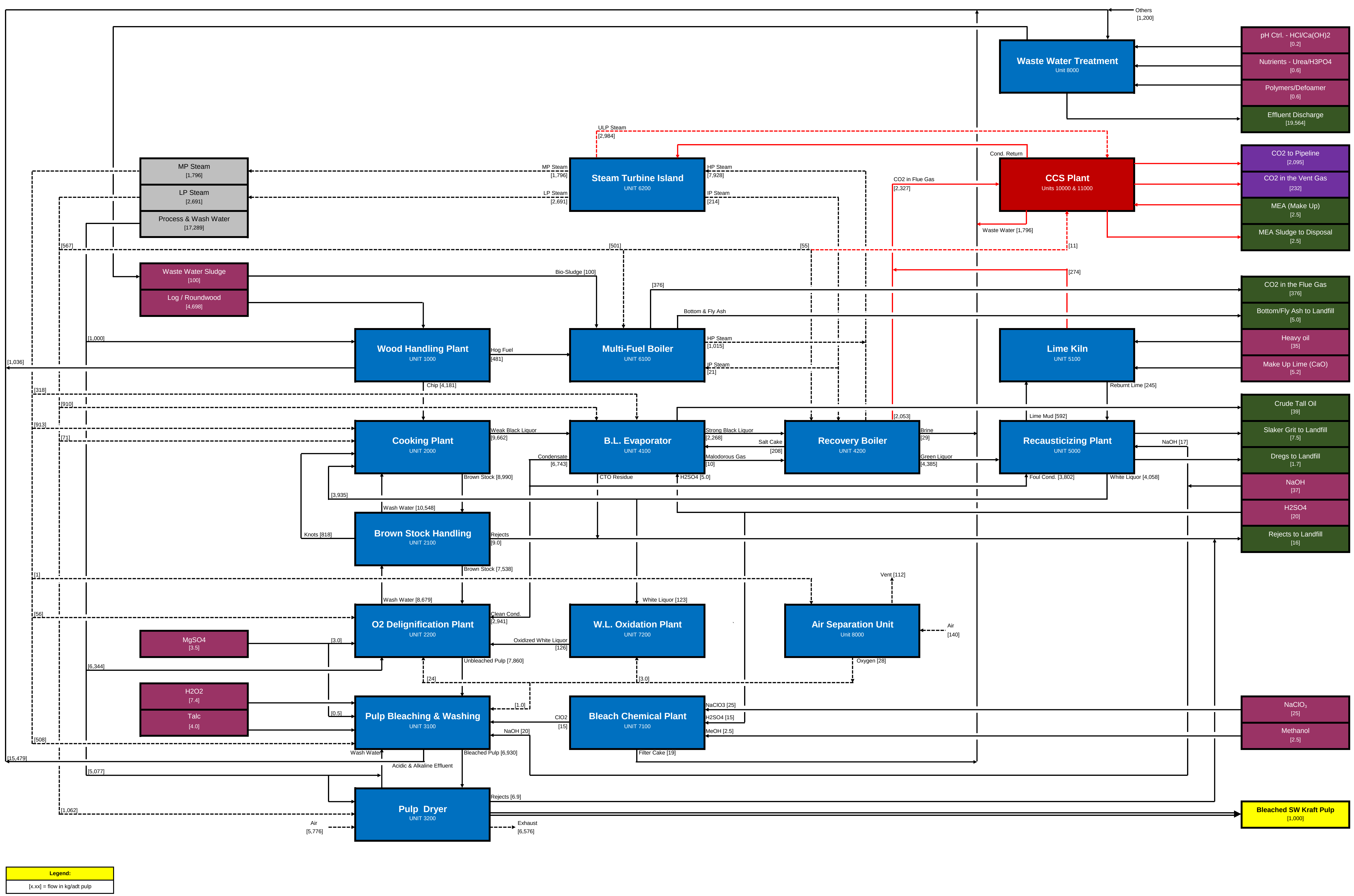
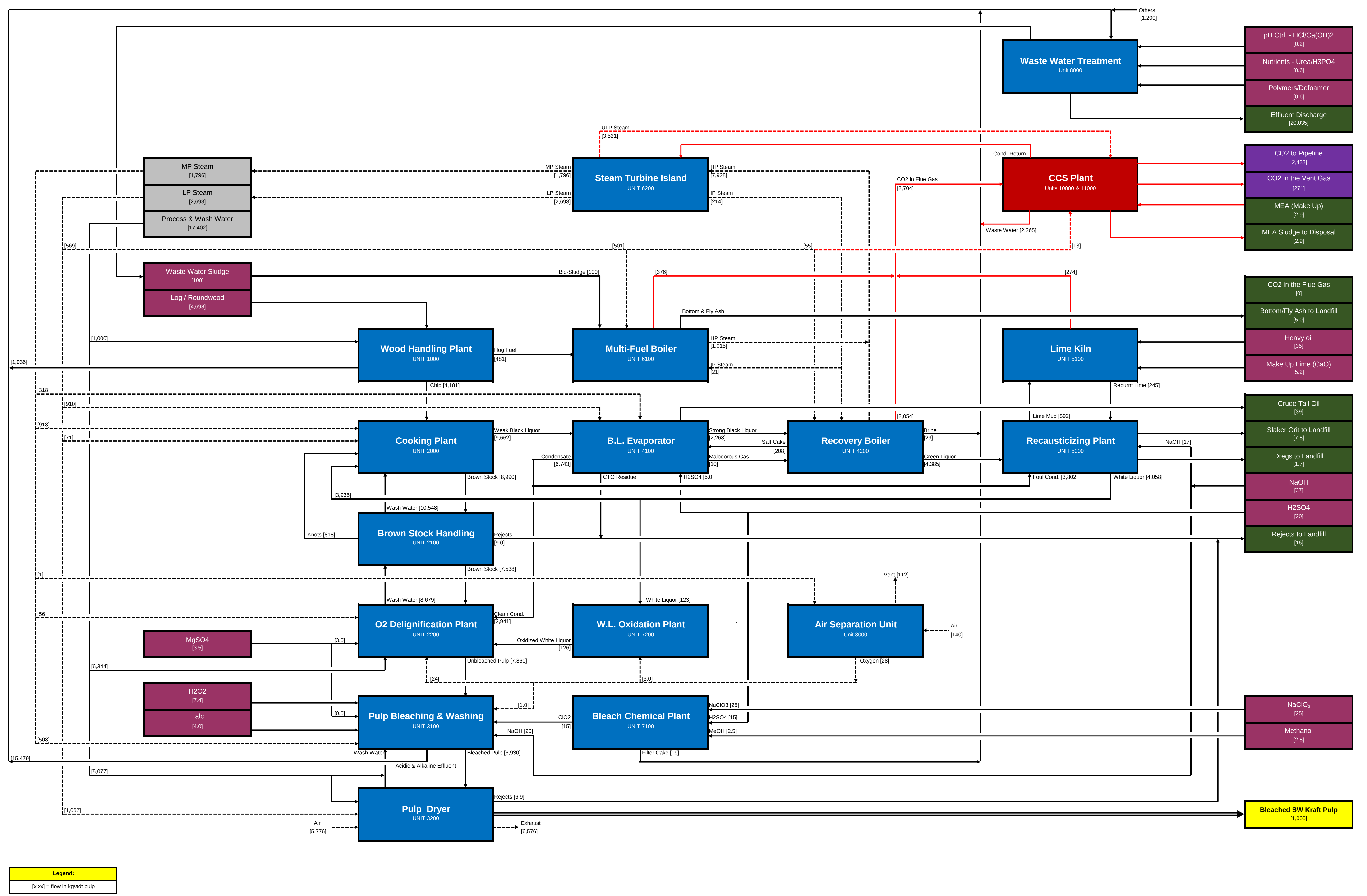


VTT	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
CUSTOMER REPORT: VTT-CR-01312-15	**Case 2A-6[MP]: Market Pulp Mill with CCS (800,000 adt/y)** (Capture of CO_2 from Flue Gases of the Recovery Boiler, Multi-fuel Boiler and Lime Kiln)	1.0	Dec. 16	SS	KO	KO	6 of 6



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Annex II: Integrated Pulp & Board Mill with CCS Overall Block Flow Diagram

- Annex II-1: Case 2B-1[CO2MP] – Capture of CO_2 from Flue Gas of Recovery Boiler
- Annex II-2: Case 2B-2 – Capture of CO_2 from Flue Gas of Multi-fuel Boiler
- Annex II-3: Case 2B-3 – Capture of CO_2 from Flue Gas of Lime Kiln
- Annex II-4: Case 2B-4[CO2MP] – Capture of CO_2 from Flue Gases of Recovery Boiler and Multi-fuel Boiler
- Annex II-5: Case 2B-5 [CO2MP] – Capture of CO_2 from Flue Gases of Recovery Boiler and Lime Kiln
- Annex II-6: Case 2B-6[CO2MP] – Capture of CO_2 from Flue Gases of Recovery Boiler, Multi-fuel Boiler and Lime Kiln

CUSTOMER REPORT: VTT-CR-01312-15

SCHEMATIC BLOCK FLOW DIAGRAM

Case 2B-1[CO2MP]: Integrated Pulp (800,000 adt/y) & Board (400,000 adt/y) Mill with CCS

(Capture of CO_2 from Flue Gas of the Recovery Boiler)

REVISION	DATE	BY	CHKD	APP.	SHEET
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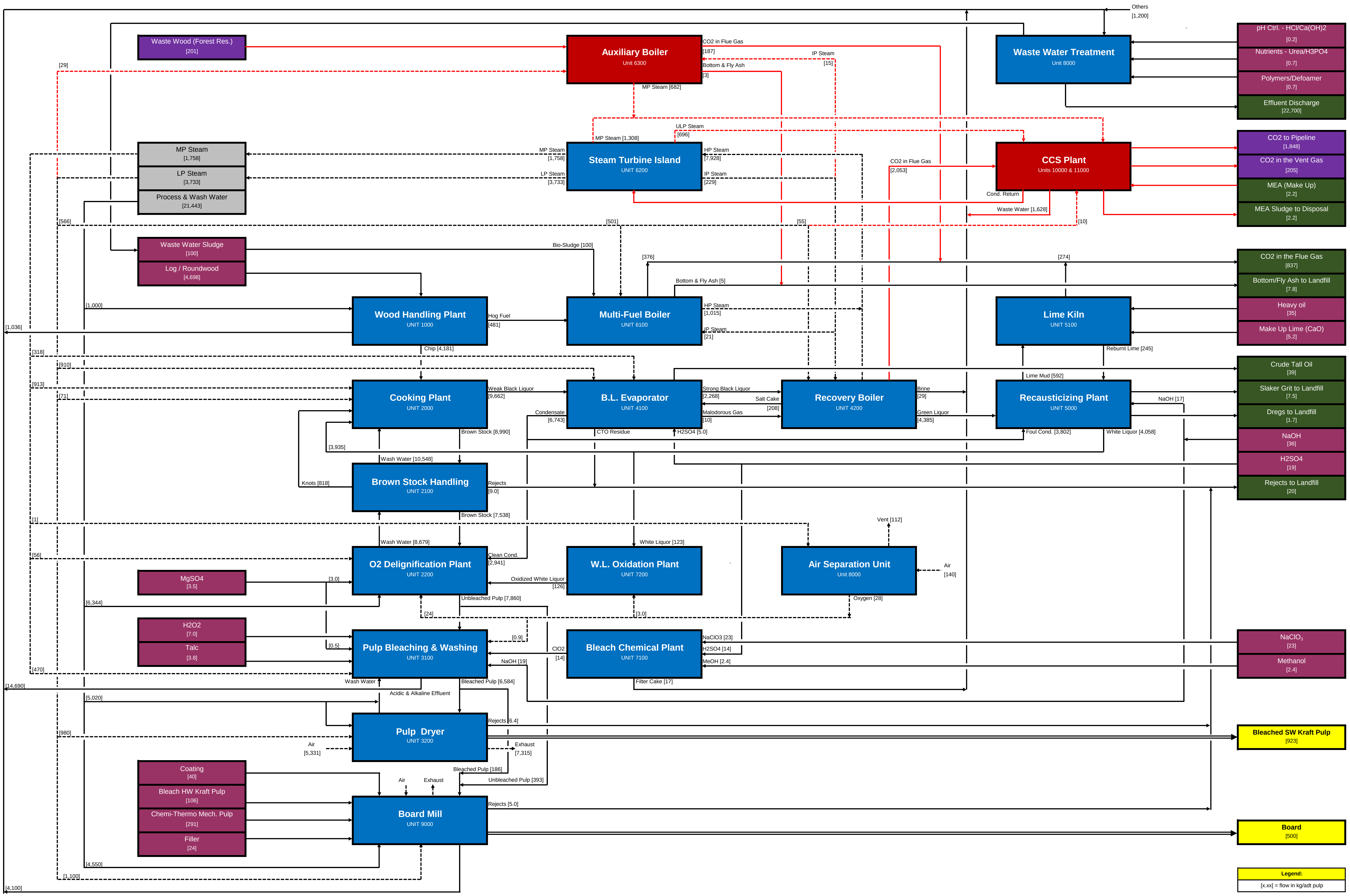

CUSTOMER REPORT: VTT-CR-01312-15	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
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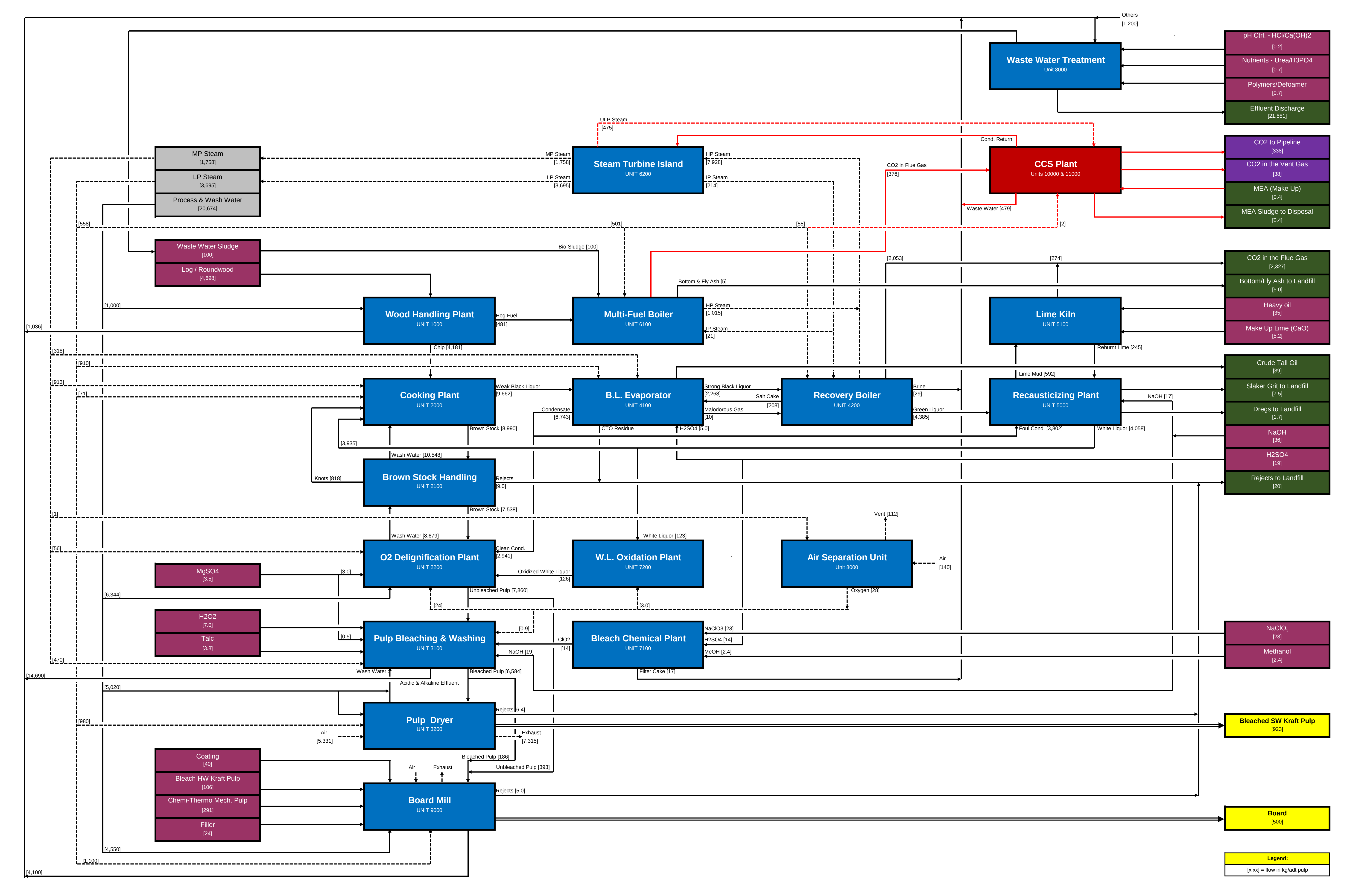
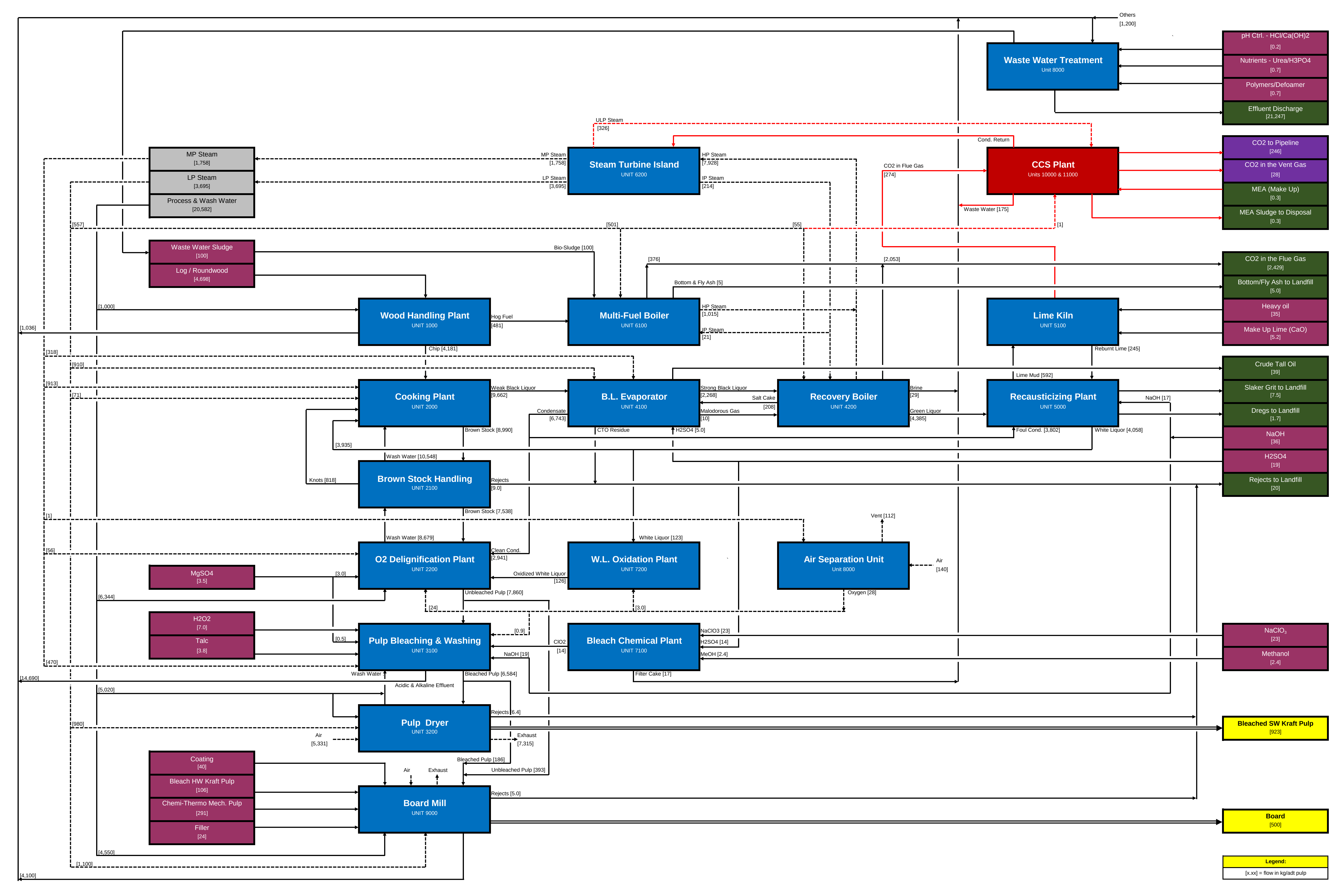


VTT	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
CUSTOMER REPORT: VTT-CR-01312-15	**Case 2B-3: Integrated Pulp (800,000 adt/y) & Board (400,000 adt/y) Mill with CCS** (Capture of CO_2 from Flue Gas of the Lime Kiln)	1.0	Dec. 16	SS	KO	KO	3 of 6



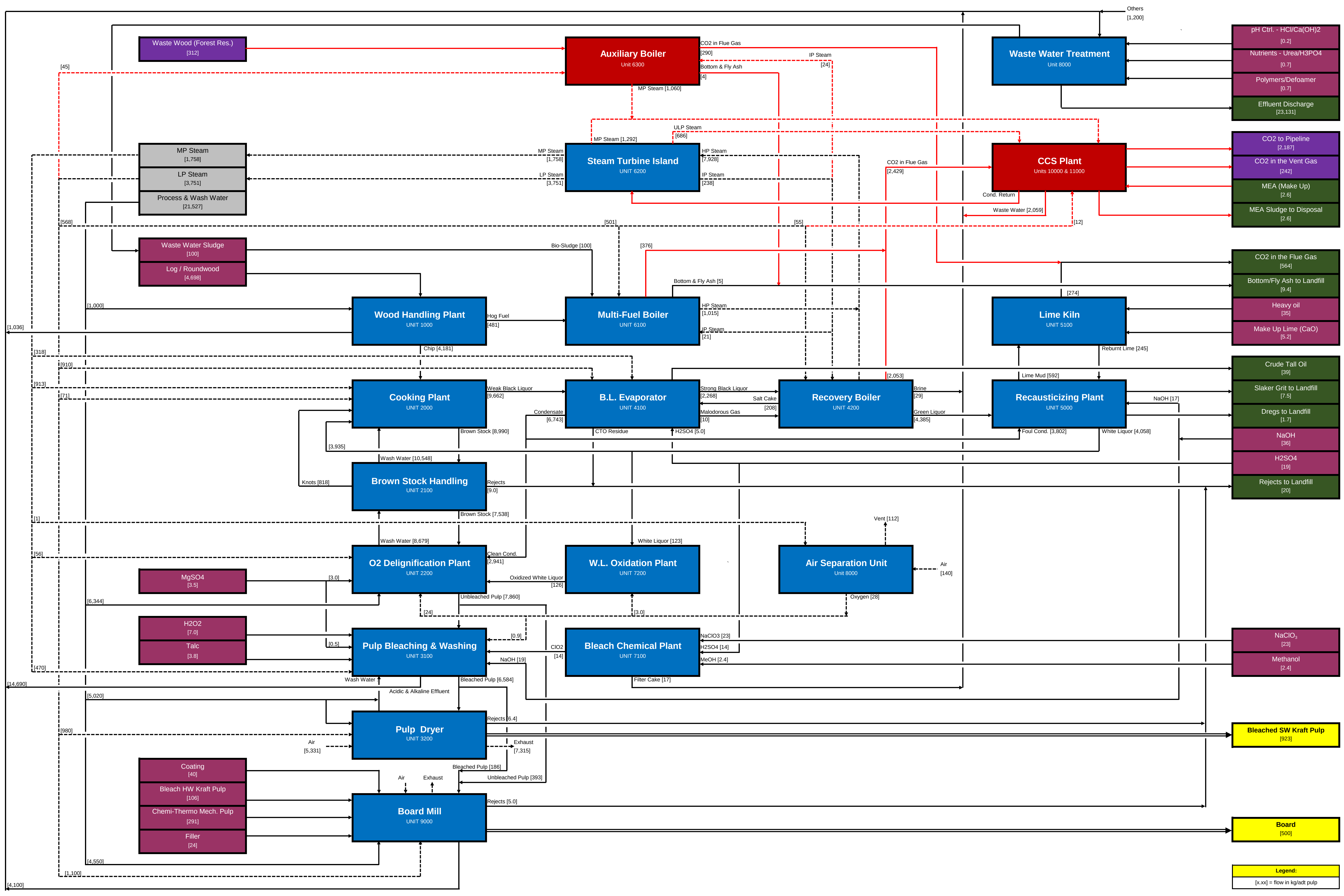
CUSTOMER REPORT: VTT-CR-01312-15

SCHEMATIC BLOCK FLOW DIAGRAM

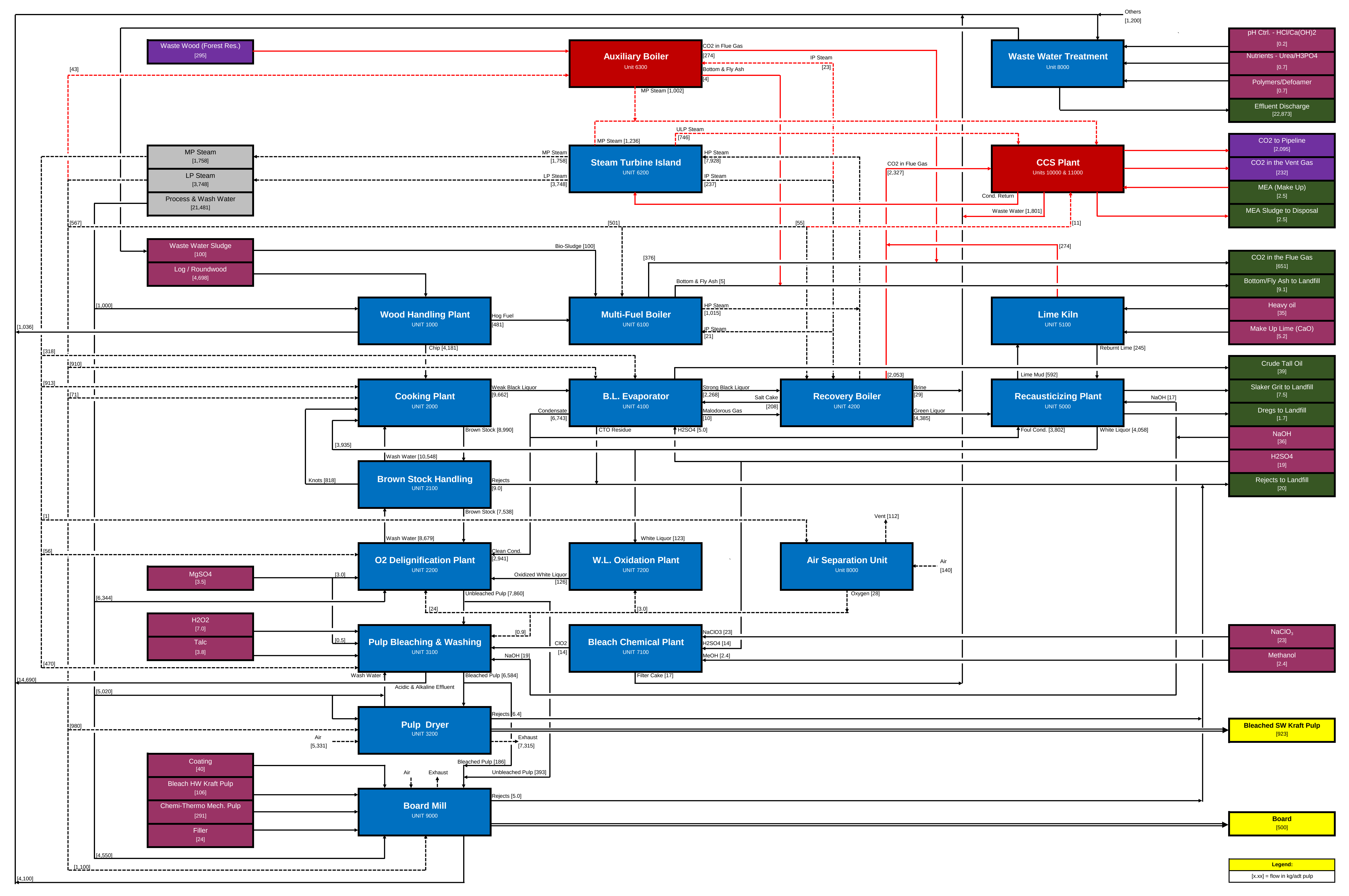
Case 2B-4[CO2MP]: Integrated Pulp (800,000 adt/y) & Board (400,000 adt/y) Mill with CCS

(Capture of CO_2 from Flue Gases of the Recovery Boiler and Multi-fuel Boiler)

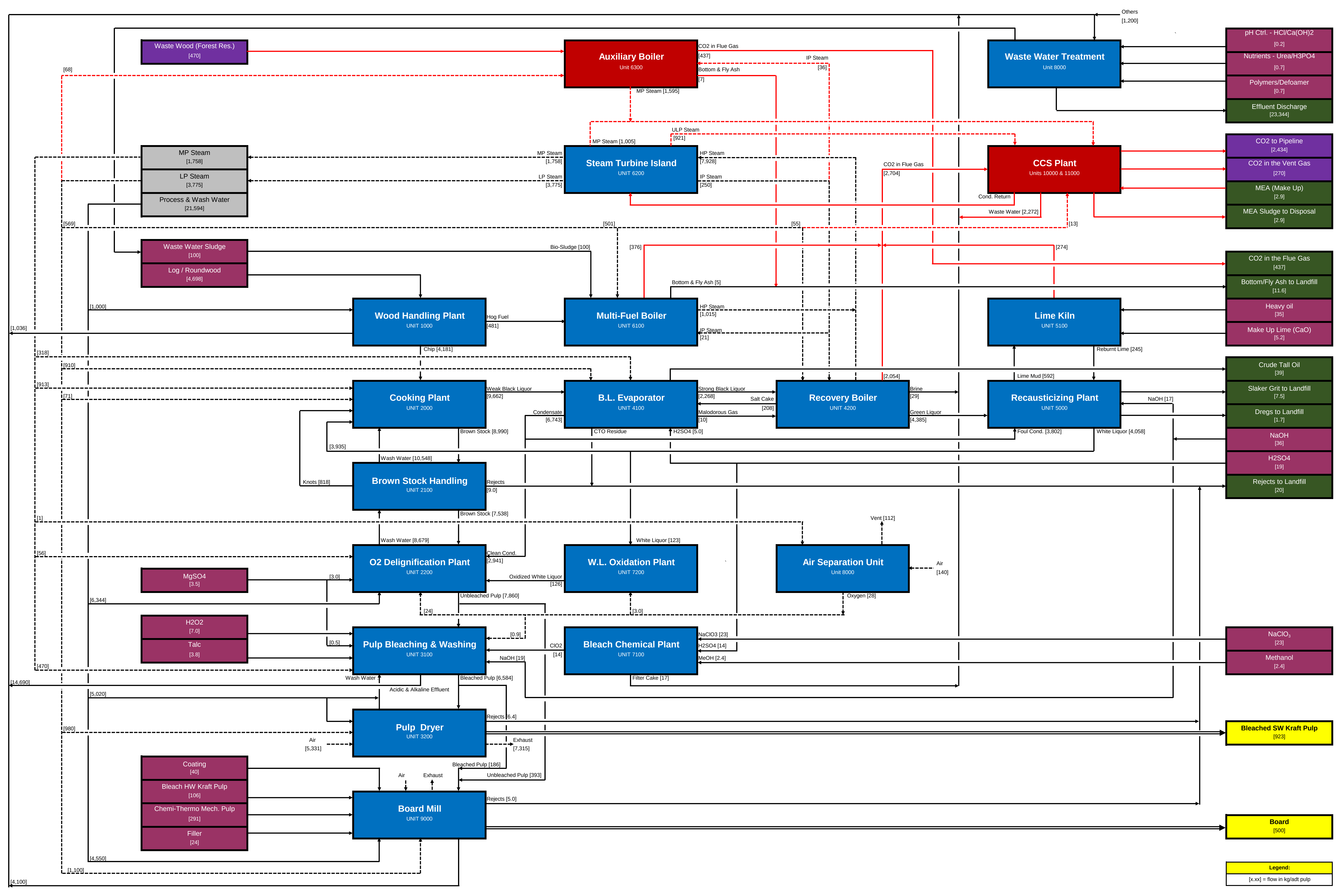
REVISION	DATE	BY	CHKD	APP.	SHEET
1.0	Dec. 16	SS	KO	KO	4 of 6



CUSTOMER REPORT: VTT-CR-01312-15	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
	Case 2B-5 CO2MP: Integrated Pulp (800,000 adt/y) & Board (400,000 adt/y) Mill with CCS (Capture of CO_2 from Flue Gases of the Recovery Boiler and Lime Kiln)	1.0	Dec. 16	SS	KO	KO	5 of 6



CUSTOMER REPORT: VTT-CR-01312-15	SCHEMATIC BLOCK FLOW DIAGRAM	REVISION	DATE	BY	CHKD	APP.	SHEET
	Case 2B-6[CO2MP]: Integrated Pulp (800,000 adt/y) & Board (400,000 adt/y) Mill with CCS (Capture of CO_2 from Flue Gases of the Recovery Boiler, Multi-fuel Boiler and Lime Kiln)	1.0	Dec. 16	SS	KO	KO	6 of 6



CCS in P&P industry

Annex III: Considerations for the Supply of Additional Steam to the CCS Plant

(Summary of Results – Performance)

Considerations for the Supply of Additional Steam to the CCS Plant

(Summary of Results – Performance)

1. INTRODUCTION

The annex explains the different options considered in this study when supplying the steam for the CO_2 capture and compression plant.

<u>Basis of Design</u>

The orginal steam turbine of the reference mills assumed in this study has been described in Annex III of the report presented by Kangas et. al. [1].

Figure A3-1 presents the simplified block flow diagram of the original steam turbine assumed in this study. This figure also illustrated where excess MP steam (13 bar(a)) or LP steam (4.2 bar(a)) could be extracted, de-pressurised and desuperheated to supply the ULP steam (2 bar(a)) required by the CCS Plant. In cases where excess steam from the original steam turbine is not sufficient, an auxiliary boiler could be deployed to provide the additional steam required.

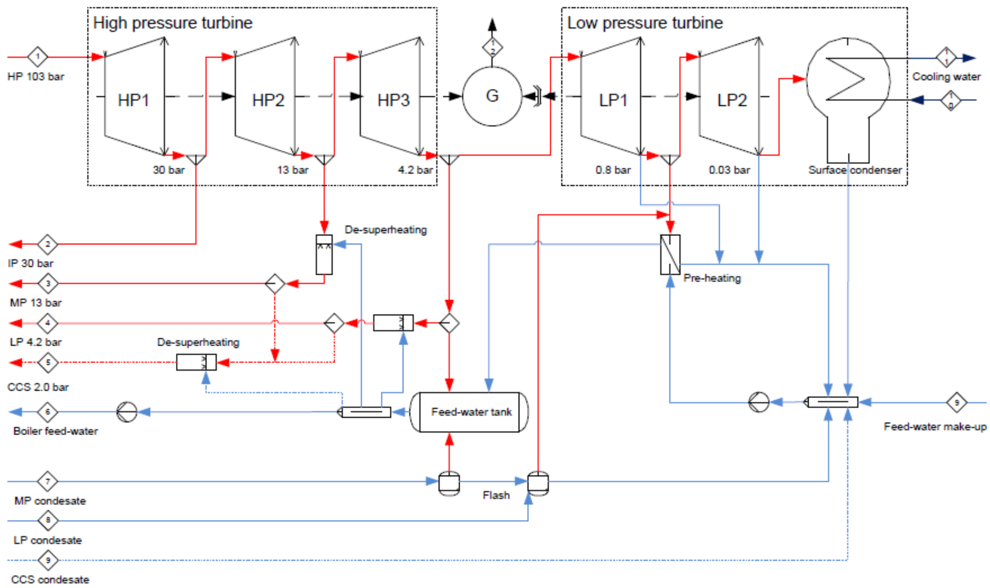


Figure A3-1: Generic configuration of the steam turbine [1]

For all the CCS cases, the following has been assumed:

- Supply of HP steam (103 bar(a) / 505°C) from the recovery boiler and multi-fuel boiler is assumed constant. As this is limited by the amount of concentrated black liquor (from the black liquor evaporator) and barks (from wood handling plant) to be processed by the mill.

- The steam extraction pressures are unchanged compared to the base case. These include the extraction of steam at:
    - o 30 bar(a) / 13 bar(a) / 4.2 bar(a) – used by pulp and board mill processes
    - o 0.8 bar(a) – used for pre-heating boiler feed water and condensates
    - o 0.03 bar(a) – is set as the condenser pressure for the LP section of the steam turbine.

- Amount of excess steam that could be supplied by the original steam turbine to the CCS plant is limited by the steam and electricity demand of the pulp (and board) mill. It is important that the supply of the steam and electricity to the mill is guaranteed before any dispatch of excess energy to the CCS plant.

- The reboiler of the CO_2 stripper requires steam at 2 bar(a). The amount of steam required by the stripper's reboiler varies depending on the amount of flue gases (from recovery boiler, multi-fuel boiler and lime kiln) to be treated by the CO_2 capture plant. Also, a small amount of LP steam is needed by the amine reclaimer.

- Steam for the CCS process could be supplied by:
    - Extraction from the LP steam (4.2 bar(a)) line
    - Extraction from the MP steam (13 bar(a)) line

- It is assumed that the amount of extracted steam at 13 bar(a) and/or 4.2 bar(a) is flexible, thus larger steam extraction is possible without major modification to the steam turbine.

- In cases where the available excess steam is not sufficient to meet the additional steam demand of the CCS plant, an auxiliary boiler is considered to supplement the supply. The auxiliary boiler is designed to supply additional 13 bar(a) steam in line with the existing MP steam network of mill.

- It is possible to disconnect LP section of the turbine from the generator with a clutch if required to maximise steam supply to the CCS plant.

Pressure Reduction and De-superheating of MP or LP Steam

MP Steam (at 13 bar(a)/200^oC) or LP Steam (at 4.2 bar(a)/154^oC) extracted from the steam turbine would require pressure reduction and desuperheating to produce the ULP steam (at 2 bar(a) / 120^oC) required by the CCS plant.

The most effective way to turndown the MP or LP steam to ULP steam is by using desuperheaters. The process flow diagram for pressure reduction and desuperheating station is shown in Figure A3-2. More details and guide to the design of de-superheaters are presented in several OEM literature sources [2, 3].

De-superheaters reduce the temperature of any superheated steam by introducing finely atomized cooling water droplets into the steam flow. As the droplets evaporate, sensible heat from the superheated steam is converted into latent heat of vaporization. This effectively controls the turndown of the superheated steam closer to its saturation temperature (this could typically be controlled to between 3 to 8^oC above saturation). Consequently, the introduction of cooling water also increases the mass flow rate of the steam (after desuperheating).

Typically, cooling water used in de-superheating of steam includes:

- Boiler feed water (BFW)
- Condensate
- Demineralised water
- De-ionised water

The pressure reduction of the steam is also undertaken in the de-superheater station. Typical de-superheating devices are shown in Figure A3-2. A spray type de-superheater could typically achieve a maximum turndown of 5:1; for a venturi type de-superheater, a turndown of 10:1 is achievable; and for a steam atomising de-superheater a turndown of 50:1 is attainable.

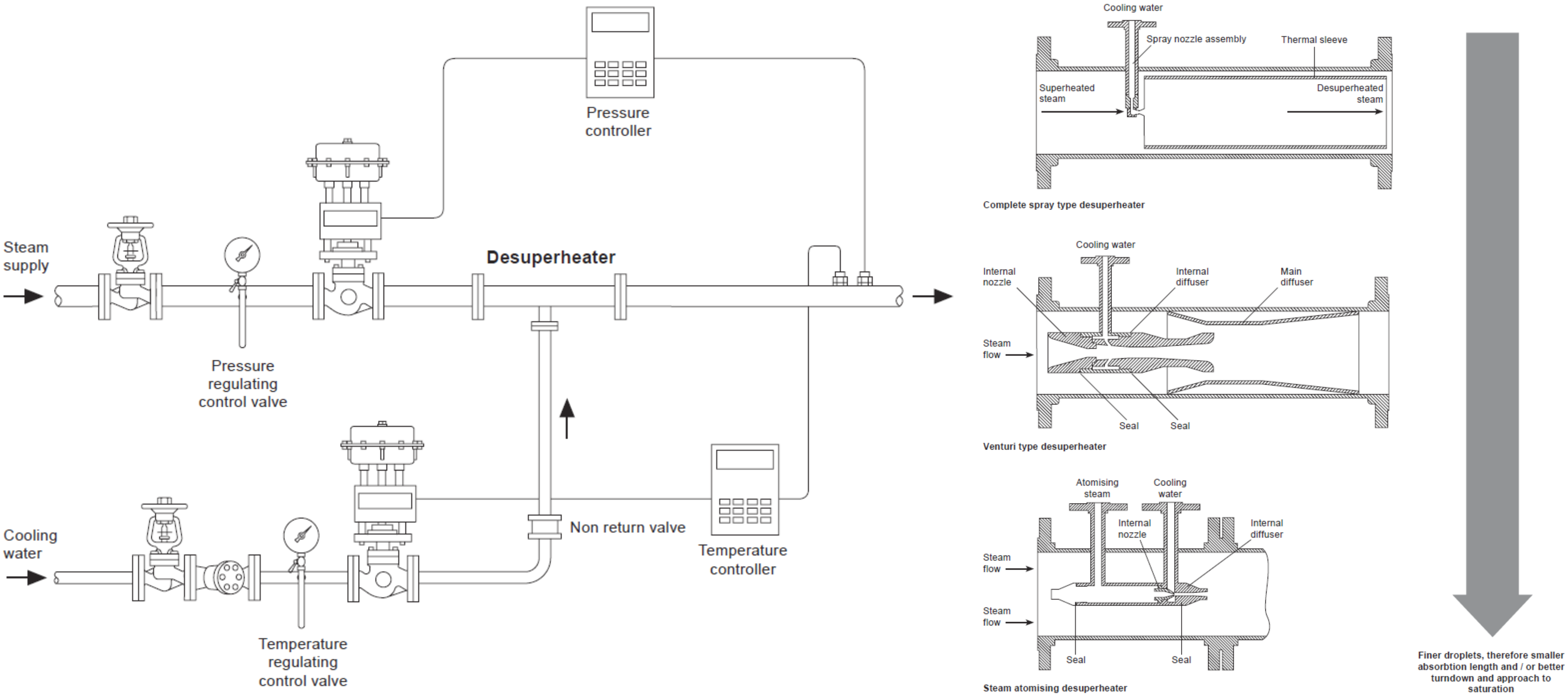


Figure A3-2: Process flow diagram of steam desuperheater (for combine pressure reduction and desuperheating station) – pictures and information courteasy of Sprirax Sarco [2]

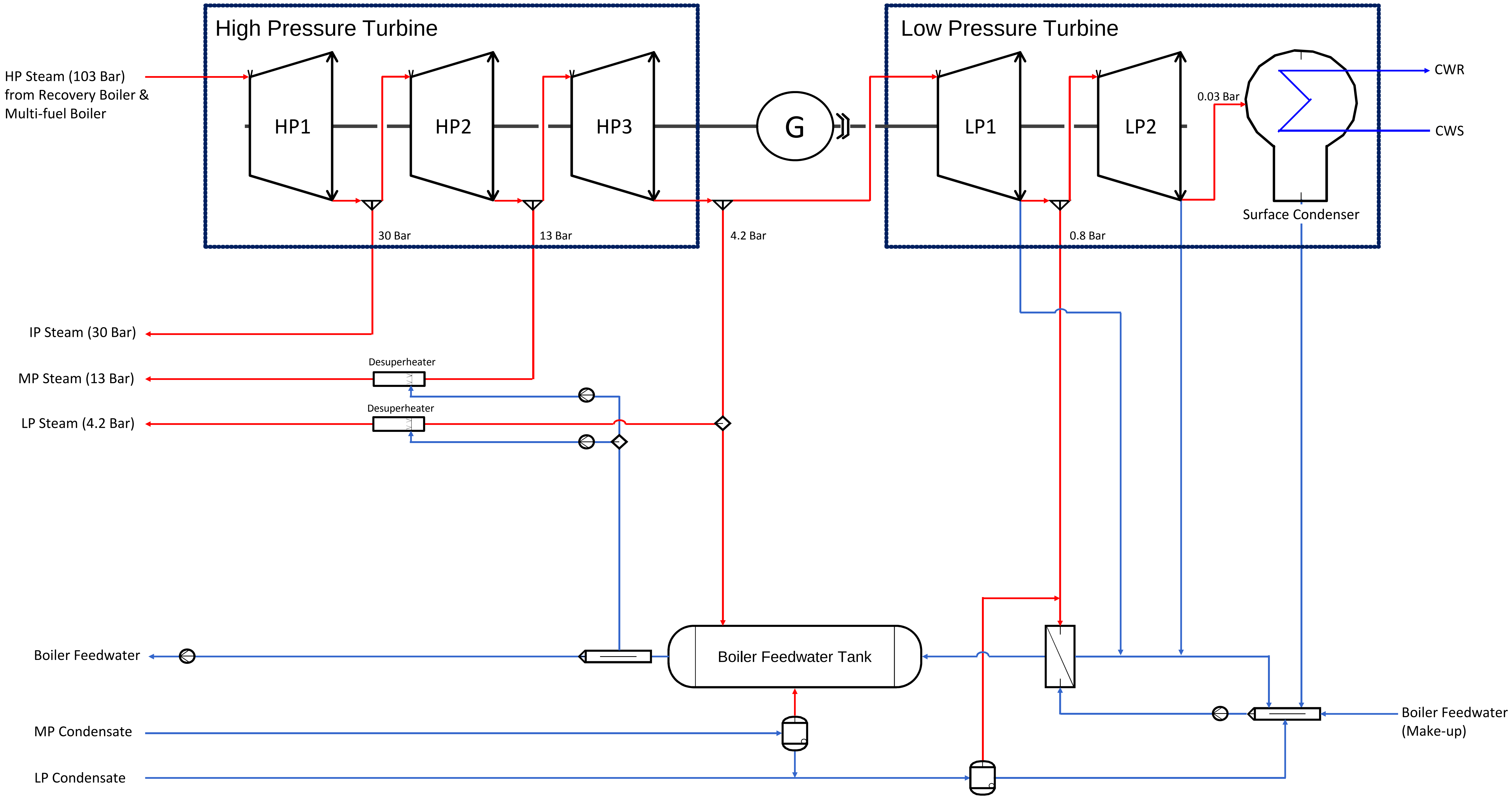
2. SUPPLY OF ULP STEAM TO THE CCS PLANT – OPTIONS CONSIDERED

The different options considered for the steam turbine island is presented and described in section 5.2.2 of this report.

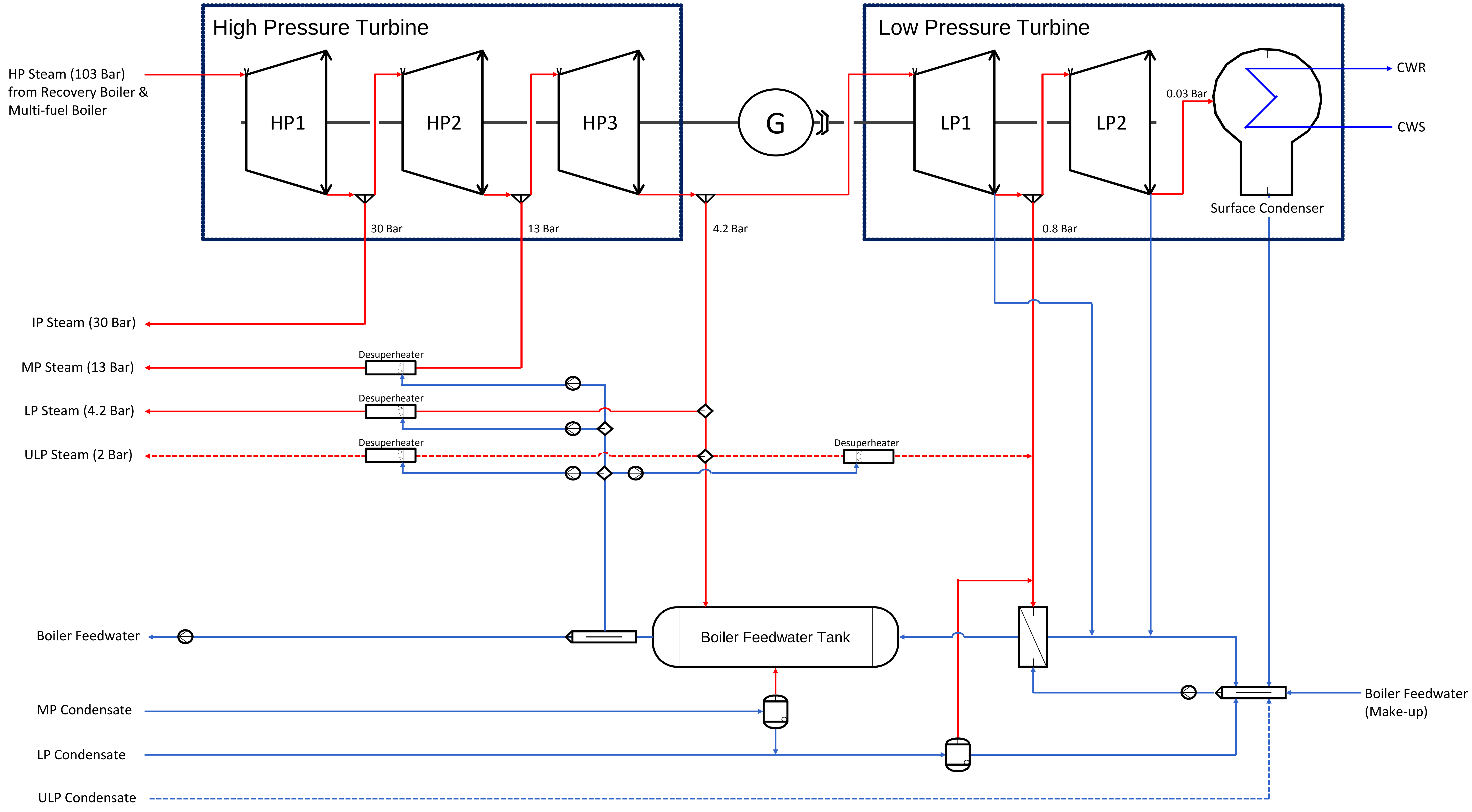
The following simplified block flow diagrams of the steam turbine island present the different configurations evaluated for the mill without and with CCS cases:

- Sheet 1: Base Cases 1A and 1B
- Sheet 2: Cases 2A-1 to 2A-3, 2A-5 and 2B-2 to 2B-3
- Sheet 3: Case 2A-4
- Sheet 4: Cases 2A-6, 2B-1 and 2B-4 to 2B-6
- Sheet 5: Case 2A-6^{MP}
- Sheet 6: Cases 2B-1^{MP}, 2B-4^{MP} to 2-B6^{MP}
- Sheet 7: Cases 2B-1^{CO2MP}, 2B-4^{CO2MP} to 2B-6^{CO2MP}

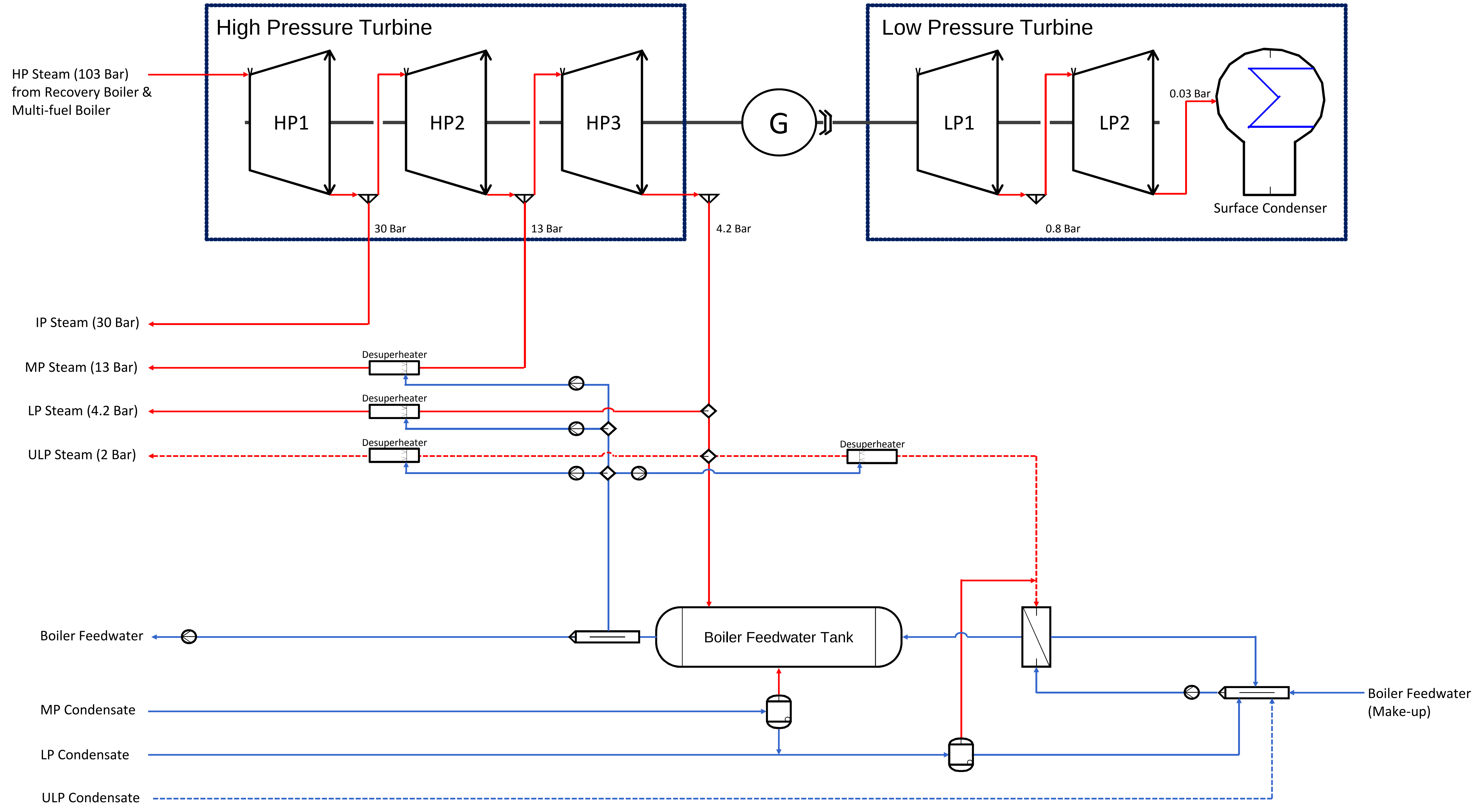
CUSTOMER REPORT: VTT-CR-01312-15	Schematic Block Flow Diagram	REVISION	DATE	BY	CHKD	APP.	SHEET
	Steam Turbine Island (Base Case 1A & Base Case 1B)	1.0	Sep-16	SS	PK	PK	1 of 7



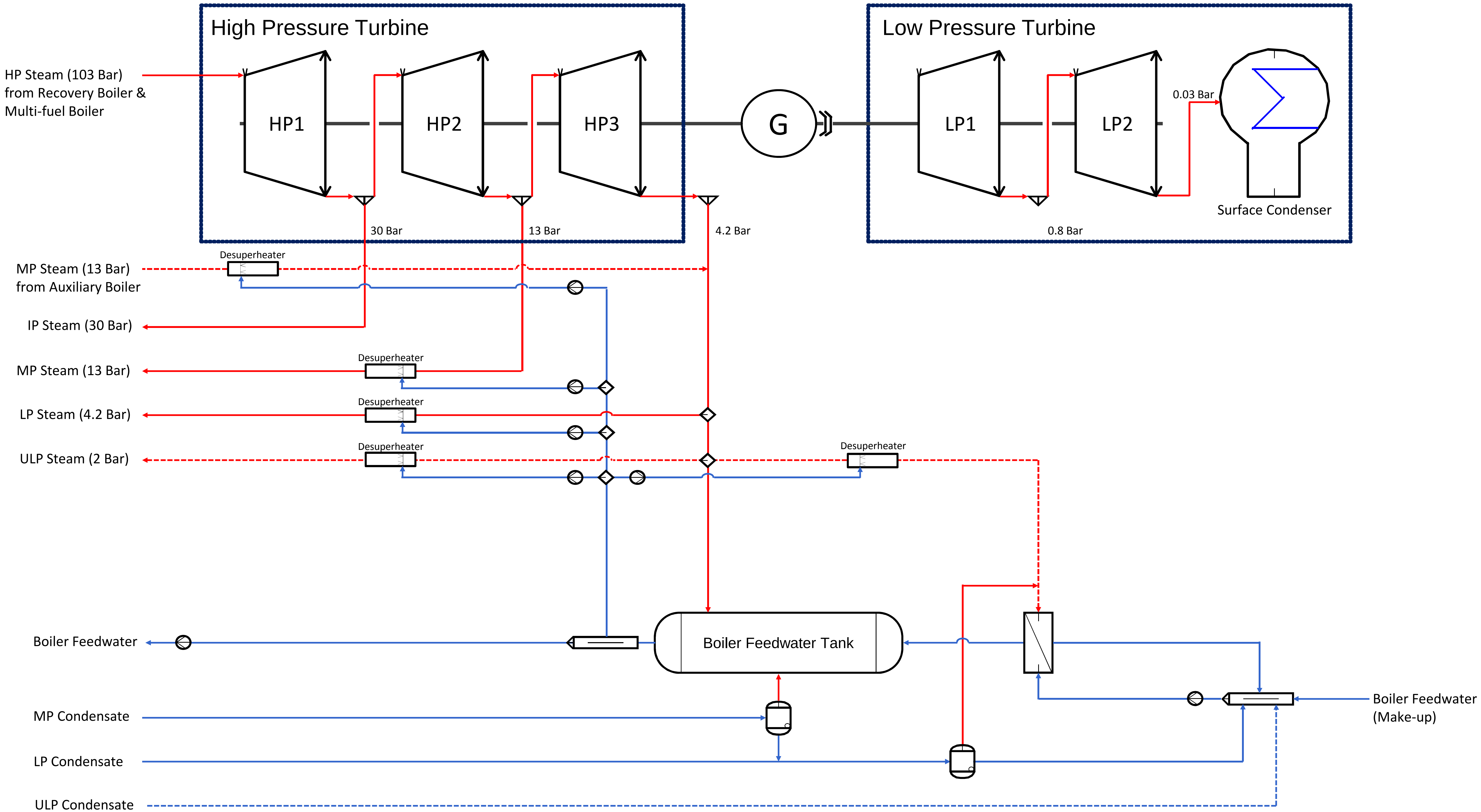
CUSTOMER REPORT: VTT-CR-01312-15	Schematic Block Flow Diagram	REVISION	DATE	BY	CHKD	APP.	SHEET
	Steam Turbine Island (Cases 2A-1 to 2A-3, 2A-5, & 2B-2 to 2B-3)	1.0	Sep-16	SS	PK	PK	2 of 7



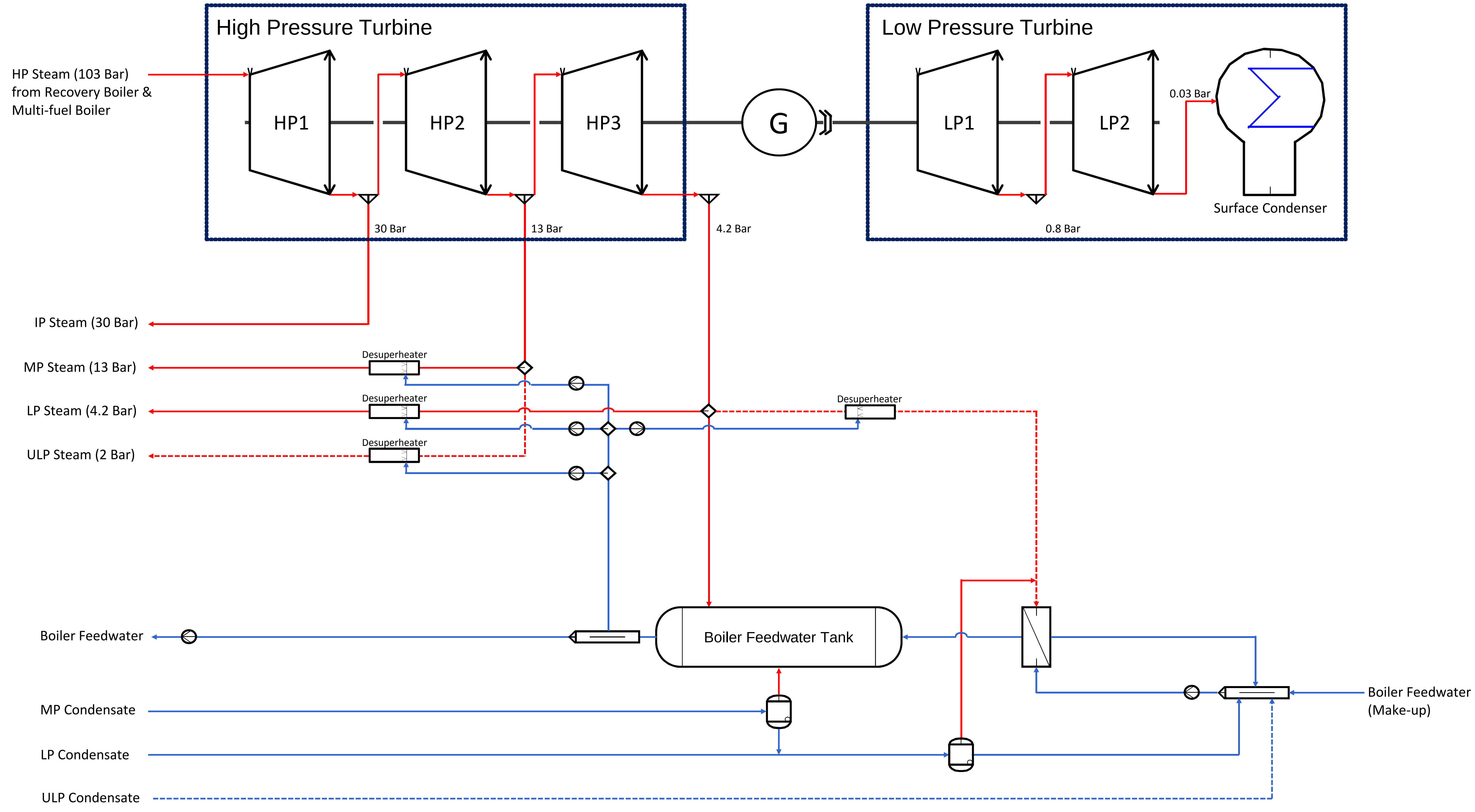
	Schematic Block Flow Diagram	REVISION	DATE	BY	CHKD	APP.	SHEET
CUSTOMER REPORT: VTT-CR-01312-15	**Steam Turbine Island** (Case 2A-4)	1.0	Sep-16	SS	PK	PK	3 of 7



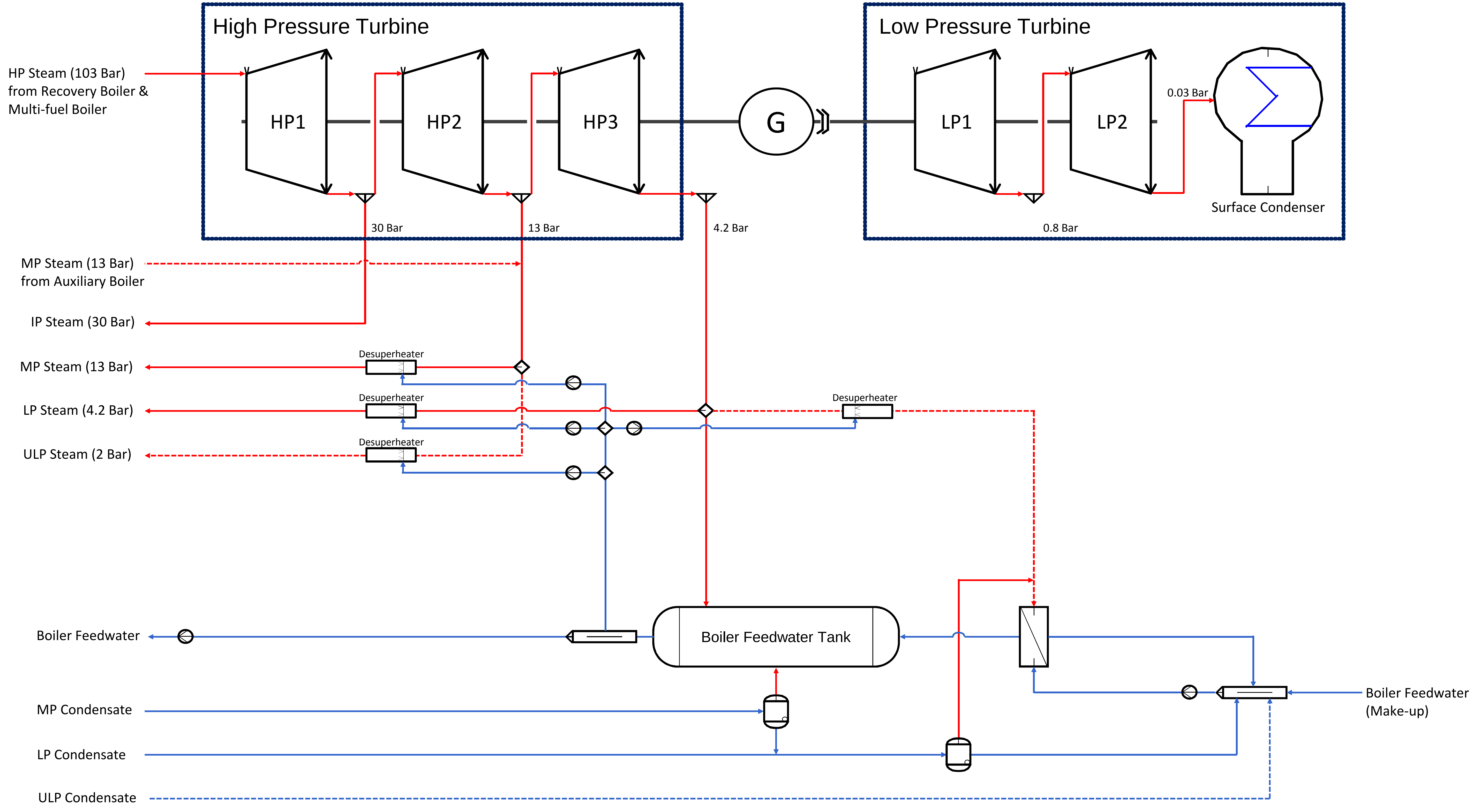
CUSTOMER REPORT: VTT-CR-01312-15	Schematic Block Flow Diagram	REVISION	DATE	BY	CHKD	APP.	SHEET
	Steam Turbine Island (Cases 2A-6, 2B-1 & 2B-4 to 2B-6)	1.0	Sep-16	SS	PK	PK	4 of 7



	Schematic Block Flow Diagram	REVISION	DATE	BY	CHKD	APP.	SHEET
	Steam Turbine Island (Case 2A-6[MP])	1.0	Sep-16	SS	PK	PK	5 of 7
CUSTOMER REPORT: VTT-CR-01312-15							



CUSTOMER REPORT: VTT-CR-01312-15	Schematic Block Flow Diagram **Steam Turbine Island** (Cases 2B-1^MP & 2B-4^MP to 2B-6^MP)	REVISION	DATE	BY	CHKD	APP.	SHEET
		1.0	Sep-16	SS	PK	PK	6 of 7



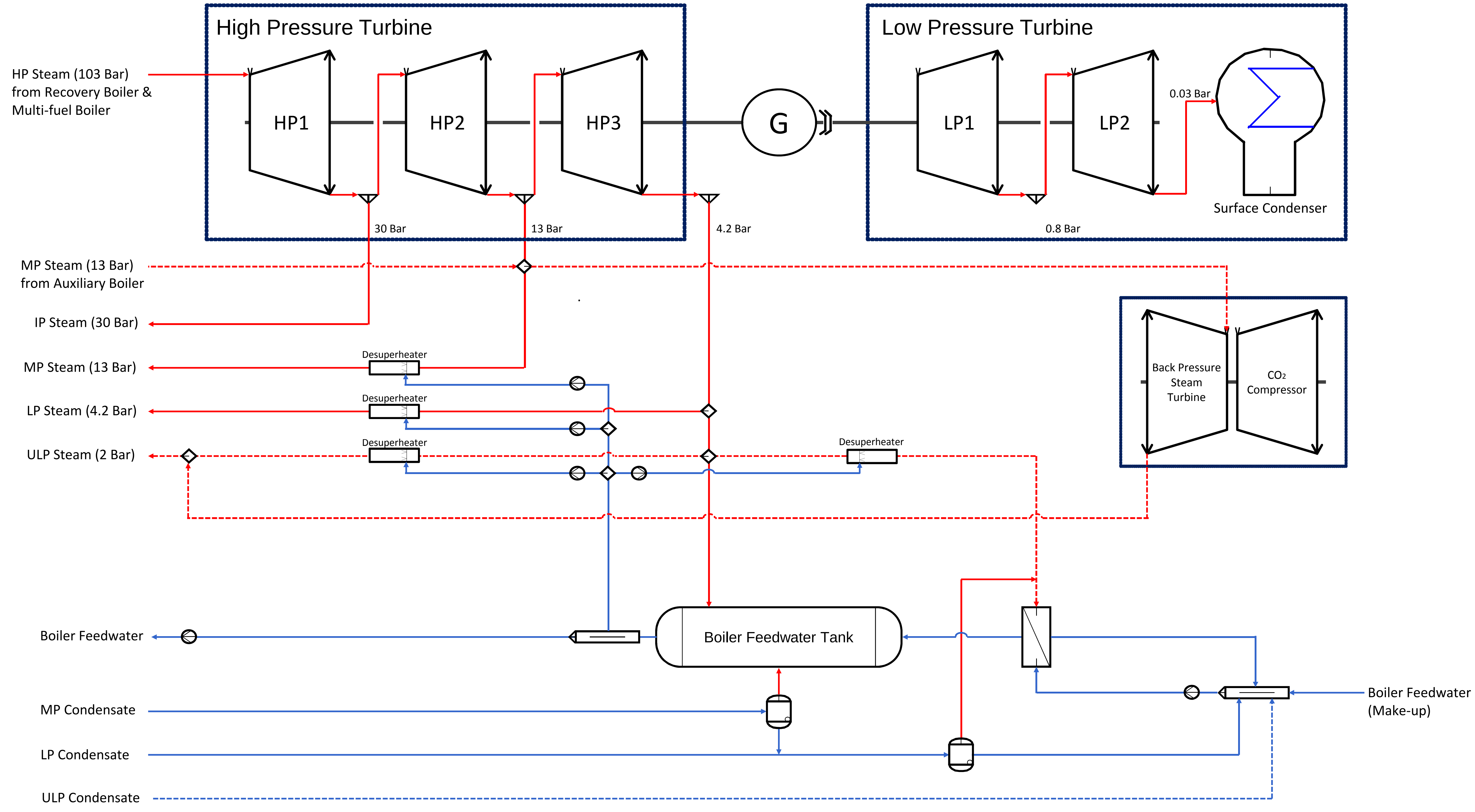
CUSTOMER REPORT: VTT-CR-01312-15

Schematic Block Flow Diagram

Steam Turbine Island

(2B-1^{CO2MP} & 2B-4^{CO2MP} to 2B-6^{CO2MP})

REVISION	DATE	BY	CHKD	APP.	SHEET
1.0	Sep-16	SS	PK	PK	7 of 7



3. SUMMARY OF RESULTS

This section of the Annex summarised the steam and electricity balance of the mill without and with CCS. Three different configurations on how to supply the additional steam to the CCS plant have been evaluated. These results are presented in Tables A3-1 to A3-4.

Table A3-1 - Steam and electricity balance of the pulp mill (Base Case 1A) and six different CO_2 capture retrofit cases with steam turbine modification based on Configuration I (Extraction of 4.2 bar(a) steam to supply the 2 bar(a) steam required by the CO_2 capture plant)

	Base Case 1A	Pulp Mill w/CCS 2A-1	2A-2	2-A3	2A-4	2A-5	2A-6
Steam Demand							
Pulp Mill							
Steam 30 bar [t/h]	20.4	20.4	20.4	20.4	20.4	20.4	20.4
Steam 13 bar [t/h]	171.0	171.0	171.0	171.0	171.0	171.0	171.0
Steam 4.2 bar [t/h]	255.2	255.2	255.2	255.2	255.2	255.2	255.2
CCS Plant							
Steam 13 bar [t/h]	-	-	-	-	-	-	-
Steam 4.2 bar [t/h]	-	0.9	0.1	0.1	1.1	1.0	1.3
Steam 2.0 bar [t/h]	-	256.0	45.4	30.0	290.6	285.1	336.4
Auxiliary Boiler							
Steam 30 bar [t/h]	-	-	-	-	-	-	0.8
Steam 4.2 bar [t/h]	-	-	-	-	-	-	1.6
Steam Supply							
Ex: Steam Turbine							
Steam 30 bar [t/h]	20.4	20.4	20.4	20.4	20.4	20.4	21.2
Steam 13 bar [t/h]	171.0	171.0	171.0	171.0	171.0	171.0	171.0
Steam 4.2 bar [t/h]	255.2	256.2	255.4	255.3	256.4	256.3	258.1
Steam 2 bar [t/h]	-	256.0	45.4	30.0	290.6	285.1	336.4
Ex: Auxiliary Boiler							
Steam 13 bar [t/h]	-	-	-	-	-	-	38.0
Electricity Demand							
Pulp Mill	61.0	61.0	61.0	61.0	61.0	61.0	61.0
CCS Plant	-	23.5	4.4	2.8	28.5	26.9	31.4
Auxiliary Boiler	-	-	-	-	-	-	0.9
Total [MWe]	61.0	84.5	65.4	63.8	89.5	87.9	93.3
Electricity Supply							
Ex: Steam Turbine							
HP Section [MWe]	130.4	130.4	130.4	130.4	130.4	130.4	130.4
LP Section [MWe]	37.9	7.7	33.0	34.7	-	4.3	-
Total [MW$_e$]	168.3	138.1	163.4	165.1	130.4	134.7	130.4
Electricity Export to the Grid	107.3	53.6	98.0	101.3	40.9	46.8	37.1

Table A3-2 - Steam and electricity balance of the integrated pulp and board mill (Base Case 1B) and six different CO_2 capture retrofit cases with steam turbine modification based on Configuration I (Extraction of 4.2 bar(a) steam to supply the 2 bar(a) steam required by the CO_2 capture plant)

	Base Case	Integrated Pulp & Board Mill w/CCS					
	1B	2B-1	2B-2	2B-3	2B-4	2B-5	2B-6
Steam Demand							
Pulp & Board Mill							
Steam 30 bar [t/h]	20.4	20.4	20.4	20.4	20.4	20.4	20.4
Steam 13 bar [t/h]	167.3	167.3	167.3	167.3	167.3	167.3	167.3
Steam 4.2 bar [t/h]	351.8	351.8	351.8	351.8	351.8	351.8	351.8
CCS plant							
Steam 13 bar [t/h]	-	-	-	-	-	-	-
Steam 4.2 bar [t/h]	-	0.9	0.1	0.1	1.1	1.0	1.3
Steam 2.0 bar [t/h]	-	255.7	45.3	31.1	289.3	284.2	335.4
Auxiliary boiler							
Steam 30 bar [t/h]	-	1.1	-	-	1.8	1.7	2.7
Steam 4.2 bar [t/h]	-	2.2	-	-	3.5	3.3	5.3
Steam Supply							
Ex: Steam Turbine							
Steam 30 bar [t/h]	20.4	21.5	20.4	20.4	22.1	22.0	23.1
Steam 13 bar [t/h]	167.3	167.3	167.3	167.3	167.3	167.3	167.3
Steam 4.2 bar [t/h]	351.8	354.9	351.9	351.9	356.4	356.1	358.5
Steam 2 bar [t/h]	-	255.7	45.3	31.1	289.3	284.2	335.4
Ex: Auxiliary Boiler							
Steam 13 bar [t/h]	-	53.2	-	-	85.2	80.3	129.1
Electricity Demand							
Pulp Mill	94.3	94.3	94.3	94.3	94.3	94.3	94.3
CCS Plant	-	23.5	4.4	2.8	28.5	26.9	31.4
Auxiliary Boiler	-	1.3	-	-	2.1	1.9	3.1
Total [MWe]	94.3	119.1	98.7	97.1	124.8	123.1	128.8
Electricity Supply							
Ex: Steam Turbine							
HP Section [MWe]	130.6	130.6	130.6	130.6	130.6	130.6	130.6
LP Section [MWe]	27.1	-	21.8	23.5	-	-	-
Total [MW_e]	157.7	130.6	152.4	154.1	130.6	130.6	130.6
Electricity Export to the Grid	63.4	11.5	53.7	57.0	5.8	7.5	1.8

Table A3-3 - Steam and electricity balance of the pulp (and board) mill and five different CO_2 capture retrofit cases with steam turbine modification based on Configuration II (Extraction of 13 bar(a) steam to supply the 2 bar(a) steam required by the CO_2 capture plant)

	Base Case 1A	Mill w/CCS 2A-6MP	Base Case 1B	Integrated Pulp & Board Mill w/CCS 2B-1MP	2B-4MP	2B-5MP	2B-6MP
Steam Demand							
Pulp & Board Mill							
Steam 30 bar [t/h]	20.4	20.4	20.4	20.4	20.4	20.4	20.4
Steam 13 bar [t/h]	171.0	171.0	167.3	167.3	167.3	167.3	167.3
Steam 4.2 bar [t/h]	255.2	255.2	351.8	351.8	351.8	351.8	351.8
CCS plant							
Steam 13 bar [t/h]	-	-	-	-	-	-	-
Steam 4.2 bar [t/h]	-	1.3	-	0.9	1.1	1.0	1.3
Steam 2.0 bar [t/h]	-	336.4	-	255.7	289.3	284.2	335.4
Auxiliary boiler							
Steam 30 bar [t/h]	-	-	-	0.8	1.5	1.4	2.4
Steam 4.2 bar [t/h]	-	-	-	1.7	3.0	2.8	4.8
Steam Supply							
Ex: Steam Turbine							
Steam 30 bar [t/h]	20.4	20.4	20.4	21.2	21.9	21.8	22.8
Steam 13 bar [t/h]	171.0	171.0	167.3	167.3	167.3	167.3	167.3
Steam 4.2 bar [t/h]	255.2	256.5	351.8	354.4	355.9	355.6	357.9
Steam 2 bar [t/h]	-	336.4	-	255.7	289.3	284.2	335.4
Ex: Auxiliary Boiler							
Steam 13 bar [t/h]	-	-	-	40.5	72.5	67.8	116.9
Electricity Demand							
Pulp Mill	61.0	61.0	94.3	94.3	94.3	94.3	94.3
CCS Plant	-	31.4	-	23.5	28.5	26.9	31.4
Auxiliary Boiler	-	-	-	1.0	1.8	1.6	2.8
Total [MWe]	61.0	92.4	94.3	118.8	124.5	122.8	128.5
Electricity Supply							
Ex: Steam Turbine							
HP Section [MWe]	130.4	113.7	130.6	120.2	120.2	120.2	120.2
LP Section [MWe]	37.9	-	27.1	-	-	-	-
Total [MW_e]	168.3	113.7	157.7	120.2	120.2	120.2	120.2
Electricity Export to the Grid	107.3	21.3	63.4	1.4	-4.3	-2.6	-8.3

Table A3-4 - Steam and electricity balance of the integrated pulp and board mill and four different CO_2 capture retrofit cases with steam turbine modifications based on Configuration III (Extraction of 13 bar(a) steam and to be supplemented by the auxiliary boiler to supply the steam required for the back pressure steam turbine driver of the CO_2 compressor. ULP steam is produced from the back pressure steam turbine and this is to be supplemented by de-superheating any available 4.2 bar(a) steam from the mill).

	Base Case	Integrated Pulp & Board Mill w/CCS			
	1B	2B-1^{CO2MP}	2B-4^{CO2MP}	2B-5^{CO2MP}	2B-6^{CO2MP}
Steam Demand					
Pulp & Board Mill					
Steam 30 bar [t/h]	20.4	20.4	20.4	20.4	20.4
Steam 13 bar [t/h]	167.3	167.3	167.3	167.3	167.3
Steam 4.2 bar [t/h]	351.8	351.8	351.8	351.8	351.8
CCS plant					
Steam 13 bar [t/h]	-	184.1	218.6	207.8	241.2
Steam 4.2 bar [t/h]	-	0.9	1.1	1.0	1.3
Steam 2.0 bar [t/h]	-	255.7	289.3	284.2	335.4
Auxiliary boiler					
Steam 30 bar [t/h]	-	1.3	2.1	2.0	3.1
Steam 4.2 bar [t/h]	-	2.7	4.2	4.0	6.3
Steam Supply					
Ex: Steam Turbine					
Steam 30 bar [t/h]	20.4	21.7	22.5	22.4	23.5
Steam 13 bar [t/h]	167.3	286.4	284.9	279.6	256.5
Steam 4.2 bar [t/h]	351.8	355.4	357.1	356.8	359.4
Steam 2 bar [t/h]	-	66.3	65.3	71.0	87.8
Ex: Auxiliary Boiler					
Steam 13 bar [t/h]	-	65.0	101.0	95.5	152.0
Ex: Back Pressure Steam Turbine					
Steam 2 bar [t/h]	-	189.5	223.9	213.2	247.6
Electricity Demand					
Pulp Mill	94.3	94.3	94.3	94.3	94.3
CCS Plant	-	7.8	9.9	9.2	10.9
Auxiliary Boiler	-	1.6	2.4	2.3	3.7
Total [MWe]	94.3	103.6	106.6	105.8	108.9
Electricity Supply					
Ex: Steam Turbine					
HP Section [MWe]	130.6	124.2	124.5	124.5	127.3
LP Section [MWe]	27.1	-	-	-	-
Total [MW_e]	157.7	124.2	124.5	124.5	127.3
Electricity Export to the Grid	63.4	20.6	17.9	18.7	18.4

4. REFERENCES

[1] Kangas, P.; Kaijaluoto, S. and Santos, S. (2016). **CCS in P&P industry – Reference Plants: Performance.** *Project Report VTT-CR-01301-15. 22.* (included in IEAGHG Report No. 2016-10).

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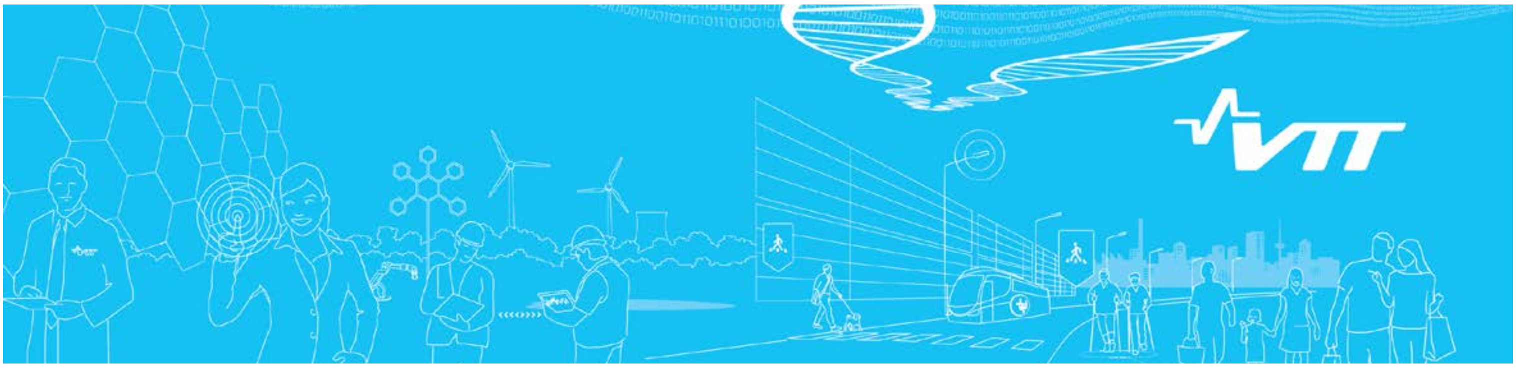
[3] Fisher (2002). **Product Bulletin: Design DMA, DMA/AF, DSA, DVG/AF, and DVI Desuperheaters.** *Document No.: 85.2:DMA*



CUSTOMER REPORT

VTT-CR-01712-16 | 25.2.2017

CCS in P&P Industry – Mills with CCS: Economic Evaluation

Authors: Kristin Onarheim[1], Stanley Santos[2]

Confidentiality: Final version v0.8

[1] VTT Technical Research Centre of Finland
[2] IEAGHG

Report's title

CCS in P&P industry – Mills with CCS: Economic Evaluation

Customer, contact person, address	**Order reference**
IEA Greenhouse Gas R&D Programme & ÅF Consult Oy	
Project name	**Project number/Short name**
CCSP&P	**102035**

Summary

The results of the economic evaluations of typical Finnish pulp and board mills integrated with post-combustion CO_2 capture are presented in this report: The evaluation include cases for (i.) market pulp mill producing 800,000 adt of bleached softwood Kraft pulp (BSKP) annually, and (ii) an integrated pulp and board mill producing 740,000 adt of bleached softwood Kraft pulp and 400 000 adt of 3-ply folding box board annually.

This study assumed that the reference mills were commissioned in 2005 and the CO_2 capture and storage facilities are retrofitted to the pulp (and board) mill in 2015.

Capital costs for the CO_2 capture plant and associated costs to modify the mill were estimated based on the cost database developed by VTT. The annual operating costs were assessed based on the heat and mass balance of the mills without and with CCS.

Discounted cash flow analysis based on 25 years economic life is used to evaluate the levelised cost of pulp production (LCOP) or breakeven prices for pulp on EBITDA basis.

The LCOP of the air dried tonne (adt) of BSKP for base cases 1A and 1B is 523 €. Correspondingly, the LCOB for base case 1B (evaluated using the LCOP estimated for base case 1A) is 679 €/adt.

The retrofit of the CCS facilities to the market pulp mill (base case 1A) on year 10 increases the LCOP of the pulp produced. The results present a price range from 543 to 677 €/adt depending on the overall capture rate. These correspond to a CO_2 avoided cost ranging from 62 to 91 €/t.

On the other hand, the retrofit of the CCS facilities to the integrated pulp and board mill (base case 1B) on year 10 increases the LCOP of the pulp produced with a price range from 545 to 714 €/adt. These were evaluated by maintaining the board price constant at 679 €/adt. These results correspond to a CO_2 avoided cost ranging from 82 to 92 €/t.

This study also evaluated the potential impact of the CO_2 emission tax. Six different scenarios were assessed. It could be concluded that the recognition of the biogenic CO_2 (and how these are accounted for) and the renewable electricity credit awarded to the mill as additional incentives are some of the important factors that could impact the levelised cost of the pulp and board production. It could also be concluded that providing the negative CO_2 emissions credit is essential to incentivise the deployment of bio-CCS or BECCS.

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1. Background

This report presents the economic evaluation assessing the costs of retrofitting the CO_2 capture facilities into two reference mills:

(i) Kraft pulp mill producing 800,000 adt of bleached softwood Kraft pulp annually (Base Case 1A).

(ii) Integrated pulp and board mill producing 740,000 adt of bleached softwood Kraft pulp and 400 000 adt of 3-ply folding box board annually (Base Case 1B).

The economic evaluation for the reference cases (Base Case 1A and Base Case 1B) are presented in the report by Kangas et al. [1]. This serves as the starting point in the evaluation of the economics of retrofitting the CO_2 capture plant to the pulp mill or integrated pulp and board mill.

For each of the base cases, six different capture cases were evaluated:

(i) Cases 2A-1 & 2B-1: Capture of CO_2 from flue gas of the recovery boiler (REC) only

(ii) Cases 2A-2 & 2B-2: Capture of CO_2 from flue gas of the multi-fuel boiler (MFB) only

(iii) Cases 2A-3 & 2B-3: Capture of CO_2 from flue gas of the lime kiln (LK) only

(iv) Cases 2A-4 & 2B-4: Capture of CO_2 from flue gases of both REC and MFB

(v) Cases 2A-5 & 2B-5: Capture of CO_2 from flue gases of both REC and LK

(vi) Cases 2A-6 & 2B-6: Capture of CO_2 from flue gases of all the three sources.

The basis for the economic evaluation of the different CCS cases is assessed using the estimates made to the total investment required to modify the mill and to retrofit the CO_2 capture facilities; and the overall mass and energy balances as described in the previous report - '*CCS in P&P industry – CCS Plants: Performance*' [2].

Additionally, different scenarios were assessed to determine the impact of the cost of CO_2 emissions to the breakeven price of the pulp.

The cost of CO_2 emissions is represented in the form of CO_2 emissions tax considering scenarios where biogenic CO_2 emissions are recognised as neutral or not. If the biogenic CO_2 is captured, should this be given any credit for the negative emissions is also considered. Furthermore, the impact to the renewable electricity produced by the mill and the credit that it can receive is also examined.

Sensitivity analyses to the cost of CO_2 emission, credit given to the negative CO_2 emissions and incentives to the renewable electricity should demonstrate the dynamics on how the different policy frameworks defining the incentives for CCS, renewable energy, and negative emissions could impact the breakeven price of the market pulp.

2. Financial assumptions

The cost estimates were derived in general accordance to the practice of IEAGHG in estimating costs of the plant without and with CO_2 capture. Where applicable, the criteria for the economic evaluation used in this study is based on the information retrieved from IEAGHG document "Criteria for Technical and Economic Assessment of Plants with Low CO_2 Emissions" Version C-6, March 2014 [3]. The assumptions are adapted to accommodate the conditions of the plant location.

The results of the economic evaluation are reported based on Earnings Before Interest, Taxes, Depreciation and Amortisation (EBITDA). The calculation of the costs of production include the investment costs of the mill and the CO_2 capture plant, the fixed operating costs (labour, maintenance and others), variable operating costs (raw-materials, chemicals, utilities, waste and logistics) and revenues (pulp, crude tall-oil and electricity). Based on the Discounted Cash Flow (DCF) analysis, the breakeven price or levelised cost of the market pulp are estimated by setting the net present value (NPV) = 0.

This section summarises the different assumptions used in the techno-economic evaluation of retrofitting CO_2 capture facilities to the reference mills.

2.1. Plant location

The reference pulp mills are located at the north-western coast of Finland. The CO_2 capture plant is located in the close vicinity to the different flue gas sources of the mill (recovery boiler, lime kiln and multi-fuel boiler). No specific construction requirements or constraints on delivery of equipment have been assumed. The site is level with only minimal site preparation required.

2.2. Plant life

Typical plant life of the pulp mill or the integrated pulp and board mill is around 20-30 years before any major re-investment and revamps are required [1]. This study assumes an economic plant life of 25 years for the reference mills.

For all the cases with CCS, it is assumed that the CO_2 capture facilities are commissioned on the 10^{th} year after the mill started its operation. Sensitivity analysis is undertaken to assess the economic impact on the year when CCS is retrofitted to the pulp mill or integrated pulp and board mill.

2.3. Design and construction period

Construction of the CO_2 capture plant is assumed to be completed within 24 months from the issuance of the "Notice to Proceed". The capital expenditures curve during construction is given in Table 1. During the construction of the CO_2 capture facilities, the mill is assumed to operate normally (i.e. without any disruption to the pulp and board production schedule).

Table 1 Capital expenditure during construction period

Year	CAPEX (% of Total Plant Cost)	CO_2 capture capacity	Mill capacity
8	50 %	0 %	100%
9	50 %	0 %	100%
10	0 %	90 %	100%
11-25	0 %	100 %	100%

2.4. Commissioning

The CO_2 capture plant is commissioned in 2015, when the pulp mill is on its 10^{th} year of operation.

During the first year of operation of the CO_2 capture plant, only 90% of the capacity has been assumed to accommodate any possible in-efficiency during start-up (see Table 1).

This study also assumed that the tying-in of the CO_2 capture facilities to the mill operation could be completed during the regular maintenance turn-around period without affecting the mill's normal operation.

2.5. Decommissioning

Decommissioning and remediation of land by the end of plant life are excluded from the analysis. It is assumed that the residual value of the plant and land will cover all decommissioning cost.

2.6. Capital charges

All of the capital required for the construction of the mill and the CO_2 capture facilities are treated as debt, i.e. financial leverage (debt to capital ratio) equal to 100%. The capital is assumed to be available according to the capital expenditure schedule given in Table 1.

2.7. Discount rate

The discounted cash flow analysis (DCF) is applied in the evaluation of the breakeven price of air dried tonne of pulp and board. A discount rate of 8% was assumed.

2.8. Recurring capital expenditure

All major capital expenditure required during the operation of plant is assumed to be included in the annual maintenance cost.

There will be no major recurring capital expenditure will be expected for the mill and the CO_2 capture and compression plant.

2.9. Working capital

In addition to the working capital required by the reference mills - as described in [1], additional working capital needed to cover the inventory of the MEA solvent and additional fuel (for cases where auxiliary boiler is deployed) are included.

2.10. Currency

The cost estimates for CO_2 capture facilities and associated modification to the mill are developed in EUR (Q2-2015). When required, the currency conversion is calculated based on the average rate of the particular year in question. For 2015, the following exchange rate is assumed: 1.0 EUR = 1.1 USD.

2.11. Inflation

Inflation is not considered in the discounted cash flow analysis.

2.12. Depreciation

Depreciation is not included in the analysis. The cash flow analysis was reported based on Earnings Before Interests, Taxes, Depreciation and Amortisation (EBITDA) basis.

2.13. Estimate accuracy

The accuracy of this study is ±35%. This accuracy is within the accepted boundary defined under the classification of AACE Class IV.

3. Investment cost

The total investment costs of retrofitting a CO_2 capture facility to the pulp mill or pulp and board mill are reported as Total Plant Cost (TPC) and Total Capital Requirement (TCR).

3.1. Total plant cost (TPC)

TPC is defined as the total installed cost (TIC) of the plant including the project contingency. For all of the cases, the TPC has been estimated through a combination of utilizing a cost database gathered in-house by VTT and ÅF Consult Oy, and quotes from vendors if required.

The estimated TPC of the mill is based on the equipment costs reported in the year 2005 (Q4); and the investment costs of the CO_2 capture plant is estimated based on the equipment costs reported in the year 2015 (Q2).

The estimated TPC for the reference mill is reported by Kangas et al. [1]. This is summarised in Table 2. The costs reported for 2005 are estimated based on the reference cost quoted by the OEMs on a plant turnkey basis, and using the ratio of the reference plant capacity and current capacity to determine the TIC. A scaling factor of 0.6 is used for all cases. The TIC reported for 2015 (Q2) is adjusted from the TIC of 2005 (Q4) using the Chemical Engineering Plant Cost Index (CEPCI). A project contingency of 10% of the TIC to cover any possibility of cost overruns is added to provide the TPC of the reference mills.

The estimated TPC for the CO_2 capture facilities reported in this study accounts for the (a.) direct materials cost, (b.) construction cost, (c.) EPC and other cost, and (d.) project contingency.

The direct material costs include costs of all major plant equipment and bulk materials. These are estimated based on the cost database developed by VTT and using the capacity ratio to scale up or down (as applicable). A scaling factor of 0.7 is assumed for all cases for the CO_2 capture facility.

The construction costs include any mechanical, civil, electrical and instrumentation work needed in the erection and assembly of the plant and equipment. Also included in the construction costs are the direct labour and bulk materials costs relevant to any civil works, steel works, site preparation, and buildings. These costs are estimated based on the percentage of the direct material costs.

Other costs include costs for the engineering and construction management services, commissioning, personnel and operators training, other soft costs required by the contractors (i.e. contractor's overhead, bond, insurance, legal fee, etc…) and other costs (i.e. heavy lifts, cleaning, erection of temporary facilities, and miscellaneous expenses). These costs are estimated based on the percentage of the sum of the direct materials and construction costs.

Tables 3 and 4 present the TIC and TPC for the CO_2 capture facilities for all the CCS cases for the pulp mill and the integrated pulp and board mill, respectively. A project contingency of 10% of the TIC is added to provide the TPC of the CO_2 capture facilities.

The TPC related to the modification to the mill (mainly covering the changes to the steam turbine island and wastewater treatment plant) could be very site specific depending on the current condition of the equipment. It is assumed that the original equipment is in good shape and would not require major re-investment or revamp. The TPC is estimated based on incorporating the possible changes to the original equipment commissioned in 2005 and the additional equipment needed to accommodate any changes to the capacity (i.e. flow rates).

Table 2: Total plant cost -reference mills without CCS

Unit No.	Unit Process	Base Case 1A			Base Case 1B		
		Capacity	2005-Q4 (€ million)	2015-Q2 (€ million)	Capacity	2005-Q4 (€ million)	2015-Q2 (€ million)
0000	Mill infrastructure	800,000 adt/y	67	83	1,140,000 adt/y	82	103
1000	Wood handling yard • Wood storage • De-icing • Debarking lines • Chipping lines • Knife grinder • Chip storage with chip piles • Screening lines • Related conveyors	943 m^3/h	53	67	943 m^3/h	53	67
2000	Cooking plant • Chip bin • Impregnation vessel • Continuous digester • Blow line • Re-boiler • Turpentine recovery system	2795 adt/d	107	134	2795 adt/d	107	134
2100	Brown stock handling • Diffuser washer • DD-washer • De-knotting • Screening	included in Unit 2000			included in Unit 2000		
2200	O2 delignification • 2-stage oxygen delignification • Two DD-washers	included in Unit 2000			included in Unit 2000		
3100	Pulp bleaching and washing • D0-Eop-D1-P stages • Four DD-washers	2667 adt/d	49	62	2535 adt/d	48	60
3200	Pulp drying • Screening and cleaning • Dilution head box • Twin-wire former • Combi-press with shoe-press • Airborne dryer • Cutting • Baling	2824 adt/d	112	140	2612 adt/d	107	134
4100	Black liquor evaporators • 7-stage evaporation • Malodorous gas collection • tall-oil plant	804 t_{H2O}/h	48	59	804 t_{H2O}/h	48	59
4200	Kraft recovery boiler • Recovery boiler • Electrostatic precipitators (ESP) • Flue gas stack • Boiler feed water plant • Condensate treatment • Ash leaching plant.	4985 tds/d	160	200	4985 tds/d	160	200
5000	Recausticising plant • Green liquor filtering • Dregs washing • Slaker • Re-causticizers • White liquor filtering	11,120 m^3_{WL}/d	49	62	11,120 m^3_{WL}/d	49	62
5100	Lime kiln • Lime dewatering unit • Lime mud dryer • Lime kiln • Lime cooler • ESP • Flue gas stack	included in Unit 5000			included in Unit 5000		
Sub-Total: (**€ million**)			645	807		654	819

Table 2: Total plant cost -reference mills without CCS (cont'd)

Unit No.	Unit Process	Base Case 1A Capacity	Base Case 1A 2005-Q4 (€ million)	Base Case 1A 2015-Q2 (€ million)	Base Case 1B Capacity	Base Case 1B 2005-Q4 (€ million)	Base Case 1B 2015-Q2 (€ million)
6100	Multi-fuel boiler • Circulating fluidized bed boiler • ESP • Flue gas stack	82MW_{th}	56	70	82MW_{th}	56	70
6200	Steam Turbine Island • Extraction / back pressure turbine • Condensing turbine • Generator set	187MW_e (gross)	51	63	175MW_e (gross)	49	61
7100	Bleach chemical plant • Reactor • Heat exchanger • Absorber • Salt cake washer	34 t_{ClO2}/d	14	17	32 t_{ClO2}/d	13	16
7200	White liqour oxidation plant	included in Unit 7100			included in Unit 7100		
7300	Air separation unit • Process air filter • Main air compressor • Process air pre-treatment • Cold box (incl. 2-column cryogenic distillation) • Oxygen compressor	64 t_{O2}/d	8	10	64 t_{O2}/d	8	10
8000	Waste water treatment plant • Fresh water plant • Mechanical and chemical treatment • Activated sludge treatment	49,000 m3/d	25	31	57,000 m3/d	27	34
9000	Board machine • Water and broke system • Screening and cleaning • Dilution head box (3 units) • Formers (3 units) • Press section • Drying section • Coating • Winding • Packaging				400,000 adt/y	136	170
	Total Plant Installed Cost - TIC (**€ million**)		799	998		943	1,180
	Project Contingency (10%)		80	100		94	118
	Total Plant Cost - TPC (**€ million**)		878	1,098		1,037	1,298

Table 3: Total plant cost - CO_2 capture and compression plant (pulp mill with CCS cases)

	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Direct Contact Cooler • DCC (incl. packing, distributor and collector) • Recirculation pump • Heat exchanger • Ductwork	4.10	1.04	0.60	4.56	4.30	4.76
Amine absorber section • Absorber column (incl. packing and column internals) • Water wash column (incl. packing and column internals) • Heat exchangers • Pumps • Flue gas reheater	28.91	7.84	4.59	32.10	30.36	33.49
Amine circulation system • Solvent pumps (lean, semi-lean and rich solvents) • Lean - rich amine cross heat exchangers • Trim coolers • Closed loop cooling system • Lean solvent filtration system	2.73	0.74	0.43	3.04	2.87	3.17
Stripper section • Stripper column (incl. packings and column internals) • Water wash column (incl. packings and column internals) • Condenser and reflux drums • Reboilers • Pumps	63.00	17.08	10.01	69.96	66.15	72.98
Compression and dehydration • Compressor package (incl. liquid CO_2 pump, electric motor driver) • Heat exchangers • Condensers • Dehydration unit	7.66	2.08	1.22	8.50	8.04	8.87
Auxiliaries • Amine reclaimer • Tanks and vessels (for storage), et. al.	0.95	0.26	0.15	1.06	1.00	1.10
Other direct materials cost • Piping (Interconnecting) • Steel structures • Control and instrumentation • Electrical (bulk) • Firefighting system • Bulk chemicals, process water, etc… (first fill)	20.82	5.64	3.31	23.12	21.86	24.11
Sub-total - Direct Materials Costs (€ million)	128.18	34.69	20.31	142.33	134.58	148.47
Construction • Civil works • Buildings • Equipment installation • Steel structure installation • Piping installation • Firefighting system installation • Electrical and instruments installation • Scaffolding • Insulation and painting	76.20	20.62	12.07	84.62	80.01	88.27
EPC and other costs • Engineering services - FEED, detailed design and procurement • Construction management fees • Commissioning and start-up assistance • Equipment vendor assistance • EPC overhead, contingency, bond, insurance, et. al. • Temporary construction facilities • Others (heavy lift, chemicals, cleaning, misc.)	38.02	10.29	6.02	42.21	39.91	44.03
Sub-total - Construction, EPC and Other Costs (€ million)	114.22	30.91	18.09	126.83	119.92	132.30
Total Plant Installed Cost - TIC (€ million)	242.40	65.60	38.40	269.16	254.51	280.78
Project Contingency (10%)	24.24	6.56	3.84	26.92	25.45	28.08
Total Plant Cost - TPC (€ million)	266.64	72.16	42.24	296.08	279.96	308.85

Table 4: Total plant cost - CO_2 capture and compression plant (integrated pulp and board mill with CCS cases)

	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Direct Contact Cooler • DCC (incl. packing, distributor and collector) • Recirculation pump • Heat exchanger • Ductwork	4.10	1.04	0.60	4.56	4.30	4.76
Amine absorber section • Absorber column (incl. packing and column internals) • Water wash column (incl. packing and column internals) • Heat exchangers • Pumps • Flue gas reheater	28.91	7.84	4.59	32.10	30.36	33.49
Amine circulation system • Solvent pumps (lean, semi-lean and rich solvents) • Lean - rich amine cross heat exchangers • Trim coolers • Closed loop cooling system • Lean solvent filtration system	2.73	0.74	0.43	3.04	2.87	3.17
Stripper section • Stripper column (incl. packings and column internals) • Water wash column (incl. packings and column internals) • Condenser and reflux drums • Reboilers • Pumps	63.00	17.08	10.01	69.96	66.15	72.98
Compression and dehydration • Compressor package (incl. liquid CO_2 pump, elec. motor or steam turbine driver) • Heat exchangers • Condensers • Dehydration unit	15.31	2.08	1.22	17.00	16.08	17.73
Auxiliaries • Amine reclaimer • Tanks and vessels (for storage), et. al.	0.95	0.26	0.15	1.06	1.00	1.10
Other direct materials cost • Piping (Interconnecting) • Steel structures • Control and instrumentation • Electrical (bulk) • Firefighting system • Bulk chemicals, process water, etc… (first fill)	20.82	5.64	3.31	23.12	21.86	24.11
Sub-total - Direct Materials Costs (€ million)	135.84	34.69	20.31	150.83	142.62	157.34
Construction • Civil works • Buildings • Equipment installation • Steel structure installation • Piping installation • Firefighting system installation • Electrical and instruments installation • Scaffolding • Insulation and painting	80.75	20.62	12.07	89.67	84.79	93.54
EPC and other costs • Engineering services - FEED, detailed design and procurement • Construction management fees • Commissioning and start-up assistance • Equipment vendor assistance • EPC overhead, contingency, bond, insurance, et. al. • Temporary construction facilities • Others (heavy lift, chemicals, cleaning, misc.)	40.29	10.29	6.02	44.73	42.30	46.66
Sub-total - Construction, EPC and Other Costs (€ million)	121.04	30.91	18.09	134.40	127.09	140.20
Total Plant Installed Cost - TIC (€ million)	256.87	65.60	38.40	285.24	269.71	297.54
Project Contingency (10%)	25.69	6.56	3.84	28.52	26.97	29.75
Total Plant Cost - TPC (€ million)	282.56	72.16	42.24	313.76	296.68	327.30

For the changes to the steam turbine island – as described in the report by Onarheim et al. [2], the estimated TPC covers the additional direct materials, construction, EPC costs and project contingency (based on 10% TIC) needed to modify the steam turbine's extraction line (i.e. steam extraction from 4.2 bar(a) or 13.0 bar(a) lines), and adding the new de-superheating station(s) and associated equipment (i.e. valves, tanks, drums, etc.).

For the changes to the wastewater treatment plant, the estimated TPC covers the costs of adding new settling tanks, valves, pumps, blowers, etc. to cover the handling of the additional volume of wastewater to be treated from the CO_2 capture plant.

New plant equipment and components such as the flue gas booster fans, the additional stack (if necessary) and associated ducting are estimated based on the quoted price from the OEMs. It is assumed that construction, the EPC and other costs for these installations is 45% of the estimated TPC.

The auxiliary boiler is based on a bubbling fluid bed technology. The estimates include costs related to major equipment and bulk materials (covering the fuel handling and storage equipment, boiler house, boiler, ESP and stack), construction cost, and EPC and other miscellaneous costs. This is estimated based on reference price quoted by the OEMs on a plant turnkey basis and using the capacity ratio to scale up or down (as required). A scaling factor of 0.6 is used for all cases.

Tables 5 and 6 summarise the estimated TPC for all the modifications to the mill.

3.2. Total capital requirement (TCR)

TCR is defined as the sum of the following:

- Total plant cost (TPC)
- Spare parts cost
- Start-up cost
- Owner's cost
- Interest during construction
- Working capital

For all the CCS cases, the TCR consists of two set of calculations:

- TCR during the construction, commissioning and start-up of the mill (i.e. year -3 to year 2)
- TCR during the construction, commissioning and start-up of the CO_2 capture facilities and the associated modifications to the mill (i.e. year 8 to year 10).

The TCR during the construction and start-up of the mill (i.e. from year -3 to year 1) includes the following:

- 1% of TPC (reference mill) to cover the spare parts
- Start-up cost which includes:
    - 2% of TPC to cover the start-up CAPEX
    - 2.1% of annual fuel bill to cover additional fuel cost during start-up
    - 25% of annual operating expense (O&M, Fuel and Raw Materials)
    - 8.3% of chemicals cost
- 7% of TPC (reference mill) to cover the owner's cost

Table 5: Total plant cost - modifications to the pulp mill (for all Case 2As)

	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Recovery boiler (Unit 4200) • Flue gas booster fan • Ductwork	0.59	-	-	0.59	0.59	0.59
Lime kiln (Unit 5100) • Flue gas booster fan • Ductwork	-	-	0.18	-	0.18	0.18
Multi-fuel boiler (Unit 5100) • Flue gas booster fan • Ductwork	-	0.28	-	0.28	-	0.28
Steam turbine island (Unit 6200) • Associated modifications to the steam extraction line • Associated modifications to the BFW and condensates system • De-superheating station(s) and associated equipment • Pumps • Others	6.04	6.04	6.04	6.04	6.04	9.06
Auxiliary boiler (Unit 6300) • Fuel handling • Bubbling fluidized bed boiler and associated equipment • BFW and condensate system • gas-gas heater • ESP • Flue gas stack	-	-	-	-	-	-
Waste water treatment (Unit 8000) • Settling tanks, valves, pumps - handling of additional wastewater from CCS plant • Associated modification to the mechanical / chemical treatment plant	3.92	3.49	3.31	4.04	3.97	4.10
Others • Common flue gas stack				1.00	1.00	1.00
Total Plant Installed Cost - TIC (€ million)	10.55	9.81	9.54	11.95	11.78	15.21
Project Contingency (10%)	1.05	0.98	0.95	1.20	1.18	1.52
Total Plant Cost - TPC (€ million)	11.60	10.79	10.49	13.15	12.96	16.73

Table 6: Total plant cost - modifications to the integrated pulp and board mill (for all Case 2Bs)

	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Recovery boiler (Unit 4200) • Flue gas booster fan • Ductwork	0.59	-	-	0.59	0.59	0.59
Lime kiln (Unit 5100) • Flue gas booster fan • Ductwork	-	-	0.18	-	0.18	0.18
Multi-fuel boiler (Unit 5100) • Flue gas booster fan • Ductwork	-	0.28	-	0.28	-	0.28
Steam turbine island (Unit 6200) • Associated modifications to the steam extraction line • Associated modifications to the BFW and condensates system • De-superheating station(s) and associated equipment • Pumps • Others	8.72	5.81	5.81	8.72	8.72	8.72
Auxiliary boiler (Unit 6300) • Fuel handling • Bubbling fluidized bed boiler and associated equipment • BFW and condensate system • gas-gas heater • ESP • Flue gas stack	22.00	-	-	33.00	32.00	38.00
Waste water treatment (Unit 8000) • Settling tanks, valves, pumps - handling of additional wastewater from CCS plant • Associated modification to the mechanical / chemical treatment plant	4.22	3.79	3.61	4.34	4.27	4.40
Others • Common flue gas stack	-	-	-	1.00	1.00	1.00
Total Plant Installed Cost - TIC (€ million)	35.53	9.89	9.61	47.93	46.76	53.17
Project Contingency (10%)	3.55	0.99	0.96	4.79	4.68	5.32
Total Plant Cost - TPC (€ million)	39.08	10.87	10.57	52.73	51.44	58.49

- 8% interest during construction
- Working capital which covers 30 days of feedstock, fuel and other raw materials; and 15 days of finished products.

The TCR during the retrofit of the CO_2 capture facilities includes the following:

- 1% of TPC (CO_2 capture facilities and associated modifications to the mill) to cover the spare parts
- 3 to 3.5% of TPC (CO_2 capture facilities and associated modifications to the mill) to cover the start-up cost
  - 3% of TPC for all cases without the auxiliary boiler
  - 3.5% of TPC for cases with auxiliary boiler added.
- 7% of TPC (CO_2 capture facilities and associated modifications) owner's cost
- 8% interest during construction
- Additional working capital covering the inventories of the MEA and the make-up solvent

Table 7 presents the TCR during the construction and commissioning of the pulp mill and the pulp and board mill. Tables 8 and 9 present the TCR during the retrofit of the CO_2 capture facilities for all CCS cases.

The schedule of capital expenditure for all the cases is summarised in Tables 10 and 11.

3.3. Summary of results

Tables 12 and 13 summarise the CAPEX of the mills without and with CCS.

Table 7: Total Capital Requirement - TCR - during construction and commissioning of the pulp mill (Base Case 1A) or integrated pulp and board mill (Base Case 1B)

	Base Case 1A	Base Case 1B	Remarks	
Total Plant Cost	878.35	1,036.86		See Table 2
Spare Parts	8.78	10.37	1.0%	of TPC
Start-Up Cost				
Strart-up CAPEX	17.57	20.74	2.0%	of TPC
Additional fuel bill	6.93	6.93	2.1%	of annual fuel bill - see note (1)
Start-up O&M	65.50	71.72	25.0%	of fixed O&M, feedstock and fuel bill - see note (2)
Chemicals and others	2.27	2.18	8.3%	of chemicals bill - see note (3)
Owner's Cost	61.48	72.58	7.0%	of TPC - see note (4)
Interest during construction	263.49	309.74	8.0%	charged annually - see note (5)
Working Capital	37.12	61.04		See note (6)
Total Capital Requirement - TCR (€ million)	1,341.50	1,592.17		

Table 8: Total Capital Requirement - TCR - during construction and commissioning of the CO2 capture facilities and associated modifications of the pulp mill (All Case 2A's)

	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP	Remarks	
Total Plant Cost	278.24	82.95	52.73	309.23	292.92	325.58		See Tables 3 & 5
Spare Parts	2.78	0.83	0.53	3.09	2.93	3.26	1.0%	of TPC
Start-Up Cost								
Strart-up CAPEX	8.35	2.49	1.58	9.28	8.79	9.77	3.0%	of TPC
Additional fuel bill	-	-	-	-	-	-		see note (7)
Start-up O&M	-	-	-	-	-	-		see note (7)
Chemicals and others	-	-	-	-	-	-		see note (7)
MEA solvent - first fill	0.64	0.10	0.08	0.76	0.72	0.86	105.0%	MEA volume x unit cost
Owner's Cost	19.48	5.81	3.69	21.65	20.50	22.79	7.0%	of TPC
Interest during construction	41.09	12.24	7.78	45.67	43.26	48.09	8.0%	charged annually - see note (5)
Working Capital	4.86	1.17	0.79	5.55	5.26	6.26		See note (6)
Total Capital Requirement - TCR (€ million)	€ 355.44	€ 105.59	€ 67.18	€ 395.22	€ 374.38	€ 416.61		

Table 9: Total Capital Requirement - TCR - during construction and commissioning of the CO2 capture facilities and associated modifications of the integrated pulp & board mill (All Case 2B's)

	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP	Remarks	
Total Plant Cost	321.64	83.03	52.81	366.49	348.12	385.78		See Tables 4 & 6
Spare Parts	3.22	0.83	0.53	3.66	3.48	3.86	1.0%	of TPC
Start-Up Cost								
Strart-up CAPEX	11.26	2.49	1.58	12.83	12.18	13.50	3% or 3.5% of TPC - see note (8)	
Additional fuel bill	-	-	-	-	-	-		see note (7)
Start-up O&M	-	-	-	-	-	-		see note (7)
Chemicals and others	-	-	-	-	-	-		see note (7)
MEA solvent - first fill	0.64	0.10	0.08	0.76	0.72	0.86	105.0%	MEA volume x unit cost
Owner's Cost	22.52	5.81	3.70	25.65	24.37	27.00	7.0%	of TPC
Interest during construction	47.63	12.25	7.79	54.28	51.55	57.14	8.0%	charged annually - see note (5)
Working Capital	6.08	1.18	0.72	7.34	6.98	8.55		See note (6)
Total Capital Requirement - TCR (€ million)	€ 412.99	€ 105.70	€ 67.21	€ 471.00	€ 447.40	€ 496.69		

Notes:

(1) The calculation for the annual fuel bill is based on amount of HFO used and the equivalent HFO (LHV basis) for the fuel value of the black liquor and barks. This is to cover any inefficiency during the start-up of the plant

(2) The calculation is based on the sum of the fixed O&M cost, roundwood (main feedstock) and HFO (imported fuel)

(3) The calculation is based on the annual consumption of all the chemicals used by the mill

(4) The owner's cost covers the costs of feasibility studies, surveys, land purchase, construction or improvement to roads and railways, water supply etc. beyond the site boundary, owner's engineering staff costs, permitting and legal fees, arranging financing and other misc. costs.

(5) Interests is charged annually based on the CAPEX spent at the end of each year.

(6) This is calculated based on 30 days inventories of raw materials, feedstocks and fuel and 15 days inventories for make-up MEA solvent and finished goods. It is assumed that working capital will be returned to the investor by the end of the plant life.

(7) It is assumed to be included in the annual O&M of the mill.

(8) 3.5% of TPC is used in Cases 2B-1CO2MP, 2B-4CO2MP, 2B-5CO2MP and 2B-6CO2MP. The additional 0.5% of the TPC is to cover the start-up of the auxiliary boiler.

Table 10: Capital expenditure schedule of the market pulp mill without and with CCS (Total TCR over the life cycle of the mill without and with CCS)

Year	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
-3	189.72	189.72	189.72	189.72	189.72	189.72	189.72
-2	395.94	395.94	395.94	395.94	395.94	395.94	395.94
-1	470.57	470.57	470.57	470.57	470.57	470.57	470.57
1	180.97	180.97	180.97	180.97	180.97	180.97	180.97
2	104.30	104.30	104.30	104.30	104.30	104.30	104.30
3 .. 7	-	-	-	-	-	-	-
8	-	150.25	44.79	28.47	166.98	158.18	175.82
9	-	172.30	51.27	32.61	191.53	181.43	201.72
10	-	32.47	9.42	6.03	36.23	34.32	38.53
11	-	0.42	0.11	0.07	0.48	0.46	0.54
12 .. 25	-	-	-	-	-	-	-
Sub-total	1,341.50	1,696.95	1,447.09	1,408.68	1,736.73	1,715.88	1,758.12
26	-37.12	-41.98	-38.30	-37.91	-42.68	-42.39	-43.39
Total Capital Requirement - TCR (€ million)*	€ 1,304.38	€ 1,654.96	€ 1,408.80	€ 1,370.77	€ 1,694.05	€ 1,673.50	€ 1,714.73

* including the return of working capital by the end of plant life

Table 11: Capital expenditure schedule of the integrated pulp and board mill without and with CCS (Total TCR over the life cycle of the mill without and with CCS)

Year	Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
-3	223.96	223.96	223.96	223.96	223.96	223.96	223.96
-2	467.39	467.39	467.39	467.39	467.39	467.39	467.39
-1	548.51	548.51	548.51	548.51	548.51	548.51	548.51
1	229.87	229.87	229.87	229.87	229.87	229.87	229.87
2	122.43	122.43	122.43	122.43	122.43	122.43	122.43
3 .. 7	-	-	-	-	-	-	-
8	-	173.69	44.84	28.52	197.90	187.98	208.32
9	-	200.68	51.32	32.65	228.69	217.22	240.79
10	-	38.07	9.43	6.04	43.75	41.57	46.81
11	-	0.55	0.11	0.07	0.66	0.63	0.77
12 .. 25	-	-	-	-	-	-	-
Sub-total	1,592.17	2,005.16	1,697.87	1,659.45	2,063.17	2,039.57	2,088.86
26	-61.04	-67.12	-62.22	-61.84	-68.38	-68.02	-69.59
Total Capital Requirement - TCR (€ million)*	€ 1,531.13	€ 1,938.03	€ 1,635.64	€ 1,597.61	€ 1,994.79	€ 1,971.55	€ 2,019.27

* including the return of working capital by the end of plant life

Table 12: Summary of results for market pulp mill without and with CCS - Total Plant Costs (TPC) and Total Captial Requirements (TCR)

Cases	Total Installed Cost (TIC) - € million			Project Contingency € million	Total Plant Costs (TPC) € million	Other CAPEX € million	Total Capital Requirements (TCR) € million
	Reference Mill / Changes to the Mills	CO2 Capture Plant	CO2 Compression				
Base Case 1A	798.50	-	-	79.85	878.35	463.15	1341.50
Case 2A-1	10.55	227.92	14.48	25.29	278.24	77.20	355.44
Case 2A-2	9.81	61.67	3.93	7.54	82.95	22.64	105.59
Case 2A-3	9.54	36.10	2.30	4.79	52.73	14.45	67.18
Case 2A-4	11.95	253.09	16.08	28.11	309.23	86.00	395.22
Case 2A-5	11.78	239.31	15.20	26.63	292.92	81.46	374.38
Case 2A-6MP	15.21	264.01	16.77	29.60	325.58	91.03	416.61

Table 13: Summary of results for integrated pulp and board mill without and with CCS - Total Plant Costs (TPC) and Total Captial Requirements (TCR)

Cases	Total Installed Cost (TIC) - € million			Project Contingency € million	Total Plant Costs (TPC) € million	Other CAPEX € million	Total Capital Requirements (TCR) € million
	Reference Mill / Changes to the Mills	CO2 Capture Plant	CO2 Compression				
Base Case 1B	942.60	-	-	94.26	1036.86	555.31	1592.17
Case 2B-1CO2MP	35.53	227.92	28.95	29.24	321.64	91.35	412.99
Case 2B-2	9.89	61.67	3.93	7.55	83.03	22.67	105.70
Case 2B-3	9.61	36.10	2.30	4.80	52.81	14.40	67.21
Case 2B-4CO2MP	47.93	253.09	32.15	33.32	366.49	104.52	471.00
Case 2B-5CO2MP	46.76	239.31	30.40	31.65	348.12	99.29	447.40
Case 2B-6CO2MP	53.17	264.01	33.54	35.07	385.78	110.91	496.69

4. Annual operating and maintenance costs

The annual operating and maintenance costs (annual O&M cost) of the mills without and with CCS accounts for the following:

- Fixed O&M cost
  - Direct labour cost
  - Indirect labour cost
  - Annual maintenance cost
  - Other fixed cost
- Variable O&M cost
  - Raw materials
  - Chemicals
  - Fuel
  - Utilities (process water, boiler feed water make-up, cooling water)
  - Waste processing and disposal (wastewater and solid waste)
- Other revenues (sales of CTO and electricity)
- Other cost
  - Marketing, logistics and distribution cost
  - CO_2 transport and storage cost

In the calculation of the annual O&M cost, the following should be noted:

- This study evaluates the cost of retrofitting the CO_2 capture facilities to the reference mills on the 10th year of the mill's operation. Thus, in all the CCS cases, the annual O&M costs for the first nine years of operation should be equal to the annual O&M costs of the reference mills.
- This study assumes that during the construction of the CO_2 capture facilities, the operation of the mill is not disrupted.
- The tie-in of the CO_2 capture facilities and associated modifications to the reference mills could be completed within the regular maintenance turn-around period of the mill. As a consequence, the mill's operation during the commissioning and start-up of the CO_2 capture facilities would not be disrupted.
- The CO_2 capture facilities only operate 7560 hours during its first year of operation (i.e. 10th year of mill's operation); and operate 8400 hours for the remaining life of the mill (i.e. 11th to 25th year of the mill's operation).

The breakdown of the annual O&M costs of the reference mills are presented in the report by Kangas et al. [1]. This section enumerates the additional annual O&M costs due to the retrofit of the CO_2 capture facilities.

4.1. Fixed O&M costs

4.1.1. Direct labour costs

Tables 14 and 15 present the breakdown of the number of personnel directly involved in the production of pulp (and board) for mills without and with CCS. The annual average salary was set to 60 000 € per person.

The CO_2 capture facilities are operated with additional 15 to 20 personnel. These include 10 to 15 operators/shift supervisors, three maintenance personnel and two senior operating managers. If an auxiliary boiler is installed, 10 additional personnel are added to the roster. These include eight operators and shift supervisors and two maintenance personnel.

4.1.2. Indirect labour costs

The indirect labour costs are 40% of the direct labour cost. These cover the costs for administration and general overhead.

Generally, administration and overhead costs are dependent on the organizational structure of the company and complexity of its operation. This normally covers functions which are not directly involved in the daily operation of the plant.

4.1.3. Annual maintenance costs

Tables 16 and 17 present the breakdown of the annual maintenance costs of the mills without and with CCS.

A precise evaluation of the annual maintenance costs would require a breakdown of the costs of the numerous components and packages of the plant. Since these costs are all strongly dependent on the type of equipment selected and statistical maintenance data provided by the selected vendors, this type of evaluation of the maintenance costs is premature at the current study level. For this reason, the annual maintenance costs of the pulp (and board) mills are estimated as a percentage of the Total Plant Cost (TPC) for each case. An average of 4% is assumed for the whole plant (without CCS).

The annual maintenance costs for the CO_2 capture facilities and auxiliary boiler (if included) is also defined based on the percentage of the TPC. A fixed value of 3% of the TPC is assumed.

For the different processes of the mill where modifications is necessary, the maintenance costs are estimated based on the percentage of the additional CAPEX due to the modifications and are added to the original annual maintenance costs of the process.

4.1.4. Other fixed costs

The other fixed costs include factors such as senior management, marketing, research and development, fees, local insurances, etc.

As these costs can vary significantly between mills and companies, this study assumes a fixed value of 25 €/adt pulp (and board) for the reference mills without CCS, and 1% of the additional TPC of the CO_2 capture facilities and associated modifications is added once CCS is retrofitted.

Tables 18 and 19 summarise the other fixed costs of the mills without and with CCS.

4.2. Variable O&M costs

The variable O&M costs are estimated based on the mass balances of the mill and the CO_2 capture facilities. Table 20 presents the key costs of raw material, chemicals, fuel, other utilities and waste processing used in the economic evaluation. This table also includes the selling price of the CTO and the electricity exported to the grid. Also the unit costs of the selling, marketing and distribution activities of the reference mills.

Table 14: Annual labour cost - pulp mill without and with CCS

		Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Pulp mill	-	120	120	120	120	120	120	120
Board mill	-	-	-	-	-	-	-	-
CO_2 capture and compression plant	-	-	20	15	15	20	20	20
Auxiliary boiler	-	-	-	-	-	-	-	-
Total - Personnel		120	140	135	135	140	140	140
Total - Direct Labour Cost (€ million)	60,000 € per person	7.20	8.40	8.10	8.10	8.40	8.40	8.40
Indirect labour cost (€ million)	40% of direct labour cost	2.88	3.36	3.24	3.24	3.36	3.36	3.36
Total - Labour Cost (€ million)		10.08	11.76	11.34	11.34	11.76	11.76	11.76

Table 15: Annual labour cost - integrated pulp and board mill without and with CCS

		Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Pulp mill	-	120	120	120	120	120	120	120
Board mill	-	120	120	120	120	120	120	120
CO_2 capture and compression plant	-	-	20	15	15	20	20	20
Auxiliary boiler	-	-	10	-	-	10	10	10
Total - Personnel		240	270	255	255	270	270	270
Total - Direct Labour Cost (€ million)	60,000 € per person	14.40	16.20	15.30	15.30	16.20	16.20	16.20
Indirect labour cost (€ million)	40% of direct labour cost	5.76	6.48	6.12	6.12	6.48	6.48	6.48
Total - Labour Cost (€ million)		20.16	22.68	21.42	21.42	22.68	22.68	22.68

Table 16: Annual maintenance cost - pulp mill without and with CCS

			Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Pulp mill	4.0%	of TPC	35.14	35.14	35.14	35.14	35.14	35.14	35.14
CO_2 capture and compression plant	3.0%	of TPC	-	8.00	2.16	1.27	8.92	8.43	9.30
Modifications to the Pulp Mill									
Kraft Recovery Boiler (Unit 4200)	6.2%	of TPC	-	0.04	-	-	0.04	0.04	0.04
Lime Kiln (Unit 5100)	6.0%	of TPC	-	-	-	0.01	-	0.01	0.01
Multi-fuel Boiler (Unit 6100)	3.0%	of TPC	-	-	0.01	-	0.01	-	0.01
Steam Turbine Island (Unit 6200)	3.0%	of TPC	-	0.20	0.20	0.20	0.20	0.20	0.30
Auxiliary Boiler (Unit 6300)	3.0%	of TPC	-	-	-	-	-	-	-
Waste Water Treatment Plant (Unit 8000)	3.0%	of TPC	-	0.13	0.12	0.11	0.13	0.13	0.14
Total - Annual Maintenance Cost (€ million)			35.14	43.51	37.63	36.73	44.44	43.95	44.93

Table 17: Annual maintenance cost - integrated pulp and board mill without and with CCS

			Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Integrated pulp and board mill	4.0%	of TPC	41.48	41.48	41.48	41.48	41.48	41.48	41.48
CO_2 capture and compression plant	3.0%	of TPC	-	8.48	2.16	1.27	9.45	8.93	9.85
Modifications to the Pulp Mill									
Kraft Recovery Boiler (Unit 4200)	6.2%	of TPC	-	0.04	-	-	0.04	0.04	0.04
Lime Kiln (Unit 5100)	6.0%	of TPC	-	-	-	0.01	-	0.01	0.01
Multi-fuel Boiler (Unit 6100)	3.0%	of TPC	-	-	0.01	-	0.01	-	0.01
Steam Turbine Island (Unit 6200)	3.0%	of TPC	-	0.29	0.19	0.19	0.29	0.29	0.29
Auxiliary Boiler (Unit 6300)	3.0%	of TPC	-	0.73	-	-	1.09	1.06	1.25
Waste Water Treatment Plant (Unit 8000)	3.0%	of TPC	-	0.14	0.13	0.12	0.14	0.14	0.15
Total - Annual Maintenance Cost (€ million)			41.48	51.15	43.97	43.07	52.49	51.95	53.08

Table 18: Other fixed O&M cost - pulp mill without and with CCS

			Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Pulp mill	25 €	per adt of pulp	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Board mill	25 €	per adt of board	-	-	-	-	-	-	-
CO_2 capture and compression plant	1%	of TPC*	-	2.78	0.83	0.53	3.09	2.93	3.26
Total - Other Fixed O&M Cost (€ million)			20.00	22.78	20.83	20.53	23.09	22.93	23.26

* This include the TPC of the CCS facilities and associated modifications to the mill

Table 19: Other fixed O&M cost - integrated pulp and board mill without and with CCS

			Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Pulp mill	25 €	per adt of pulp	18.46	18.46	18.46	18.46	18.46	18.46	18.46
Board mill	25 €	per adt of board	10.00	10.00	10.00	10.00	10.00	10.00	10.00
CO_2 capture and compression plant	1%	of TPC*	-	3.22	0.83	0.53	3.66	3.48	3.86
Total - Other Fixed O&M Cost (€ million)			28.46	31.68	29.29	28.99	32.12	31.94	32.32

* This include the TPC of the CCS facilities and associated modifications to the mill

Table 20: Key assumptions - prices of raw materials, chemicals, fuel, utilities, waste disposal and others

Raw Materials		
Wood	40.00 €	per per m3
Bleached Hardwood Kraft Pulp (BHKP)	650.00 €	per tonne
Chemi-Thermo Mechanical Pulp (CTMP)	400.00 €	per tonne
Coating	300.00 €	per tonne
Fillers	200.00 €	per tonne
Chemicals		
Sodium Hydroxide (NaOH)	370.00 €	per tonne
Hydrogen Peroxide (H2O2)	500.00 €	per tonne
Magnesium Sulphate (MgSO4)	300.00 €	per tonne
Calcium Oxide (CaO)	120.00 €	per tonne
Sulphuric Acid (H2SO4)	50.00 €	per tonne
Sodium Chlorate (NaClO3)	500.00 €	per tonne
Methanol (MeOH)	350.00 €	per tonne
Talc	200.00 €	per tonne
MEA Solvent	1,620.00 €	per tonne
Co-Product (Sold to Market)		
Crude Tall Oil (CTO)	500.00 €	per tonne
Energy and Fuel		
Heavy Fuel Oil (HFO)	400.00 €	per tonne
Waste Wood / Forest Residues	18.80 €	per m3
Electricity (Sold to the Grid)	40.00 €	MWh
Utilities		
Process Water	0.10 €	per m3
Boiler Feed Water Make Up	0.20 €	per m3
Cooling Water	0.05 €	per m3
Waste Processing and Disposal		
Rejects from Brown Stock Handling	10.00 €	per tonne
Residues from CTO Production	10.00 €	per tonne
Bottom & Fly Ash	10.00 €	per tonne
Dregs	10.00 €	per tonne
Slaker Grit	10.00 €	per tonne
Rejects from Pulp Dryer	10.00 €	per tonne
Rejects from Board Mill	10.00 €	per tonne
MEA sludge	190.00 €	per tonne
Waste Water Effluent Discharge	0.09 €	per m3
Other Miscellaneous Cost		
Product Logistics & Delivery	50.00 €	per tonne
Other Fixed Cost (incl. Insurance & Local Tax)	25.00 €	per tonne
CO2 Transport and Storage	10.00 €	per tonne

The variable O&M costs of the reference mills have been presented in the previous report by Kangas et al. [2]. This section of the report only highlights the different changes to the variable O&M costs once CCS is retrofitted.

4.2.1. Raw materials

No changes to the consumption of the raw materials (mainly roundwood, BHKP, CTMP, coating and fillers) are expected after the retrofit of CCS.

4.2.2. Chemicals

The main chemicals used by the CO_2 capture facilities is the monoethanolamine (MEA) and the NaOH (used by the amine reclaimer). There will be no changes to the consumption of other chemicals used by the pulp (and board) mills. The chemicals used in treatment of the process water, boiler feed water, cooling water, and wastewater are included in the unit costs of the utilities.

Tables 21 and 22 summarise the annual chemical costs of the mill and the CO_2 capture facilities.

4.2.3. Fuel

The main fuel imported by the pulp (and board) mills from outside the battery limit is the HFO which is used by the lime kiln. There are no changes to the HFO consumption after the retrofit of the CCS.

If an auxiliary boiler is installed, additional fuel (waste wood/forest residues) is imported from outside the battery limit. This will be the only changes expected to the annual fuel costs of the plant and are relevant to cases 2B-1^{CO2MP}, 2B-4^{CO2MP}, 2B-5^{CO2MP} and 2B-6^{CO2MP}. These costs are summarised in Table 23.

4.2.4. Other Utilities

The other utilities used by the CO_2 capture facilities include the process water, boiler feed water make-up and cooling water. The price of the utilities used in the economic evaluation is also presented in Table 20. The price includes both the CAPEX and OPEX components of these off-site facilities.

Tables 24 and 25 summarise the annual utility costs for the mills without and with CCS.

4.2.5. Waste processing and disposal

Tables 26 and 27 present the breakdown of waste processing and disposal charges of the mills without and with CCS.

No changes are expected to the amount of solid wastes generated by the pulp (and board) mills except for the additional solid wastes generated by the CO_2 capture facilities and the auxiliary boiler. These include:

- Degraded MEA products (MEA sludge) – this is sent to a specialised company for proper disposal.
- Bottom and fly ash of the auxiliary boiler – this is sent to the landfill together with bottom and fly ash from the multi-fuel boiler.

Table 21: Annual chemicals bill - pulp mill without and with CCS

			Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Pulp Mill									
Sodium Hydroxide (NaOH)	370 €	per tonne	11.01	11.01	11.01	11.01	11.01	11.01	11.01
Hydrogen Peroxide (H2O2)	500 €	per tonne	2.96	2.96	2.96	2.96	2.96	2.96	2.96
Magnesium Sulphate (MgSO4)	300 €	per tonne	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Calcium Oxide (CaO)	120 €	per tonne	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sulphuric Acid (H2SO4)	50 €	per tonne	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Sodium Chlorate (NaClO3)	500 €	per tonne	9.80	9.80	9.80	9.80	9.80	9.80	9.80
Methanol (MeOH)	350 €	per tonne	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Talc	200 €	per tonne	0.64	0.64	0.64	0.64	0.64	0.64	0.64
CO_2 capture and compression plant									
Mono-ethanolamine (MEA)	1,620 €	per tonne	-	2.87	0.53	0.37	3.40	3.24	3.76
Sodium Hydroxide (NaOH)	370 €	per tonne	-	0.07	0.01	0.01	0.08	0.08	0.09
Total - Annual Chemical Cost (€ million)			27.25	30.19	27.79	27.62	30.73	30.57	31.11

Table 22: Annual chemicals bill - integrated pulp and board mill without and with CCS

			Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Pulp and Board Mill									
Sodium Hydroxide (NaOH)	370 €	per tonne	10.71	10.71	10.71	10.71	10.71	10.71	10.71
Hydrogen Peroxide (H2O2)	500 €	per tonne	2.81	2.81	2.81	2.81	2.81	2.81	2.81
Magnesium Sulphate (MgSO4)	300 €	per tonne	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Calcium Oxide (CaO)	120 €	per tonne	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sulphuric Acid (H2SO4)	50 €	per tonne	0.77	0.77	0.77	0.77	0.77	0.77	0.77
Sodium Chlorate (NaClO3)	500 €	per tonne	9.31	9.31	9.31	9.31	9.31	9.31	9.31
Methanol (MeOH)	350 €	per tonne	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Talc	200 €	per tonne	0.61	0.61	0.61	0.61	0.61	0.61	0.61
CO_2 Capture and Compression Plant									
Mono-ethanolamine (MEA)	1,620 €	per tonne	-	2.87	0.53	0.37	3.40	3.24	3.76
Sodium Hydroxide (NaOH)	370 €	per tonne	-	0.07	0.01	0.01	0.08	0.08	0.09
Total - Annual Chemical Cost (€ million)			26.21	29.15	26.75	26.58	29.69	29.52	30.06

*Table 23: Annual fuel bill - integrated pulp and board mill**

			Base Case 1B	2B-1CO2MP	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Pulp and Board Mill							
Heavy Fuel Oil	400 €	per tonne	11.20	11.20	11.20	11.20	11.20
Waste Wood / Forest Residue	19 €	per m3	-	7.55	11.73	11.09	17.66
Total - Annual Fuel Cost (€ million)			11.20	18.75	22.93	22.29	28.86

* No changes is expected to all cases except for the CCS cases presented in this table due to the addition of auxiliary boiler.

Table 24: Annual utilities bill - pulp mill without and with CCS

			Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Pulp mill									
Process Water	0.10 €	per m3	1.31	1.31	1.31	1.31	1.31	1.31	1.31
Bolier Feed Water (Make-Up)	0.20 €	per m3	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Cooling Water	0.05 €	per m3	5.18	5.18	5.18	5.18	5.18	5.18	5.18
CO_2 capture and compression plant									
Process Water	0.10 €	per m3	-	0.073	0.011	0.004	0.079	0.076	0.085
Bolier Feed Water (Make-Up)	0.20 €	per m3	-	0.022	0.004	0.003	0.024	0.024	0.028
Cooling Water	0.05 €	per m3	-	5.32	1.20	0.67	4.82	5.17	6.62
Total - Other Utilities Cost (€ million)			6.65	12.06	7.86	7.33	11.57	11.92	13.38

Table 25: Annual utilities bill - integrated pulp and board mill without and with CCS

			Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Pulp mill									
Process Water	0.10 €	per m3	1.64	1.64	1.64	1.64	1.64	1.64	1.64
Bolier Feed Water (Make-Up)	0.20 €	per m3	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Cooling Water	0.05 €	per m3	3.78	3.78	3.78	3.78	3.78	3.78	3.78
CO_2 Capture and Compression Plant									
Process Water	0.10 €	per m3	-	0.073	0.011	0.004	0.08	0.076	0.085
Bolier Feed Water (Make-Up)	0.20 €	per m3	-	0.033	0.004	0.003	0.04	0.041	0.055
Cooling Water	0.05 €	per m3	-	5.42	1.22	0.70	6.21	5.69	8.01
Total - Other Utilities Cost (€ million)			5.58	11.11	6.82	6.29	11.91	11.39	13.73

Table 26: Annual waste disposal bill - pulp mill without and with CCS

			Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Pulp mill									
Rejects from Brown Stock Handling	10.00 €	per tonne	0.072	0.072	0.072	0.072	0.072	0.072	0.072
Residues from CTO Production	10.00 €	per tonne	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Bottom & Fly Ash	10.00 €	per tonne	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Dregs	10.00 €	per tonne	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Slaker Grit	10.00 €	per tonne	0.060	0.060	0.060	0.060	0.060	0.060	0.060
Rejects from Pulp Dryer	10.00 €	per tonne	0.055	0.055	0.055	0.055	0.055	0.055	0.055
Waste Water Effluent Discharge	0.09 €	per m3	1.280	1.280	1.280	1.280	1.280	1.280	1.280
CO_2 Capture and Compression Plant									
MEA Sludge	190.00 €	per tonne	-	0.337	0.062	0.043	0.399	0.380	0.441
Waste Water Effluent Discharge	0.09 €	per m3	-	0.117	0.034	0.013	0.148	0.130	0.164
Total - Waste Processing Cost (€ million)			1.52	1.98	1.62	1.58	2.07	2.03	2.13

Table 27: Annual waste disposal bill - integrated pulp and board mill without and with CCS

			Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Pulp and Board Mill									
Rejects from Brown Stock Handling	10.00 €	per tonne	0.072	0.072	0.072	0.072	0.072	0.072	0.072
Residues from CTO Production	10.00 €	per tonne	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Bottom & Fly Ash	10.00 €	per tonne	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Dregs	10.00 €	per tonne	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Slaker Grit	10.00 €	per tonne	0.060	0.060	0.060	0.060	0.060	0.060	0.060
Rejects from Pulp Dryer	10.00 €	per tonne	0.051	0.051	0.051	0.051	0.051	0.051	0.051
Rejects from Board Mill	10.00 €	per tonne	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Waste Water Effluent Discharge	0.09 €	per m3	1.519	1.519	1.519	1.519	1.519	1.519	1.519
CO_2 Capture and Compression Plant									
MEA Sludge	190.00 €	per tonne	-	0.337	0.062	0.043	0.399	0.380	0.441
Waste Water Effluent Discharge	0.09 €	per m3	-	0.117	0.034	0.013	0.148	0.130	0.164
Auxiliary Boiler									
Bottom & Fly Ash	10.00 €	per tonne	-	0.023	-	-	0.035	0.033	0.053
Total - Waste Processing Cost (€ million)			1.80	2.27	1.89	1.85	2.38	2.34	2.45

Additional wastewater is expected from the direct contact cooler and CO_2 compression unit. This wastewater is treated in the existing wastewater treatment plant of the mill. The changes mainly cover the taxes and local fees for discharging the treated wastewater to the sea.

4.3. Other revenues from sales of the co-products

The other revenue streams of the pulp (and board) mills include the sales of:

- Crude tall oil
- Electricity (exported to the grid)

There will be no expected changes to the amount of crude tall oil sold to the market.

Due to the increase in the demand of steam and electricity by the CO_2 capture facilities, it should be expected that the electricity production will be reduced and consequently the amount of electricity sold to the grid is also reduced.

The changes to the other revenues from sale of CTO and electricity for the mills without and with CCS are presented in Tables 28 and 29.

4.4. Other costs

Tables 30 and 31 present the other costs which accounts for (a.) marketing, logistics and distribution costs, and (b.) CO_2 transport and storage costs.

4.4.1. Marketing, logistics and distribution costs

The costs for marketing, logistics and distribution of the products sold to the global market are included in the cost analysis. These are fixed at 50 €/adt of pulp (and board).

In the discounted cash flow analysis, it should be noted that this cost item is deducted directly from the revenues of the plant as this is not part of the production costs.

There should be no changes to these costs after the retrofit of the CCS facilities.

4.4.2. CO_2 transport and storage costs

The CO_2 transport and storage costs are estimated by using a flat rate of 10 €/t CO_2 captured.

It should be noted that the assumption used in this work is much lower than the numbers typically reported for the CO_2 transport and storage costs in Finland (which is around 30 €/t CO_2 captured).

4.5. Summary of results

Tables 32 and 33 summarise the annual O&M costs of the mills without and with CCS.

Table 28: Annual revenues from co-products - pulp mill without and with CCS

			Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Pulp Mill									
Crude Tall Oil (CTO)	500 €	per tonne	15.60	15.60	15.60	15.60	15.60	15.60	15.60
Electricity (exported to grid)	40 €	per MWh	36.07	18.03	32.93	34.04	13.76	15.72	7.16
Total - Other Revenues (€ million)			51.67	33.63	48.53	49.64	29.36	31.32	22.76

Table 29: Annual revenues from co-products - integrated pulp and board mill without and with CCS

			Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Pulp and Board Mill									
Crude Tall Oil (CTO)	500 €	per tonne	15.60	15.60	15.60	15.60	15.60	15.60	15.60
Electricity (exported to grid)	40 €	per MWh	21.31	6.92	18.05	19.16	6.00	6.29	6.19
Total - Other Revenues (€ million)			36.91	22.52	33.65	34.76	21.60	21.89	21.79

Table 30: Other costs - pulp mill without and with CCS

			Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
Marketing, logistics and distribution	50 €	per tonne	40.00	40.00	40.00	40.00	40.00	40.00	40.00
CO_2 transport and storage	10 €	per tonne	-	14.79	2.71	1.97	17.50	16.76	19.47
Total - Other Cost (€ million)			40.00	54.79	42.71	41.97	57.50	56.76	59.47

Table 31: Other costs - integrated pulp and board mill without and with CCS

			Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
Marketing, logistics and distribution	50 €	per tonne	56.92	56.92	56.92	56.92	56.92	56.92	56.92
CO_2 transport and storage	10 €	per tonne	-	14.79	2.71	1.97	17.50	16.76	19.47
Total - Other Cost (€ million)			56.92	71.71	59.63	58.89	74.42	73.68	76.39

Table 32: Summary of results - annual O&M costs - pulp mill without and with CCS

	Base Case 1A	2A-1	2A-2	2A-3	2A-4	2A-5	2A-6MP
1. Fixed Cost							
1a. Direct Labour	7.20	8.40	8.10	8.10	8.40	8.40	8.40
1b. Indirect Labour Cost	2.88	3.36	3.24	3.24	3.36	3.36	3.36
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	20.00	22.78	20.83	20.53	23.09	22.93	23.26
1d. Maintenance	35.14	43.51	37.63	36.73	44.44	43.95	44.93
2. Variable Cost							
2a. Raw Materials / Feedstock	185.60	185.60	185.60	185.60	185.60	185.60	185.60
2b. Chemicals	27.25	30.19	27.79	27.62	30.73	30.57	31.11
2c. Fuel Cost	11.20	11.20	11.20	11.20	11.20	11.20	11.20
2d. Other Utilities	6.65	12.06	7.86	7.33	11.57	11.92	13.38
2e. Waste Processing & Disposal Charges	1.52	1.98	1.62	1.58	2.07	2.03	2.13
3. Other Revenues							
3a. Crude Tall Oil	-15.60	-15.60	-15.60	-15.60	-15.60	-15.60	-15.60
3b. Electricity (Sold to the Grid)	-36.07	-18.03	-32.93	-34.04	-13.76	-15.72	-7.16
4. Other Cost							
4a. Marketing, Logistics and Distribution	40.00	40.00	40.00	40.00	40.00	40.00	40.00
4b. CO2 Trasnsport and Storage Cost	-	14.79	2.71	1.97	17.50	16.76	19.47
Total - Annual O&M Costs (€ million)	285.77	340.24	298.04	294.26	348.59	345.40	360.07

Table 33: Summary of results - annual O&M costs - integrated pulp and board mill without and with CCS

	Base Case 1B	2B-1CO2MP	2B-2	2B-3	2B-4CO2MP	2B-5CO2MP	2B-6CO2MP
1. Fixed Cost							
1a. Direct Labour	14.40	16.20	15.30	15.30	16.20	16.20	16.20
1b. Indirect Labour Cost	5.76	6.48	6.12	6.12	6.48	6.48	6.48
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	28.46	31.68	29.29	28.99	32.12	31.94	32.32
1d. Maintenance	41.48	51.15	43.97	43.07	52.49	51.95	53.08
2. Variable Cost							
2a. Raw Materials / Feedstock	345.92	345.92	345.92	345.92	345.92	345.92	345.92
2b. Chemicals	26.21	29.15	26.75	26.58	29.69	29.52	30.06
2c. Fuel Cost	11.20	18.75	11.20	11.20	22.93	22.29	28.86
2d. Other Utilities	5.58	11.11	6.82	6.29	11.91	11.39	13.73
2e. Waste Processing & Disposal Charges	1.80	2.27	1.89	1.85	2.38	2.34	2.45
3. Other Revenues							
3a. Crude Tall Oil	-15.60	-15.60	-15.60	-15.60	-15.60	-15.60	-15.60
3b. Electricity (Sold to the Grid)	-21.31	-6.92	-18.05	-19.16	-6.00	-6.29	-6.19
4. Other Cost							
4a. Marketing, Logistics and Distribution	56.92	56.92	56.92	56.92	56.92	56.92	56.92
4b. CO2 Trasnsport and Storage Cost	-	14.79	2.71	1.97	17.50	16.76	19.47
Total - Annual O&M Costs (€ million)	500.81	561.89	513.24	509.45	572.94	569.82	583.69

5. Levelised cost of pulp and board (breakeven price)

The Levelised Cost of Pulp Production (LCOP) and the Levelised Cost of Board Production (LCOB) are the unit costs of the pulp and board which enable the present value from the sales of pulp and board (including the additional revenues from the sale of CTO and electricity) to equal the present value of all the costs of building, maintaining and operating the plant over its economic lifetime. In other words, this is the breakeven price of the pulp or board when the net present value (NPV) is set to zero.

The LCOP or breakeven price of the pulp produced from the mills without and with CCS is estimated using the discounted cash flow (DCF) analysis.

The DCF calculation is executed based on IEAGHG's economic assessment model developed in-house in cooperation with VTT. Using this method allows the determination of cost of pulp and board production and the cost of CO_2 avoidance (CAC). It also determines the increase in the price of pulp after the retrofit of the CCS on the 10th year of the mill's operation.

5.1. Discounted cash flow

The breakeven price of pulp and board is estimated by establishing the annual cash flow of the pulp (and board) mills without and with CCS. The annual cash flow consists of the following:

- Capital expenditures
- Working capital
- Annual revenues from sale of goods and co-products
- Fixed operating cost
- Variable operating cost
- Cost of CO_2 emissions (which includes CO_2 emissions tax, CO_2 emissions credit, renewable electricity credit, CO_2 negative emissions credit)
- Cost of CO_2 transport and storage

The breakeven price or LCOP is defined as the revenues needed to meet the cost of the pulp (and board) production without and with CCS over its economic life. The calculations are based on:

- The scheduled capital expenditure during construction and commissioning of the mills from year -3 to year 2, and the scheduled capital expenditure during the retrofit and commissioning of the CCS facilities from year 8 to year 11 (see Tables 10 and 11)
- The annual O&M costs of the mills without CCS for year 1 to year 9 (calculated based on 8400 h/a of operation, except for year 1 where the mill only operates at 6300 h/a, see Tables 32 and 33)
- The annual O&M costs of the mills with CCS for year 10 to 25 (calculated based on 8400 h/a of operation, except for year 10 where the CCS facilities only operates at 7560 h/a, see Tables 32 and 33)
- The return of the working capital on year 26

With the given information and assumptions, the following results are presented: (a.) levelised cost of pulp production or breakeven price of the pulp after the retrofit, and (b.) CO_2 avoidance cost.

In the current analysis, the price of the pulp (and board) for year 1 to 9 is set constant, or equal to the breakeven price of the pulp (and board) of the reference mills. After the retrofit (i.e. from year 10 to 25), the breakeven price of the pulp is calculated. The price of the board is fixed at the breakeven price of the board of the reference mill (without CCS).

With this assumption, it should be noted that the increase in the pulp price after the retrofit should cover all the costs of retrofitting CCS to the pulp (and board) mills.

5.2. Estimating the breakeven price of pulp and board

5.2.1. Breakeven price of pulp and board for the reference mills

The breakeven price of pulp for the market pulp mill and the breakeven price of board for the integrated pulp and board are presented in the previous report by Kangas et al. [1].

As both of the reference mills evaluated in this study have identical pulp production processes (in terms of capacity and energy use), the breakeven price of board (of Base Case 1B) is calculated by using the breakeven price of pulp of the market pulp mill (Base Case 1A).

5.2.2. Breakeven price of pulp for the market pulp mill with CCS

The breakeven price of the market pulp mill is calculated based on the methodology as described in Section 5.1.

5.2.3. Breakeven price of pulp and board for the integrated pulp and board mills with CCS

The breakeven price or LCOP of the integrated pulp and board mill is calculated based on the methodology as described in Section 5.1. The breakeven price of the board is assumed constant and this is equal to the LCOB of the reference mill without CCS (Base Case 1B).

The reason for using the breakeven price of the board based on the reference mill without CCS in calculating the breakeven price of pulp instead are due to the following reasons:

- To maintain the comparability of the results for all the cases in all of the scenarios evaluated, this study has assumed that all of the costs of retrofitting the CCS would be shouldered by the price of the pulp.
- To maintain consistency in the calculation when reporting the additional costs of retrofitting CCS in the pulp mill it should be noted that the production of board also involves the use of other types of pulp (i.e. BHKP and CTMP). Calculating the board price instead of the pulp price may present a risk of distorting the results, especially if the costs of the other types of pulp (and associated carbon footprint as part of Scope 2 emissions) going into the board mill are not considered. Without such considerations would make it more difficult to compare results from other studies.

5.3. Sensitivity analysis

The effects of ±50% change to some of the major cost factors (except for CO_2 transport and storage) to the LCOP were evaluated. The selected variables are listed below. Table 40 presents the range of values used in the various sensitivity analysis.

- Wood price (round wood and forest residue)
- Heavy fuel oil price
- Electricity price
- Discount rate
- Total plant cost

- CO_2 transport and storage cost

In the sensitivity analysis it should be noted that:

- The forest residue is indexed to the round wood price
- The range of values used for the CO_2 transport and storage covers a situation with possible income from CO_2 storage (i.e. EOR) or CO_2 capture from areas with high CO_2 transport and storage costs

Table 34: Variables for the sensitivity analysis

Variable		-50 %	-25 %	Base	25 %	50 %
Round wood	[€/m³]	20	30	40	50	60
Forest residues	[€/m³]	9.4	14.1	18.8	23.5	28.2
HFO	[€/t]	200	300	400	500	600
Electricity	[€/MWh]	20	30	40	50	60
Discount rate	[%]	4 %	6 %	8 %	10 %	12 %
TPC	[%]	50 %	75 %	100 %	125 %	150 %
CO_2 transport & storage*	[€/t]	-20	-5	10	25	40

* Negative number represent additional revenues (i.e. for cases where CO2 could be used in EOR)

5.4. Summary of results

Figures 1 to 7 illustrate the annual cash flow and the discounted cash flow for the mills without and with CCS. Figures 8 to 14 show the annual cash flow and discounted cash flow for the integrated pulp and board mills without and with CCS.

Annexes I and II present the individual cash flow (or balance sheet) for all the CCS cases. Annexes III and IV presents the annual operating expenditure of the mills for all the cases.

Tables 35 to 36 present the summary of results of breakeven prices of the pulp and board for all the cases evaluated. Figures 15 and 16 present the breakdown of the breakeven prices of the pulp and board for all the cases, respectively.

Figures 17(A) to 17(F) and Figures 18(A) to 18(F) present the results of the sensitivity analysis to the breakeven price of the pulp for the pulp mills and the integrated pulp and board mills (without and with CCS) respectively.

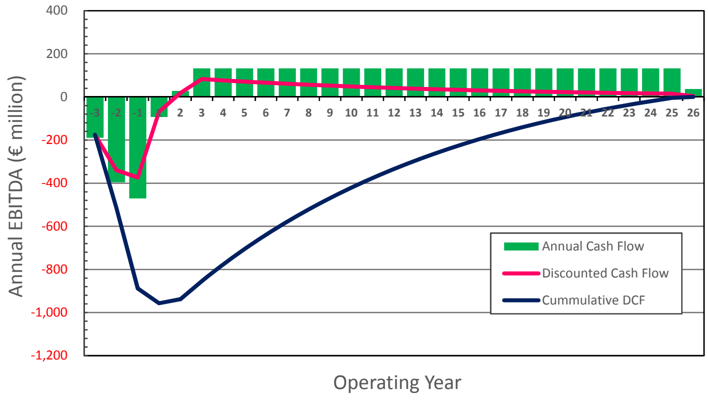


Figure 1: Cash Flow - Pulp Mill without CCS (Base Case 1A)

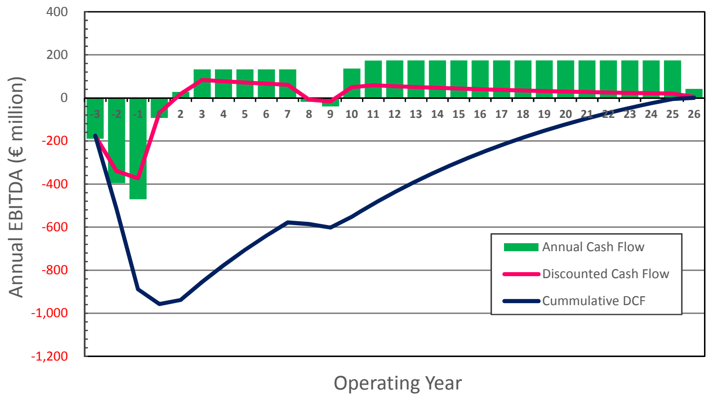


Figure 2: Cash Flow - Pulp Mill with CCS (Case 2A-1)

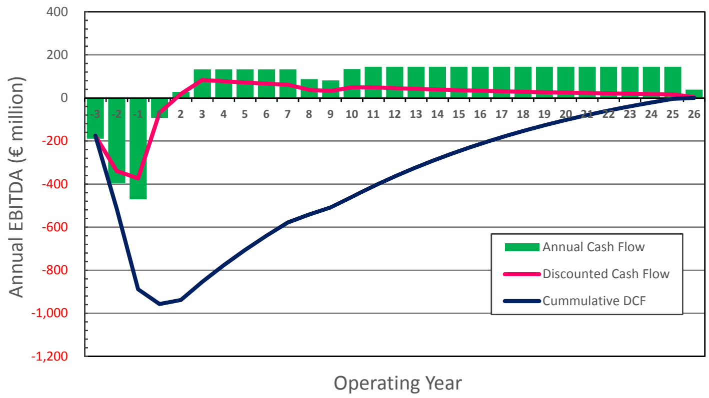


Figure 3: Cash Flow - Pulp Mill with CCS (Case 2A-2)

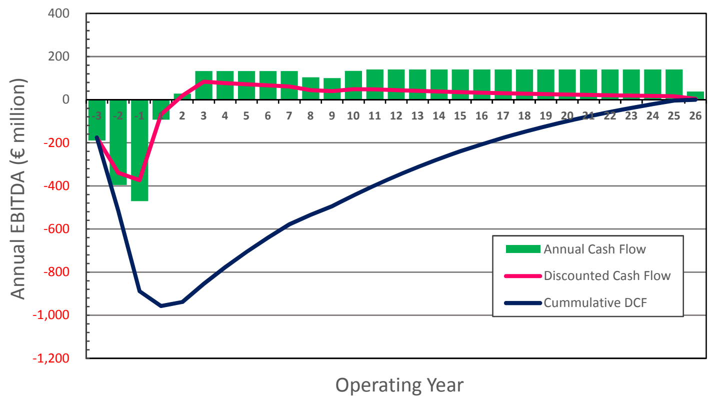


Figure 4: Cash Flow - Pulp Mill with CCS (Case 2A-3)

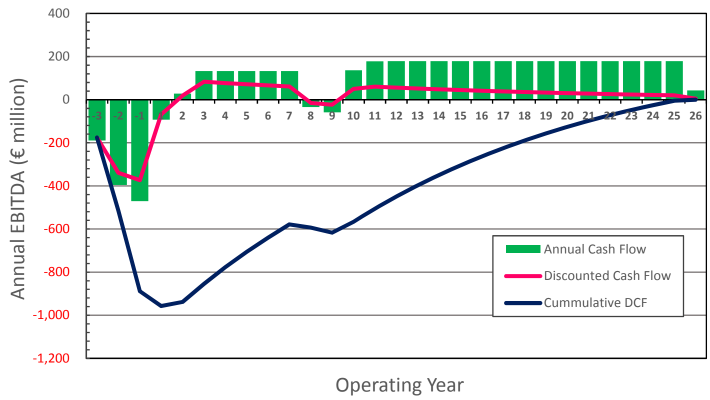


Figure 5: Cash Flow - Pulp Mill with CCS (Case 2A-4)

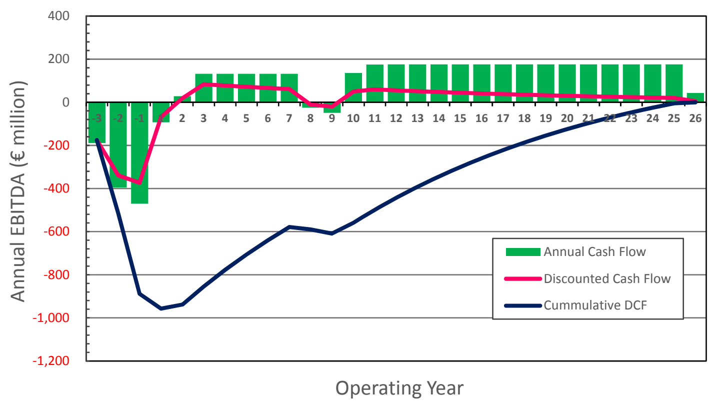


Figure 6: Cash Flow - Pulp Mill with CCS (Case 2A-5)

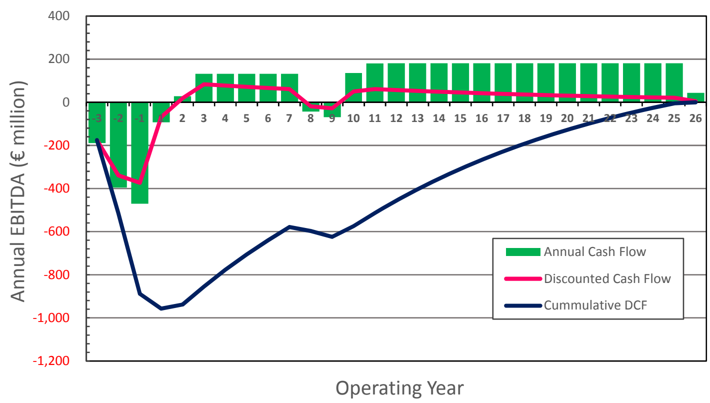


Figure 7: Cash Flow - Pulp Mill with CCS (Case 2A-6MP)

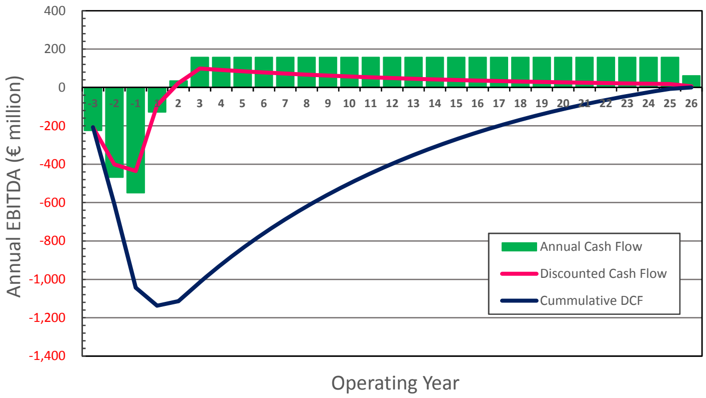


Figure 8: Cash Flow - Integrated Pulp & Board Mill without CCS (Base Case 1B)

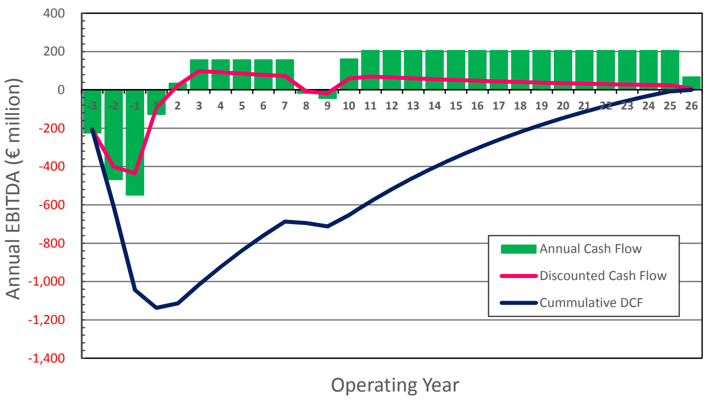


Figure 9: Cash Flow - Integrated Pulp & Board Mill with CCS (Case 2B-1 ^{CO2MP})

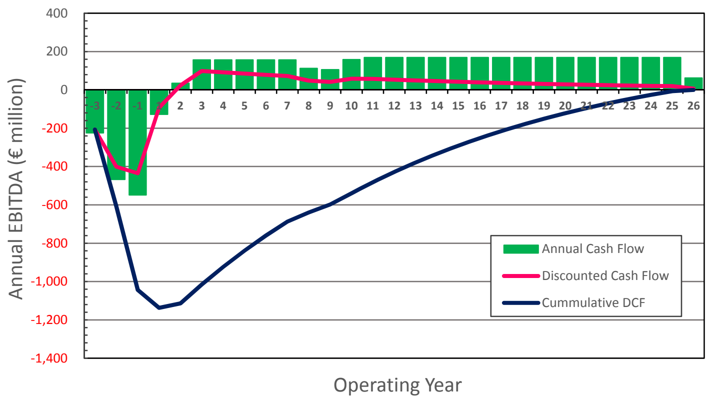


Figure 10: Cash Flow - Integrated Pulp & Board Mill with CCS (Case 2B-2)

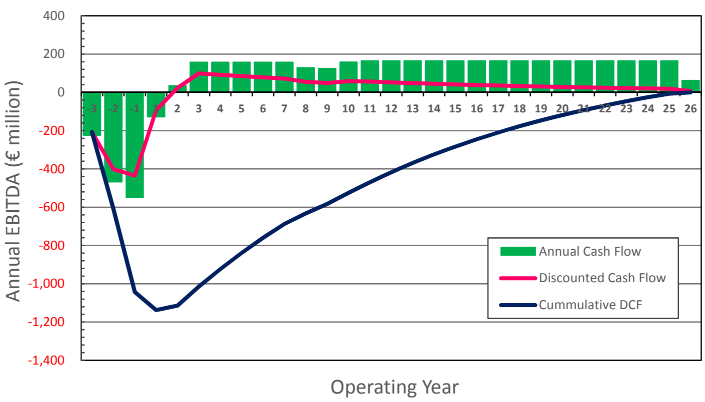


Figure 11: Cash Flow - Integrated Pulp & Board Mill with CCS (Case 2B-3)

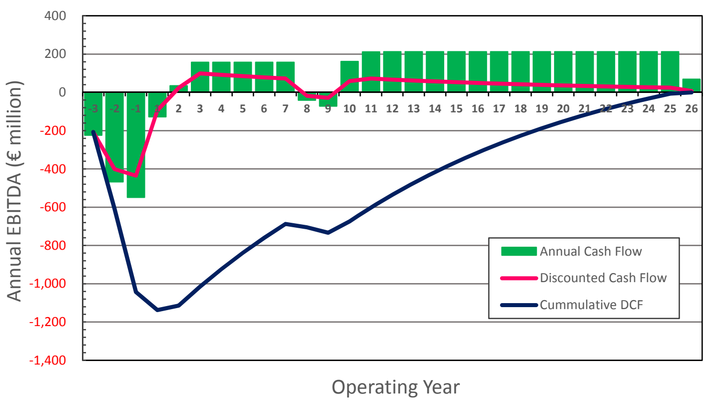


Figure 12: Cash Flow - Integrated Pulp & Board Mill with CCS (Case 2B-4 ^{CO2MP})

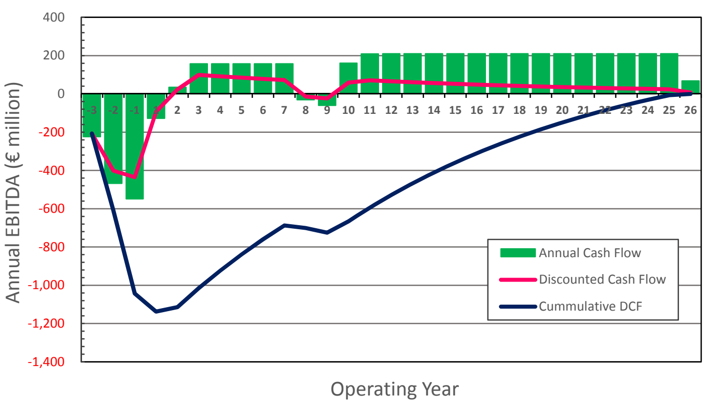


Figure 13: Cash Flow - Integrated Pulp & Board Mill with CCS (Case 2B-5 ^{CO2MP})

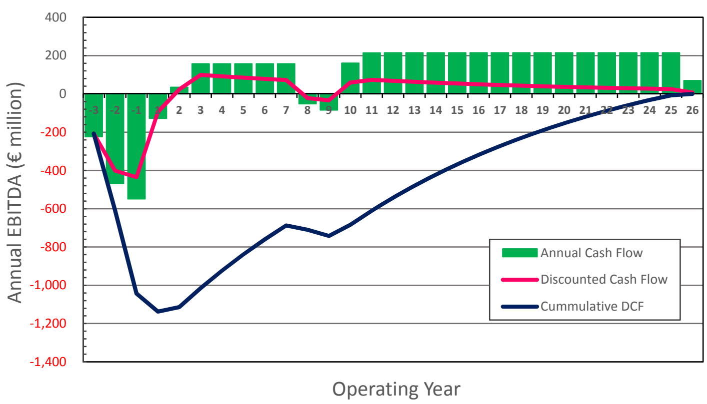


Figure 14: Cash Flow - Integrated Pulp & Board Mill with CCS (Case 2B-6 ^{CO2MP})

Table 35: Levelised cost (LCOP) or break-even price of pulp for the market pulp mill without and with CCS

Case No.	Case Description	LCOP €/adt$_{pulp}$	CAC €/t$_{CO2}$
Base Case 1A	Reference market pulp mill without CCS	522.6	-
Case 2A-1	Capture of CO2 from Recovery Boiler (REC) only	642.8	65.0
Case 2A-2	Capture of CO2 from Multi-fuel Boiler (MFB) only	553.5	91.1
Case 2A-3	Capture of CO2 from Lime Kiln (LK) only	543.1	83.1
Case 2A-4	Capture of CO2 from REC and MFB	659.0	62.4
Case 2A-5	Capture of CO2 from REC and LK	652.0	61.8
Case 2A-6MP	Capture of CO2 from all sources (REC + MFB + LK)	676.5	63.2

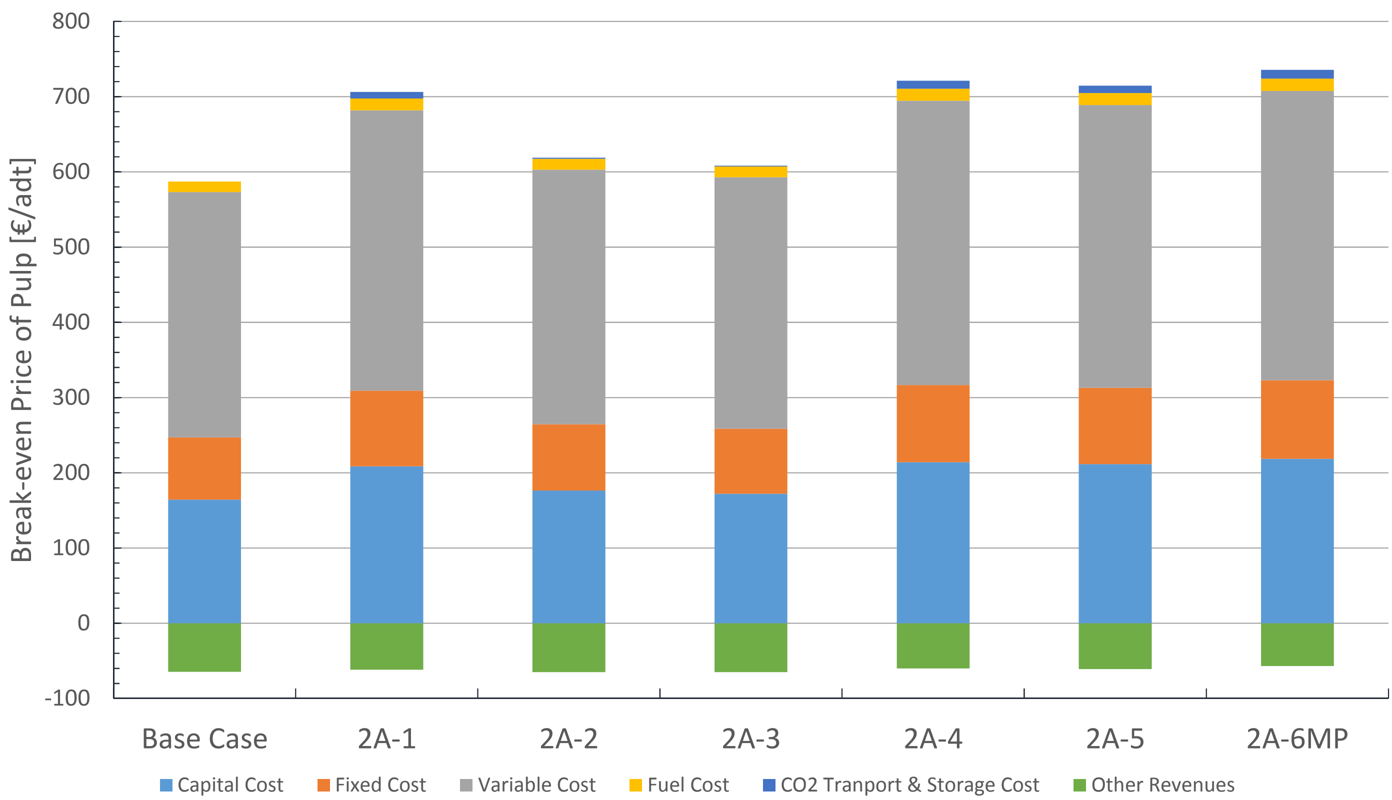


Figure 15: Levelised Cost of Pulp Production (LCOP) for pulp mills without and with CCS

Table 36: Levelised cost (LCOP) or break-even price of the pulp and associated levelised cost (LCOB) or break-even price of the board for the integrated pulp and board mill without and with CCS

Case No.	Case Description	LCOP €/adt$_{pulp}$	LCOB €/adt$_{board}$	CAC €/t$_{CO2}$
Base Case 1B	Reference market pulp mill without CCS	522.6	679.5	-
Case 2B-1CO2MP	Capture of CO2 from Recovery Boiler (REC) only	670.9	679.5	82.3
Case 2B-2	Capture of CO2 from Multi-fuel Boiler (MFB) only	556.3	679.5	91.8
Case 2B-3	Capture of CO2 from Lime Kiln (LK) only	545.0	679.5	84.0
Case 2B-4CO2MP	Capture of CO2 from REC and MFB	695.0	679.5	83.9
Case 2B-5CO2MP	Capture of CO2 from REC and LK	687.0	679.5	83.4
Case 2B-6CO2MP	Capture of CO2 from all sources (REC + MFB + LK)	713.6	679.5	88.3

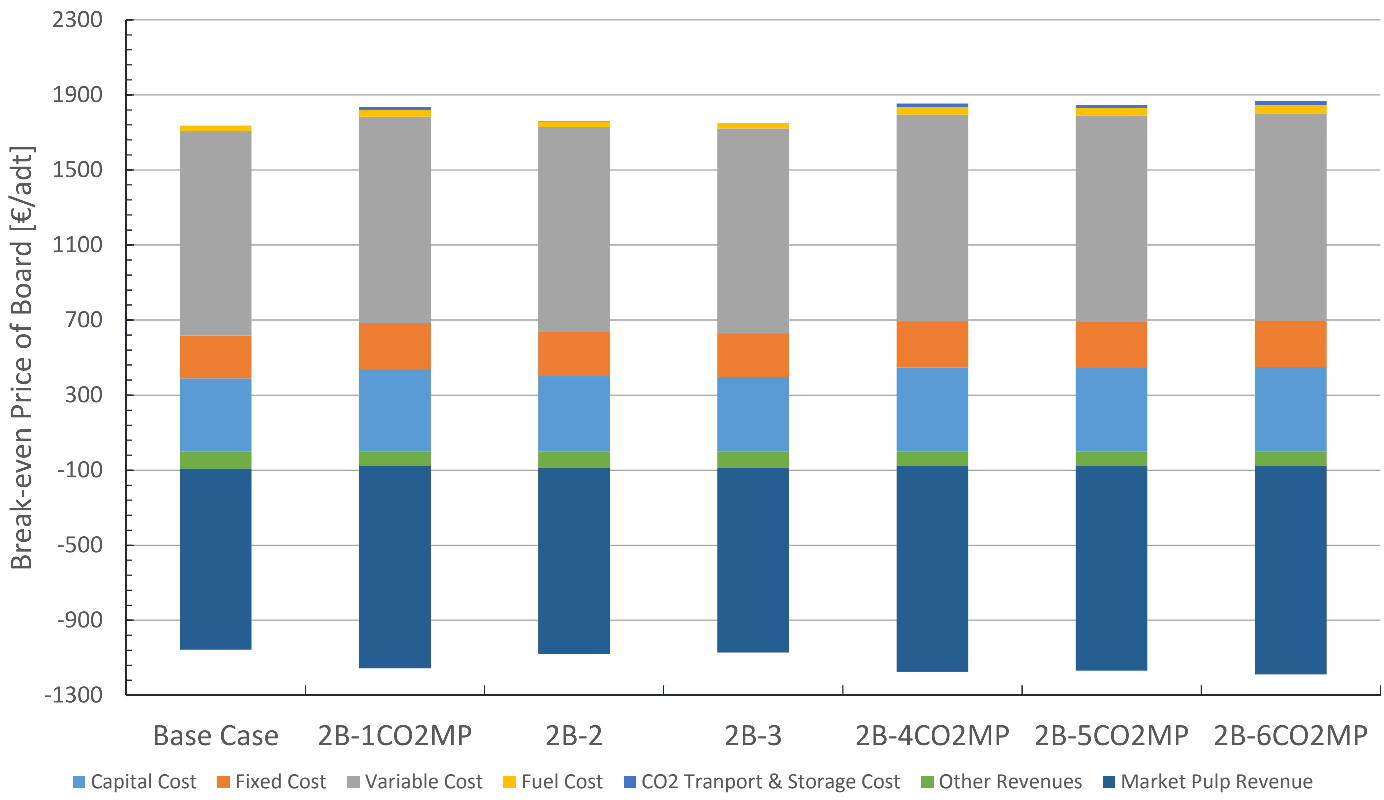
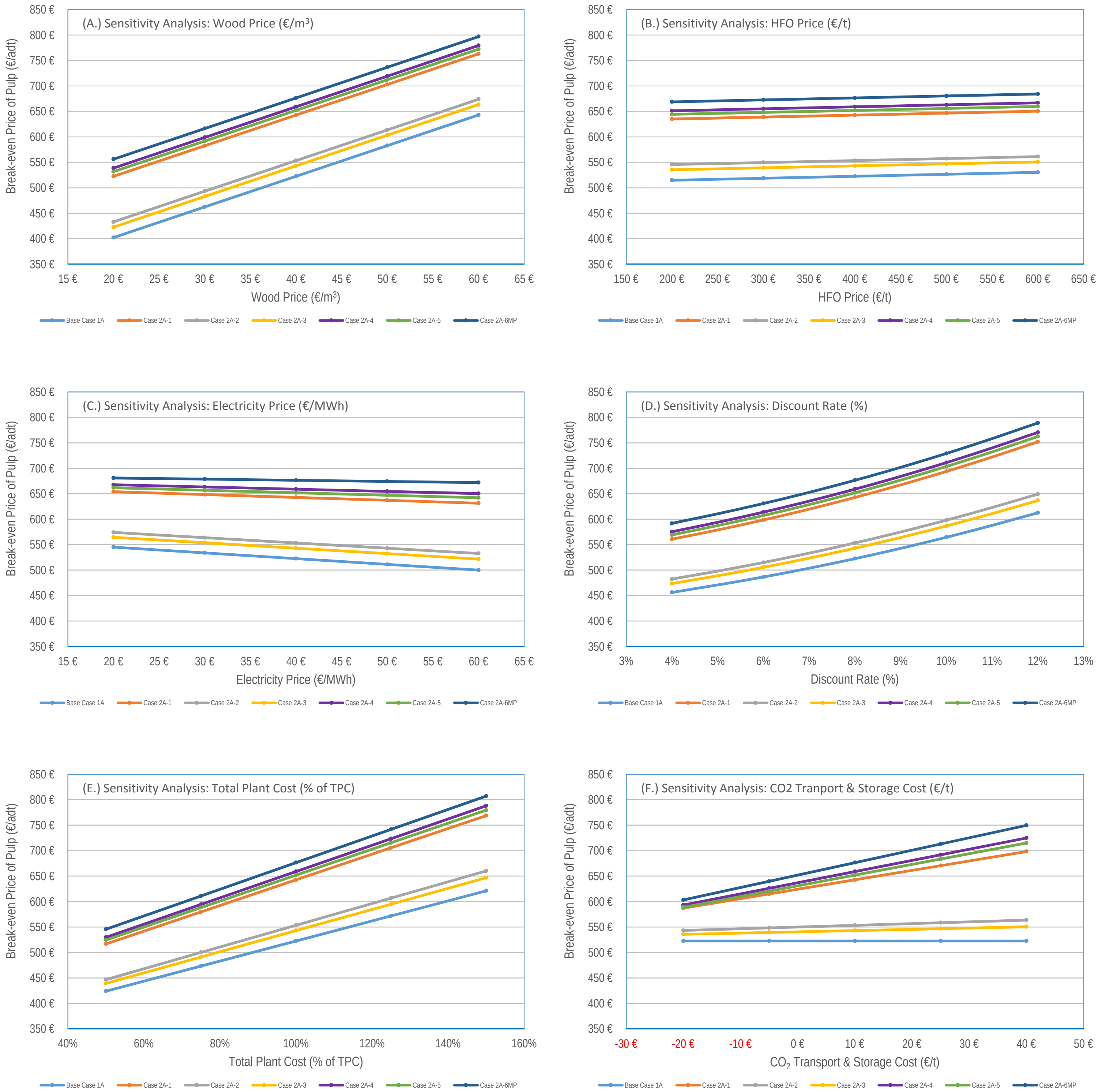
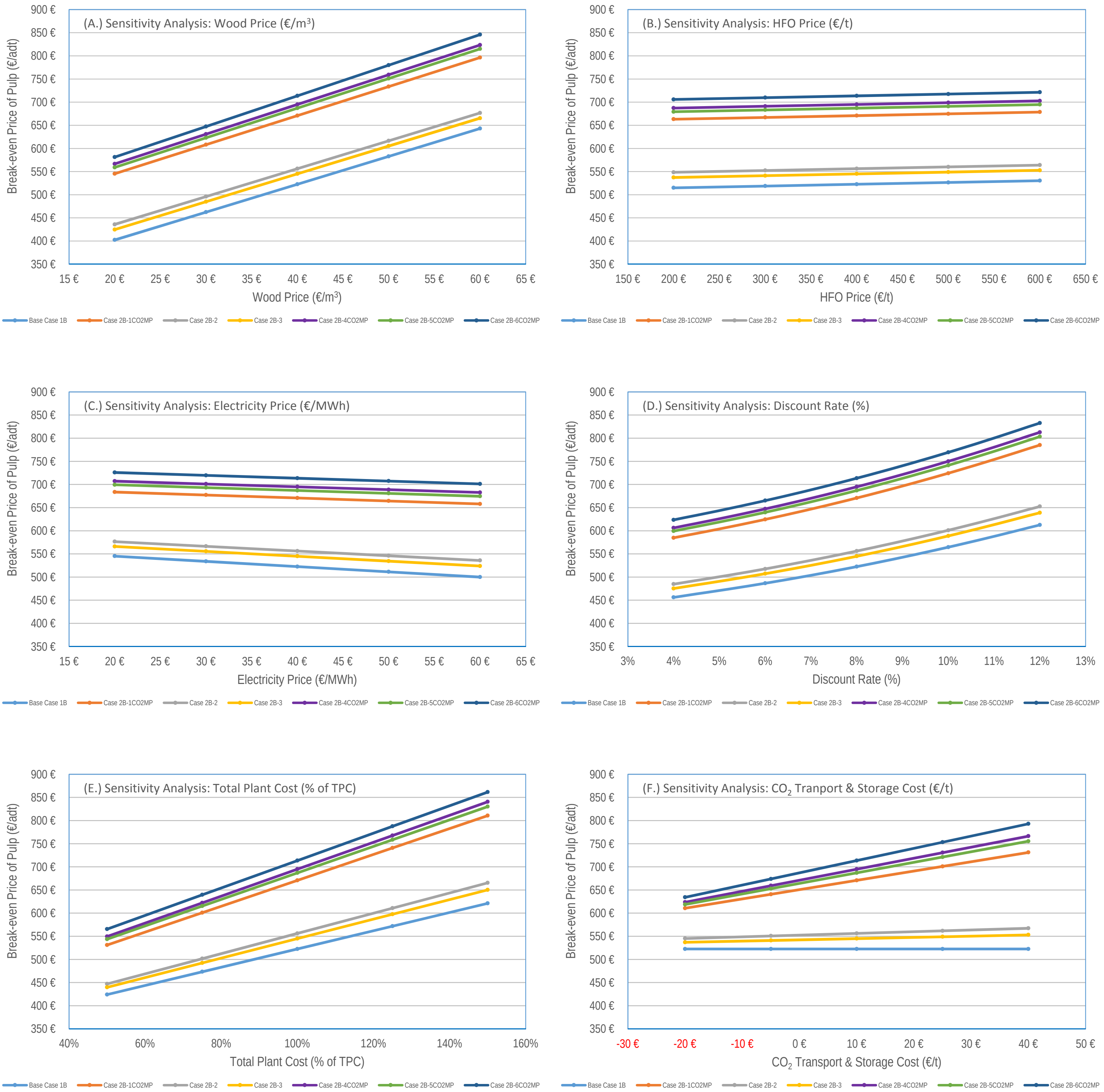


Figure 16: Levelised Cost of Board Production (LCOB) for integrated pulp and board mills without and with CCS



Figures 17(A) to (F): Pulp mills without and with CCS - sensitivity of the break-even price of pulp or LCOP to (A.) wood price; (B.) HFO price; (C.) electricity price; (D.) discount rate; (E.) total plant cost; and (F.) CO2 transport and storage cost.

Base Number: Wood price (€40/m³); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)



Figures 18(A) to (F): Integrated pulp and board mills without and with CCS - sensitivity of levelised cost of pulp production (LCOP) to (A.) wood price; (B.) HFO price; (C.) electricity price; (D.) discount rate; (E.) total plant cost; and (F.) CO2 transport and storage cost.

Base Number: Board Price (€679/adt); Wood price (€40/m^3); Waste wood price (€19/m^3); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)

6. CO_2 avoided cost

The costs of CO_2 avoided were calculated by comparing the CO_2 emissions per adt of pulp and the breakeven price of pulp or LCOP of the mills with capture and the reference mills without capture.

$$\text{CO}_2 \text{ Avoidance Cost (CAC)} = \frac{\text{LCOP}_{\text{CCS}} - \text{LCOP}_{\text{Reference}}}{\text{CO}_2\text{Emissions}_{\text{ Reference}} - \text{CO}_2\text{Emissions}_{\text{ CCS}}}$$

where:

- CAC is expressed in € per tonne of CO_2
- LCOP is expressed in € per adt of pulp
- CO_2 emission is expressed in tonnes of CO_2 per adt of pulp

6.1. Sensitivity analysis

The effects of ±50% changes to the selected variables (as listed below) to the CAC were evaluated. With a similar approach to the sensitivity analysis as described in the previous section the range of values shown in Table 34 was also used in the evaluation of the different sensitivity analysis.

- Wood price (round wood and forest residue)
- Electricity price
- Discount rate
- Total plant cost
- CO_2 transport and storage cost

6.2. Summary of results

Tables 35 and 36 also present the CO_2 avoided cost for all the cases evaluated.

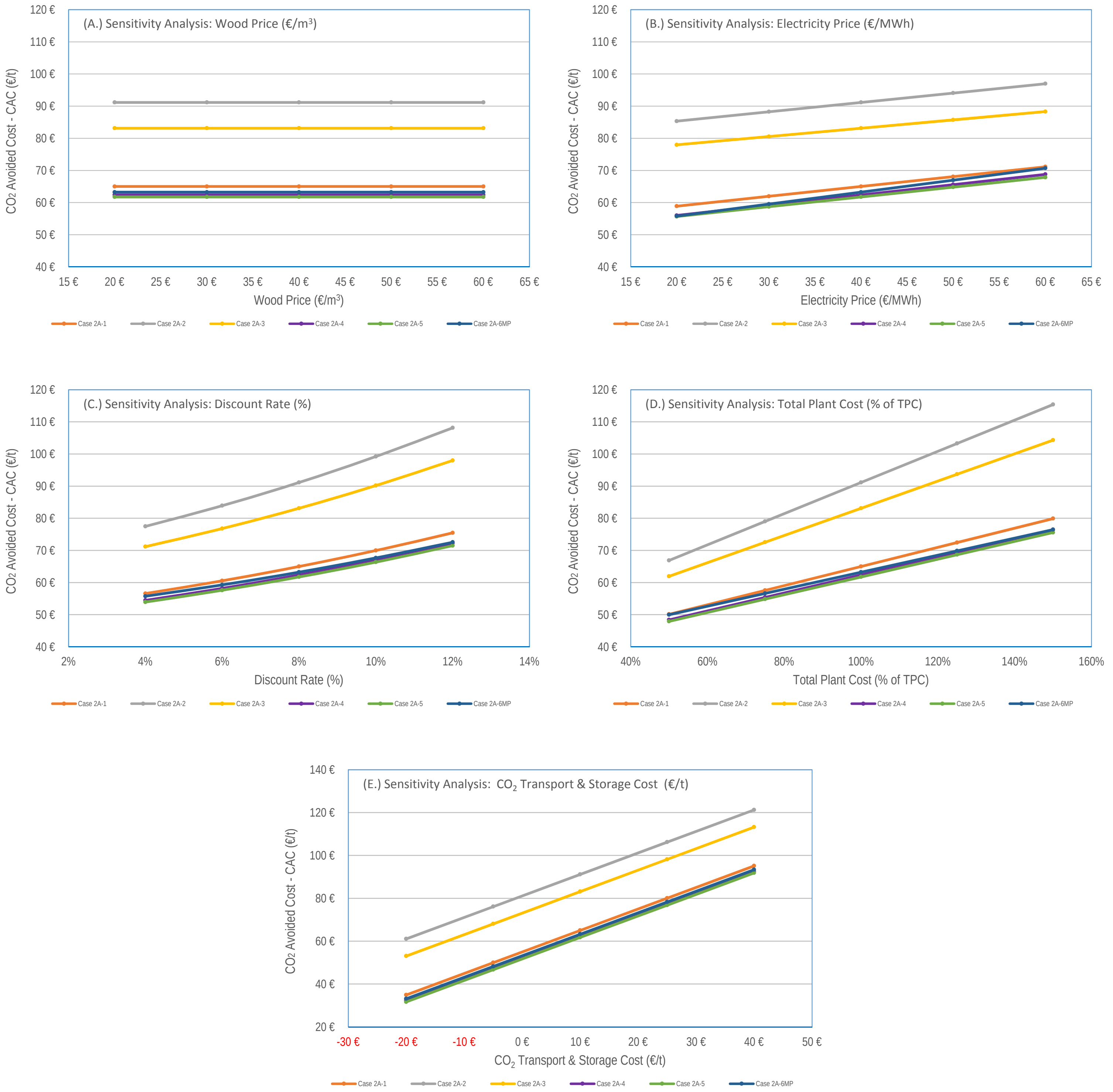
Figures 19(A) to 19(E) and Figures 20(A) to 20(E) present the results of the sensitivity analysis for the pulp mills and the integrated pulp and board mills (without and with CCS), respectively.

6.3. Cost curves

Figures 21(A) to 21(D) and Figures 22(A) to 22(D) present the different CO_2 abatement cost curves for all the CCS cases evaluated for all the pulp mills and integrated pulp and board mills (without and with CCS), respectively.

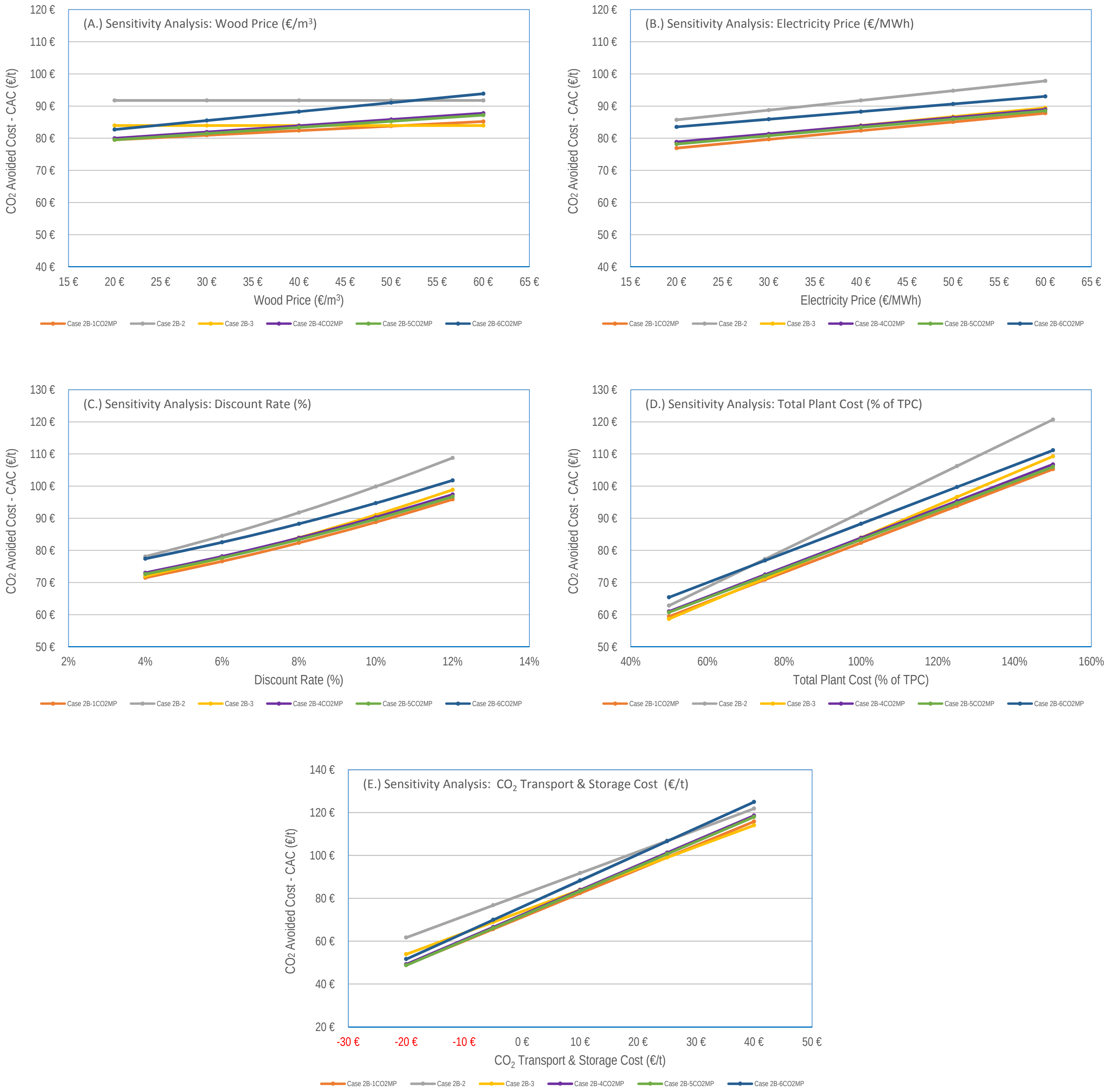
The cost curves for retrofitting CCS to an existing pulp mill or integrated pulp and board mill should illustrate the different pathways to achieve the highest possible CO_2 capture rate of the site in relation to their CO_2 avoided cost.

For all the pulp mill cases, it could be noted that the lowest possible CO_2 avoided cost that could be achieved is around 77% CO_2 avoided or a cumulative avoided CO_2 of 1.67 MTPY at a cost of 62 €/t CO_2. On the other hand, for all the integrated pulp and board mill cases, the lowest possible CO_2 avoided cost that could be achieved is around 61% CO_2 avoided or a cumulative avoided CO_2 of 1.48 MTPY at a cost of 82 €/t CO_2.



Figures 19(A) to (E): Pulp mills without and with CCS - sensitivity of CO2 avoided cost (CAC) to (A.) wood price; (B.) electricity price; (C.) discount rate; (D.) total plant cost; and (E.) CO2 transport and storage cost.

Base Number: Wood price (€40/m³); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)



Figures 20(A) to (E): Integrated pulp and board mills without and with CCS - sensitivity of CO2 avoided cost (CAC) to (A.) wood price; (B.) electricity price; (C.) discount rate; (D.) total plant cost; and (E.) CO2 transport and storage cost.

Base Number: Board Price (€679/adt); Wood price (€40/m³); Waste wood price (€19/m³); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)

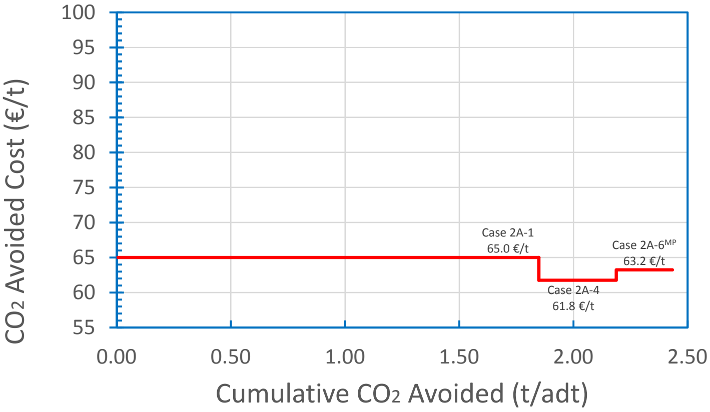


Figure 21(A): Cost curves for retrofitting CCS in a pulp mill (Case 2A-1, Case 2A-4 and Case 2A-6MP)

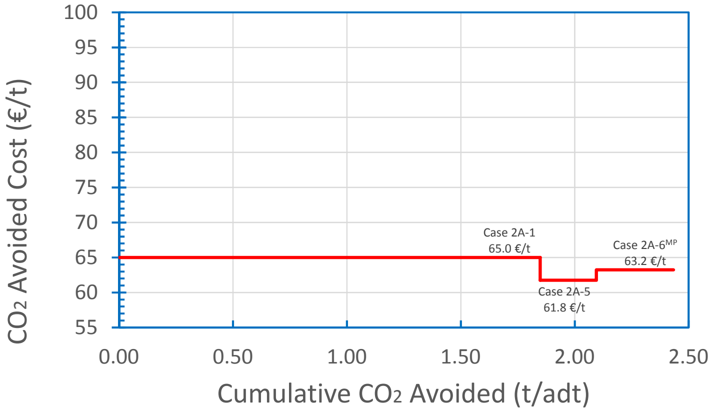


Figure 21(B): Cost curves for retrofitting CCS in a pulp mill (Case 2A-1, Case 2A-5 and Case 2A-6MP)

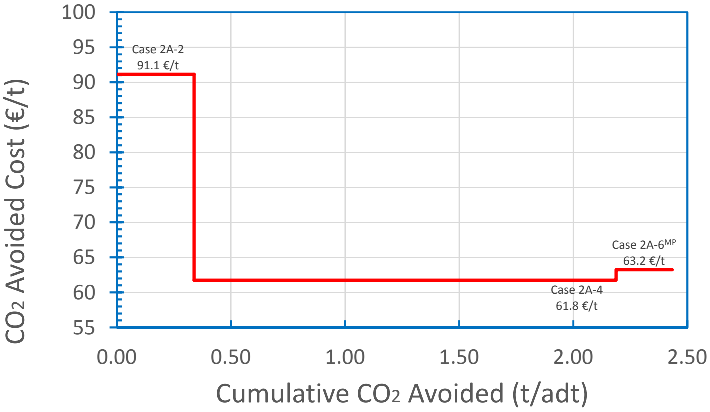


Figure 21(C): Cost curves for retrofitting CCS in a pulp mill (Case 2A-2, Case 2A-4 and Case 2A-6MP)

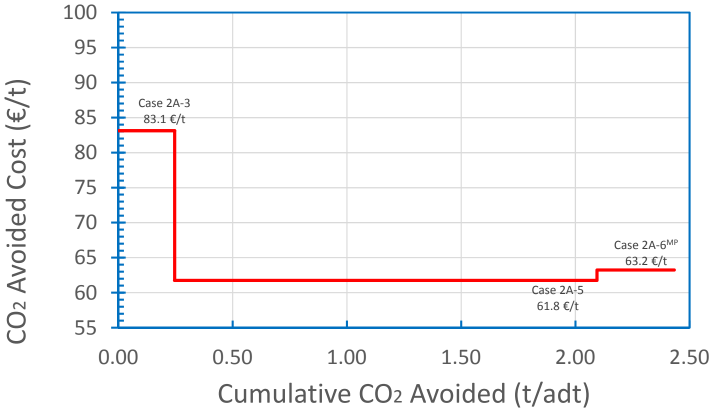


Figure 21(D): Cost curves for retrofitting CCS in a pulp mill (Case 2A-3, Case 2A-5 and Case 2A-6MP)

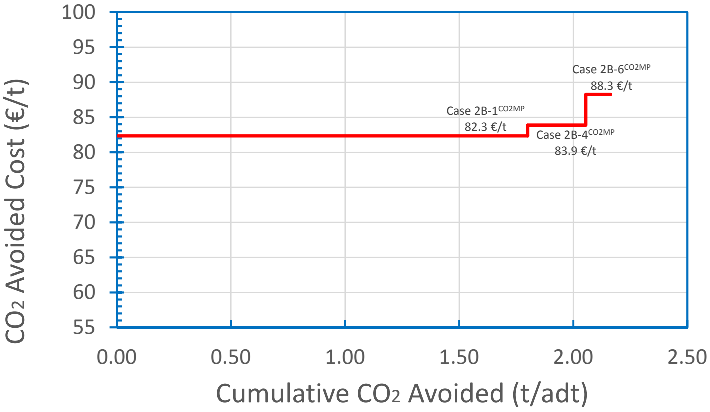


Figure 22(A): Cost curves for retrofitting CCS in an integrated mill (Case 2B-1CO2MP, Case 2B-4CO2MP and Case 2B-6CO2MP)

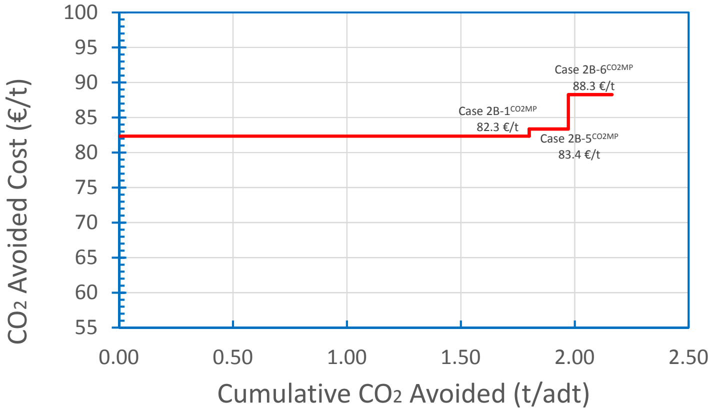


Figure 22(B): Cost curves for retrofitting CCS in an integrated mill (Case 2B-1CO2MP, Case 2B-5CO2MP and Case 2B-6CO2MP)

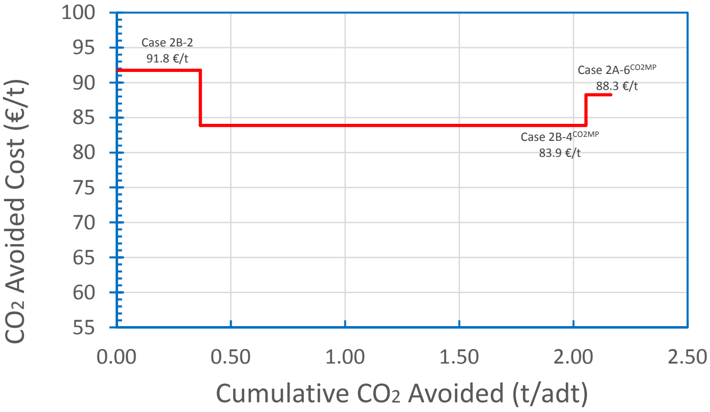


Figure 22(C): Cost curves for retrofitting CCS in an integrated mill (Case 2B-2, Case 2B-4CO2MP and Case 2B-6CO2MP)

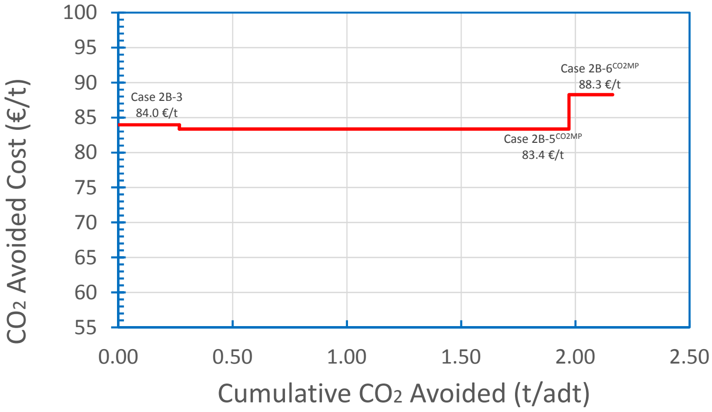


Figure 22(D): Cost curves for retrofitting CCS in a pulp mill (Case 2B-3, Case 2B-5CO2MP and Case 2B-6CO2MP)

7. CO_2 emission cost

To evaluate the impact of the cost of CO_2 emissions to the levelised cost of the market pulp the following scenarios were evaluated:

- Scenario #1:

  No CO_2 emissions tax or any incentives to the biogenic CO_2 emissions (Base number)

- Scenario #2:

  CO_2 emissions tax at 10 €/t and the biogenic CO_2 emitted by the mills is not recognized as CO_2 neutral (i.e. biogenic CO_2 is not exempted from tax)

- Scenario #3:

  CO_2 emissions tax at 10 €/t and the biogenic CO_2 is recognized as CO_2 neutral, therefore exempting CO_2 emissions from tax

- Scenario #4:

  CO_2 emissions tax at 10 €/t, the biogenic CO_2 is exempted from tax and an additional incentive is credited to the renewable electricity exported to the grid at 10% of the electricity selling price (at 4 €/MWh).

If CCS is retrofitted, the following additional scenarios were also evaluated to assess the effect of the financial credit given to the negative CO_2 emissions.

- Scenario #5:

  The same conditions as in Scenario 3, and with the negative CO_2 emissions given an additional credit of 10 €/t.

- Scenario #6:

  The same conditions as in Scenario 4, and with the negative CO_2 emissions given an additional credit of 10 €/t.

It should be noted that the CO_2 tax at 10 €/t reflects the current scenario where the EU ETS price for CO_2 is very low. Additionally, for Scenario #4, the incentive at 4 €/MWh credited to the renewable electricity that is sold to the grid also reflects the current Nordic market where incentives given to the renewable electricity are slowly being withdrawn.

7.1. Summary of results

Tables 37 and 38 summarise the LCOP of the pulp mill and integrated pulp and board mill for the all the CCS cases evaluated and subjected to the six different scenarios as defined above.

Tables 39 and 40 present the CO_2 avoided cost of the pulp mill and integrated pulp and board mill for the CCS cases.

*Table 37: LCOP or the breakeven price of the pulp for the mills without and with CCS**

**The breakeven price for all the CCS case represents the price of the pulp after the retrofit of the CO_2 capture plant.*

	Base Case 1A	Case 2A-1 (REC)	Case 2A-2 (MFB)	Case 2A-3 (LK)	Case 2A-4 (REC+MFB)	Case 2A-5 (REC+ LK)	Case 2A-6[MP] (ALL 3)[MP]
Scenario 1	522.6 €	642.8 €	553.5 €	543.1 €	659.0 €	652.0 €	676.5 €
Scenario 2	549.7 €	651.3 €	577.2 €	567.7 €	664.2 €	658.1 €	679.2 €
Scenario 3	523.7 €	643.9 €	554.5 €	543.1 €	660.1 €	652.0 €	676.5 €
Scenario 4	519.2 €	641.6 €	550.4 €	538.8 €	658.4 €	650.0 €	675.6 €
Scenario 5	523.7 €	625.3 €	551.1 €	541.7 €	638.2 €	632.1 €	653.2 €
Scenario 6	519.2 €	623.1 €	547.0 €	537.4 €	636.5 €	630.1 €	652.3 €

*Table 38: LCOP or the breakeven price of the integrated pulp and board mill for the mills without and with CCS**

**The breakeven price for all the CCS case represents the price of the pulp after the retrofit of the CO_2 capture plant.*

	Base Case 1B	Case 2B-1[CO2MP] (REC)	Case 2B-2 (MFB)	Case 2B-3 (LK)	Case 2B-4[CO2MP] (REC+MFB)	Case 2B-5[CO2MP] (REC+ LK)	Case 2B-6[CO2MP] (ALL 3)[MP]
Scenario 1	522.6 €	670.9 €	556.3 €	545.0 €	695.0 €	687.0 €	713.6 €
Scenario 2	549.7 €	679.9 €	579.7 €	569.5 €	701.5 €	694.4 €	719.1 €
Scenario 3	523.7 €	672.0 €	557.3 €	544.9 €	696.1 €	686.9 €	713.5 €
Scenario 4	519.2 €	669.4 €	553.3 €	540.7 €	693.6 €	684.4 €	711.0 €
Scenario 5	523.7 €	651.9 €	553.7 €	543.4 €	672.3 €	665.4 €	688.2 €
Scenario 6	519.2 €	649.3 €	549.6 €	539.2 €	669.9 €	662.9 €	685.8 €

*Table 39: CO_2 avoided cost for the pulp mills without and with CCS**

	Base Case 1A	Case 2A-1 (REC)	Case 2A-2 (MFB)	Case 2A-3 (LK)	Case 2A-4 (REC+MFB)	Case 2A-5 (REC+ LK)	Case 2A-6[MP] (ALL 3)[MP]
Scenario 1	-	65.0 €	91.1 €	83.1 €	62.4 €	61.8 €	63.2 €
Scenario 2	-	55.0 €	81.1 €	73.1 €	52.3 €	51.7 €	53.2 €
Scenario 3	-	65.0 €	91.1 €	78.7 €	62.4 €	61.2 €	62.8 €
Scenario 4	-	66.2 €	92.3 €	79.7 €	63.7 €	62.4 €	64.3 €
Scenario 5	-	55.0 €	81.1 €	73.1 €	52.3 €	51.7 €	53.2 €
Scenario 6	-	56.2 €	82.3 €	74.1 €	53.6 €	52.9 €	54.7 €

*Table 40: CO_2 avoided cost for the integrated pulp and board mills without and with CCS**

	Base Case 1B	Case 2B-1[CO2MP] (REC)	Case 2B-2 (MFB)	Case 2B-3 (LK)	Case 2B-4[CO2MP] (REC+MFB)	Case 2B-5[CO2MP] (REC+ LK)	Case 2B-6[CO2MP] (ALL 3)[MP]
Scenario 1	-	82.3 €	91.8 €	84.0 €	83.9 €	83.4 €	88.3 €
Scenario 2	-	72.3 €	81.7 €	73.9 €	73.9 €	73.3 €	78.3 €
Scenario 3	-	82.3 €	91.8 €	79.5 €	83.9 €	82.8 €	87.7 €
Scenario 4	-	83.4 €	93.0 €	80.6 €	84.9 €	83.8 €	88.7 €
Scenario 5	-	71.2 €	81.7 €	73.9 €	72.3 €	71.8 €	76.0 €
Scenario 6	-	72.3 €	82.9 €	75.0 €	73.3 €	72.8 €	77.0 €

7.2. Sensitivity analysis

7.2.1. CO_2 emission tax

The sensitivity of the breakeven price of pulp or levelised cost of pulp production (LCOP) to the CO_2 emission tax has been evaluated for values between 0 and 100 €/tonne of CO_2 emitted.

In this set of assessment the following assumptions were used:

- Electricity price sold to the market is set constant at 40 €/MWh. This decides the renewable electricity credit at 4 €/MWh (for Scenarios 4 and 6)
- CO_2 transport and storage costs are set at 10 €/t CO_2 stored
- Negative CO_2 emission credit is given at 10 €/t of biogenic CO_2 stored (for Scenarios 5 and 6)

Figures 23(A) to 23(E) present the sensitivity of the pulp breakeven price to the CO_2 emission tax for the market pulp mill without and with CCS under the different scenarios.

Similarly, Figures 24(A) to 24(E) present the sensitivity of the pulp breakeven price to the CO_2 emission tax for the integrated pulp and board mill under various scenarios.

The impact of the CO_2 emission tax to the breakeven prices of pulp and board (LCOP and LCOB) strongly depends on how the biogenic CO_2 emissions of the mill are classified. This is fundamentally dependent on how sustainable the main raw materials (i.e. round wood) used by the mill are sourced.

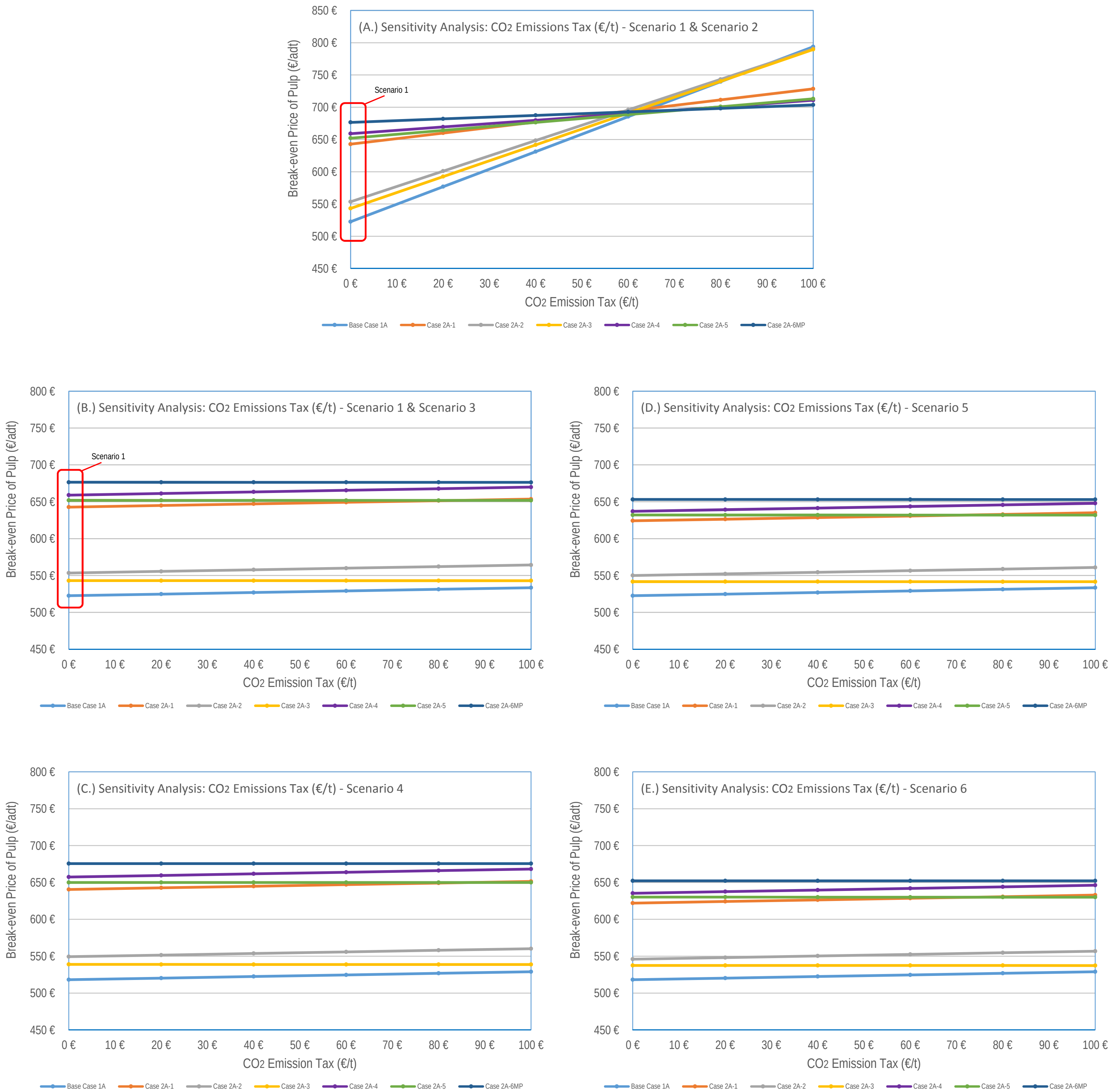
In this study, it should be noted that only the combustion related emission of the lime kiln are considered as fossil CO_2 emissions and the rest are considered as biogenic CO_2 emissions. This represents about 3 to 4% of the total CO_2 emissions from the whole site.

In this regard, the sensitivity to the CO_2 emission tax is negligible for all the scenarios assessed except for cases related to Scenario 2. This is mainly due to the low level of fossil CO_2 emissions being taxed. This clearly illustrates that there will be less incentives to install CCS to the pulp (and board) mills as long as the majority of the biogenic CO_2 emissions are recognised as CO_2 neutral, and unless the negative CO_2 emissions are given significant financial credit (as illustrated in Section 7.2.3).

On the other hand, for all the cases evaluated under Scenario 2, the biogenic CO_2 emissions are not recognised as CO_2 neutral. Thus, as expected, the sensitivity to the CO_2 emission tax could be significant. These types of cases may represent possible scenarios where the raw material is not sourced sustainably or under a regime where the regulatory framework does not recognised the CO_2 emissions derived from the burning of biomass fuels as CO_2 neutral.

In cases where only a proportion of the biogenic CO_2 emissions of the whole site are recognised as CO_2 neutral, the sensitivity of the CO_2 emission tax to the LCOP could range between the values reported in Scenario 2 and Scenario 3 as shown in Figures 23(A) to 23(B) and Figures 24(A) to 24(B).

An example of the case described above involves the EU emission trading scheme where the biogenic CO_2 emissions from the process related emissions of the lime kiln are not classified as CO_2 neutral. Consequently, this increases the amount of CO_2 emissions being taxed to around 10% (based on Scenario 3). Figures 25 and 26 illustrate such sensitivity for the cases involving the pulp mill and the integrated pulp and board mill without and with CCS respectively.



Figures 23(A) to (E): Pulp mill without and with CCS - sensitivity of pulp's break-even price to CO2 emission tax (A.) Scenario 1 & 2, (B.) Scenario 1 & 3, (C.) Scenario 4, (D.) Scenario 5, and (E.) Scenario 6.

Note:

Scenario 1: No CO2 Emission tax - Base Number

Scenario 2: Biogenic CO2 emissions are not recognised as CO2 neutral

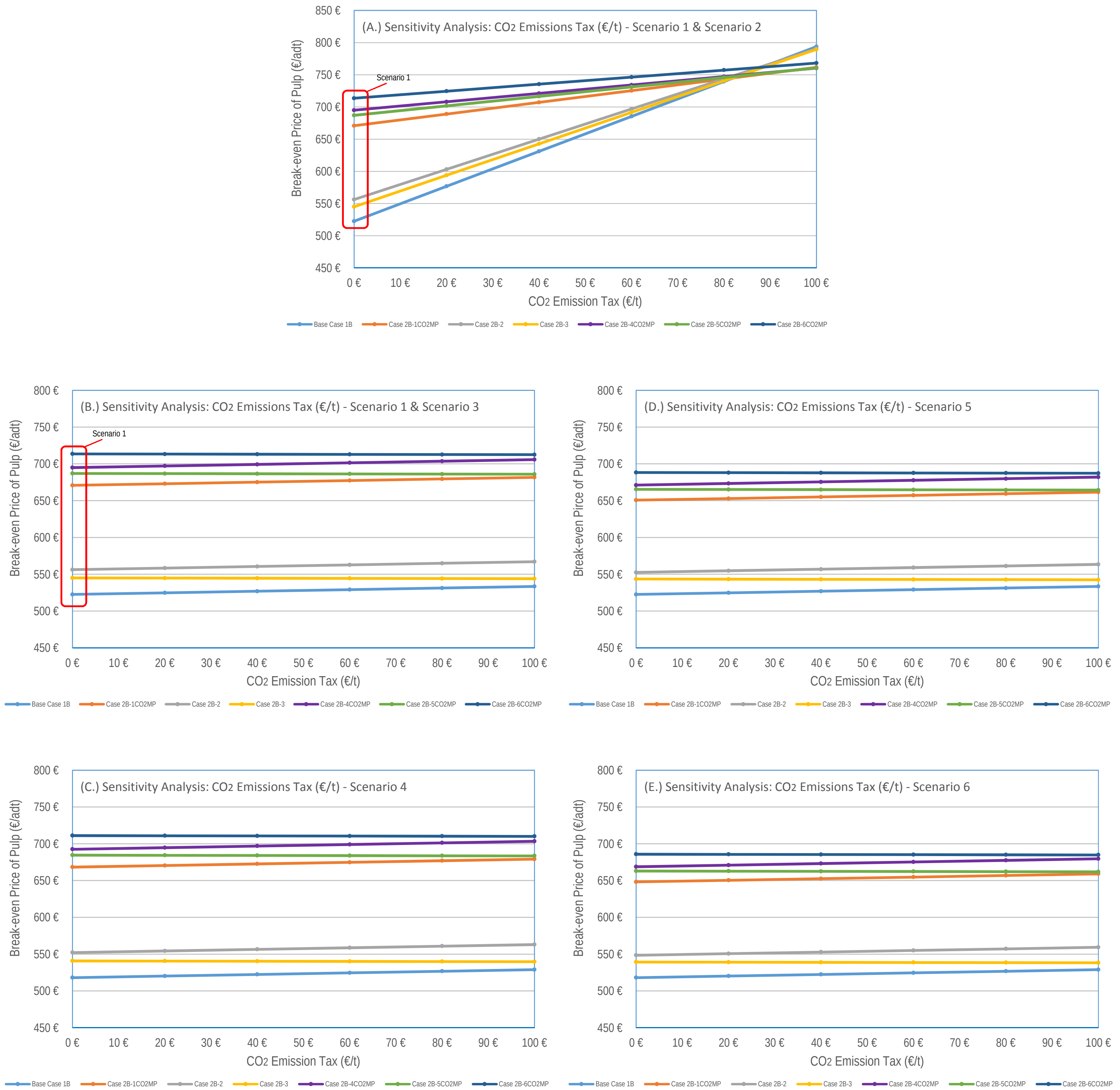
Scenario 3: All biogenic CO2 emissions are recognised as CO2 neutral therefore are tax exempted (only fossil CO2 emissions are taxed)

Scenario 4: All biogenic CO2 emissions are recognised as CO2 neutral therefore are tax exempted; additionally, renewable electricity exported to the grid are given extra credit at €4/MWh

Scenario 5: With the same conditions to Scenario 3 but with additional credit given to negative CO2 emissions at €10/t of captured biogenic CO2.

Scenario 6: With the same conditions to Scenario 4 but with additional credit given to negative CO2 emissions at €10/t of captured biogenic CO2.

Base Number: Wood price (€40/m^3); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)



Figures 24(A) to (E): Integrated pulp and board mill without and with CCS - sensitivity of pulp's break-even price to CO2 emission tax (A.) Scenario 1 & 2, (B.) Scenario 1 & 3, (C.) Scenario 4, (D.) Scenario 5, and (E.) Scenario 6.

Note:

Scenario 1: No CO2 Emission tax - Base Number

Scenario 2: Biogenic CO2 emissions are not recognised as CO2 neutral

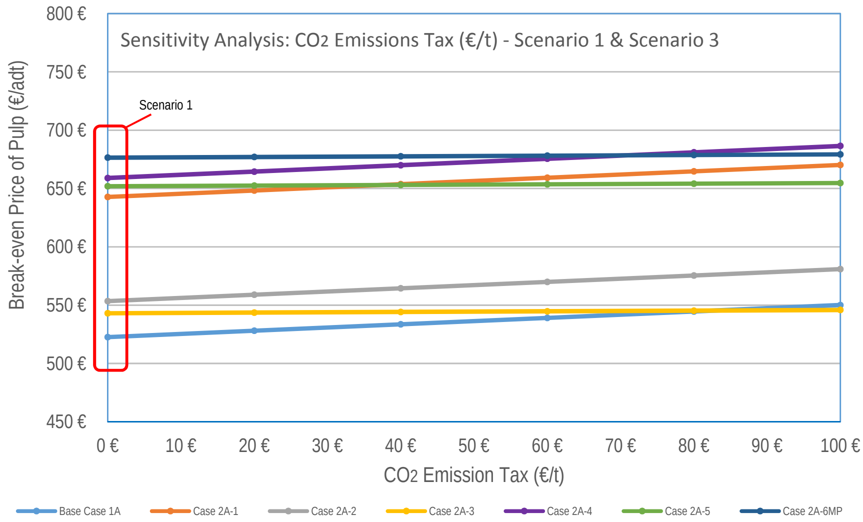
Scenario 3: All biogenic CO2 emissions are recognised as CO2 neutral therefore are tax exempted (only fossil CO2 emissions are taxed)

Scenario 4: All biogenic CO2 emissions are recognised as CO2 neutral therefore are tax exempted; additionally, renewable electricity exported to the grid are given extra credit at €4/MWh

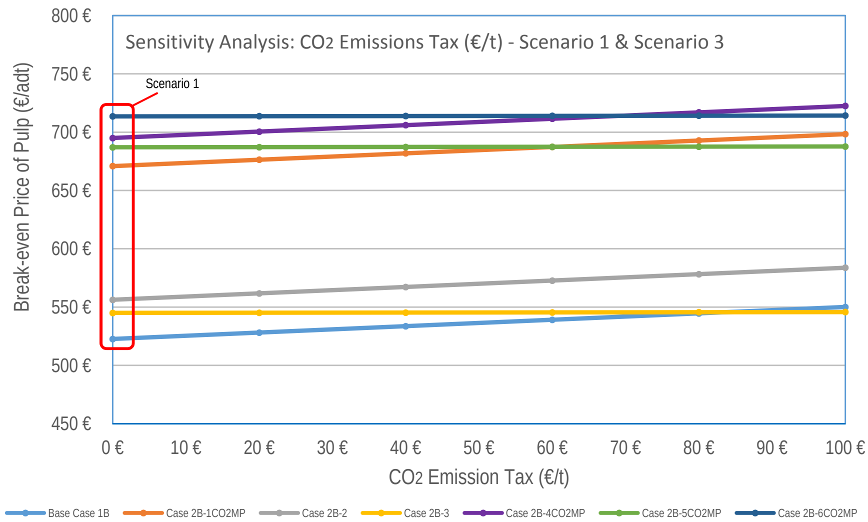
Scenario 5: With the same conditions to Scenario 3 but with additional credit given to negative CO2 emissions at €10/t of captured biogenic CO2.

Scenario 6: With the same conditions to Scenario 4 but with additional credit given to negative CO2 emissions at €10/t of captured biogenic CO2.

Base Number: Wood price (€40/m^3); Waste wood price (€19/m^3); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)



Figures 25: Pulp mill without and with CCS - sensitivity of pulp's break-even price to CO2 emission tax for Scenario 1 & 3 with the biogenic CO2 emissions of the lime kiln not being recognised as CO2 neutral therefore increasing the amount of CO2 emitted being taxed to ~10% of the total emission for the Base Case 1A - as compared to the 4% presented in Figure 23(B.)



Figures 26: Integrated pulp and board mill without and with CCS - sensitivity of pulp's break-even price to CO2 emission tax for Scenario 1 & 3 with the biogenic CO2 emissions of the lime kiln not being recognised as CO2 neutral therefore increasing the amount of CO2 emitted being taxed to ~10% of the total emission for the Base Case 1B - as compared to the 4% presented in Figure 24(B.)

Note:

Base Number: Wood price (€40/m^3); Waste wood price (€19/m^3); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)

Lime kiln's biogenic CO2 emission (for both base cases) is around 16 t/h or ~4% of the total emission of the site. Without recognising this as CO2 neutral, it increases the total CO2 emission being taxed to around 26t/h - equivalent or ~10% of the total emission.

7.2.2. Electricity price and renewable electricity credit

An important business element of the pulp (and board) production is the amount of excess electricity that could be sold to the grid. Assuming that all the raw material is sourced sustainably, electricity exported to the grid should be classified as renewable energy. Under scenario 4, the renewable electricity exported is given an additional credit.

The sensitivity of the pulp breakeven price to the electricity selling price and the associated renewable electricity credit have been evaluated for values between 20 to 100 €/MWh sold to the grid with renewable electricity credit being provided between 0% and 50% of the electricity selling price.

Figures 27(A) to 27(G) present the sensitivity of the pulp breakeven price to the electricity selling price and various level of renewable electricity credits for the market pulp mills with and without CCS.

Similarly, Figures 28(A) to 28(G) present the sensitivity of the pulp breakeven price to the electricity selling price and various level of renewable electricity credits for the integrated pulp and board mills with and without CCS.

From these assessments, it could be illustrated that the renewable electricity credit generally tends not to incentivise the deployment of CCS as this reduces the amount of excess electricity that could be sold to the grid (especially at conditions with high level of CO_2 capture rate and high electricity selling price).

7.2.3. Negative CO_2 emission credit

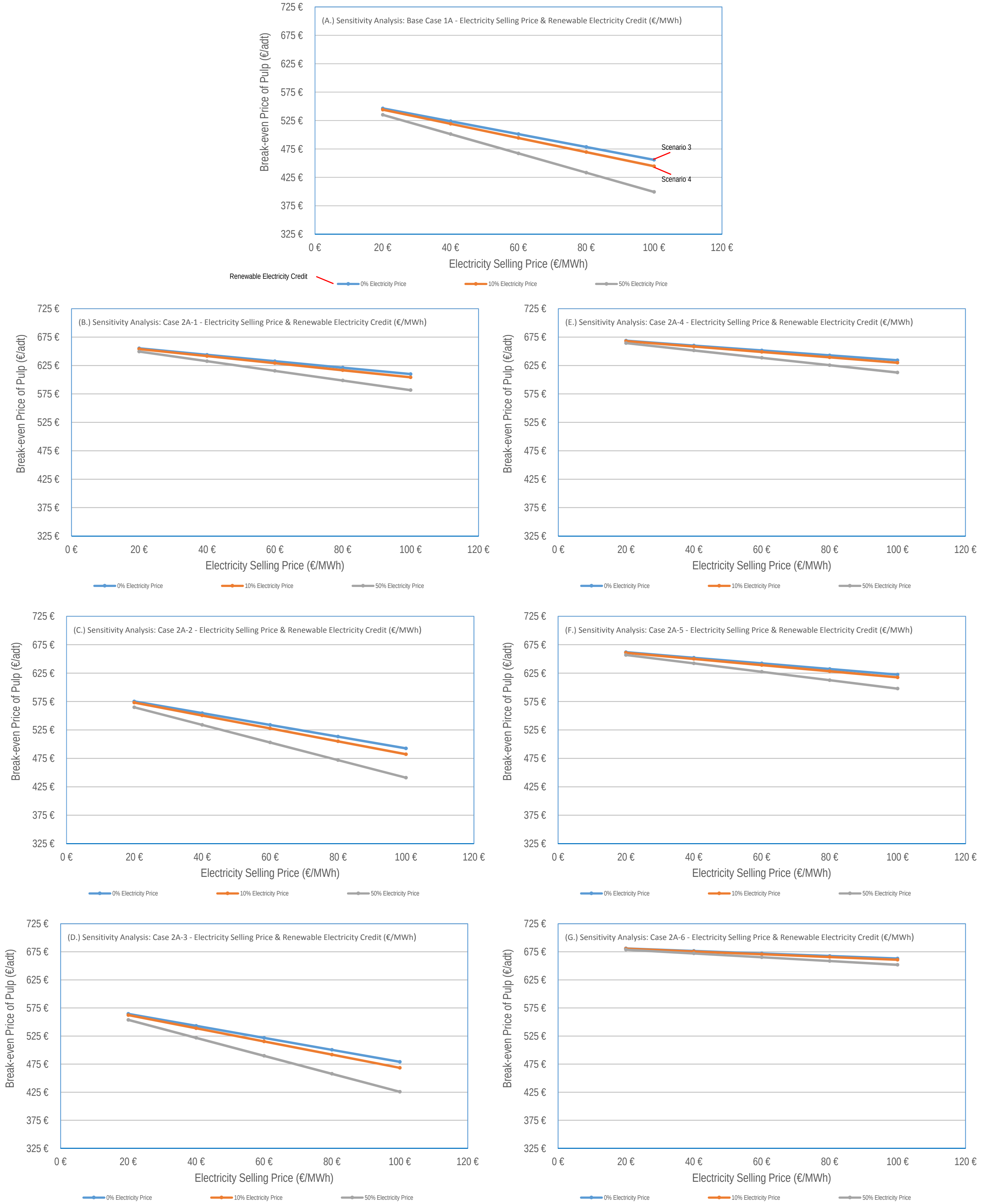
The credit given to the negative CO_2 emission has been evaluated to assess its potential to incentivise Bio-CCS.

The sensitivity of the pulp breakeven price to the CO_2 emission tax and associated negative emissions credit have been evaluated for values between 0 and 100 €/tonne of CO_2 emitted with credit being provided to negative CO_2 emissions for values between 0 and 100 €/tonne of biogenic CO_2 captured.

For the market pulp mill without and with CCS, Figures 29(A) to 29(D) present the sensitivity of the pulp breakeven price to the negative emissions credit at a CO_2 emission tax between 0 and 100 €/t under Scenarios 5 and 6, respectively.

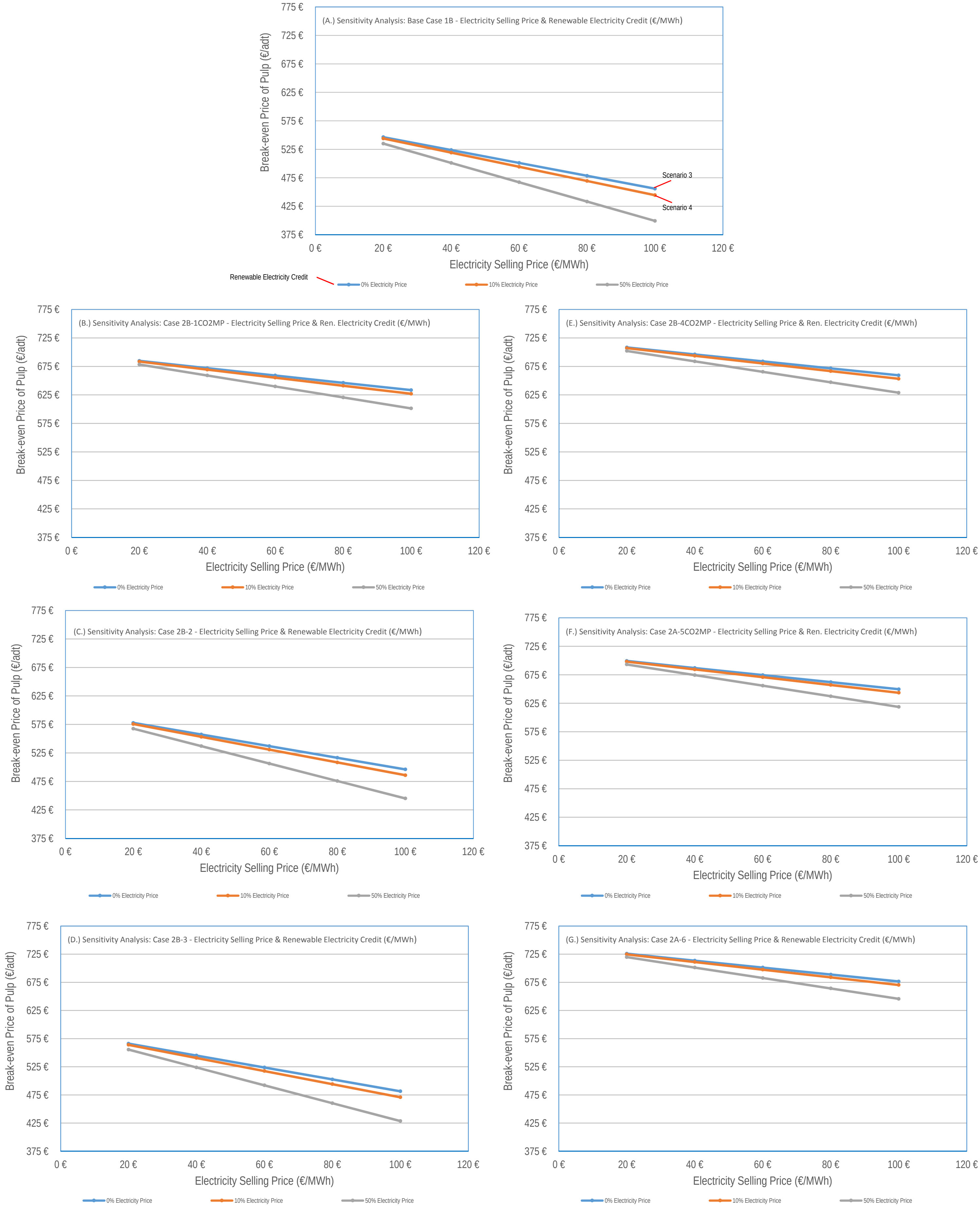
Similarly, for the integrated pulp and board mills without and with CCS, Figures 30(A) to 30(D) present the sensitivity of the pulp breakeven price to the negative emissions credit under Scenario 5 and 6, respectively.

In this assessment, it could be demonstrated that it is feasible to promote Bio-CCS by providing incentives for its negative CO_2 emissions. Furthermore, it could be observed that the addition of renewable electricity credit only provides minimal effect to the breakeven price of the market pulp.



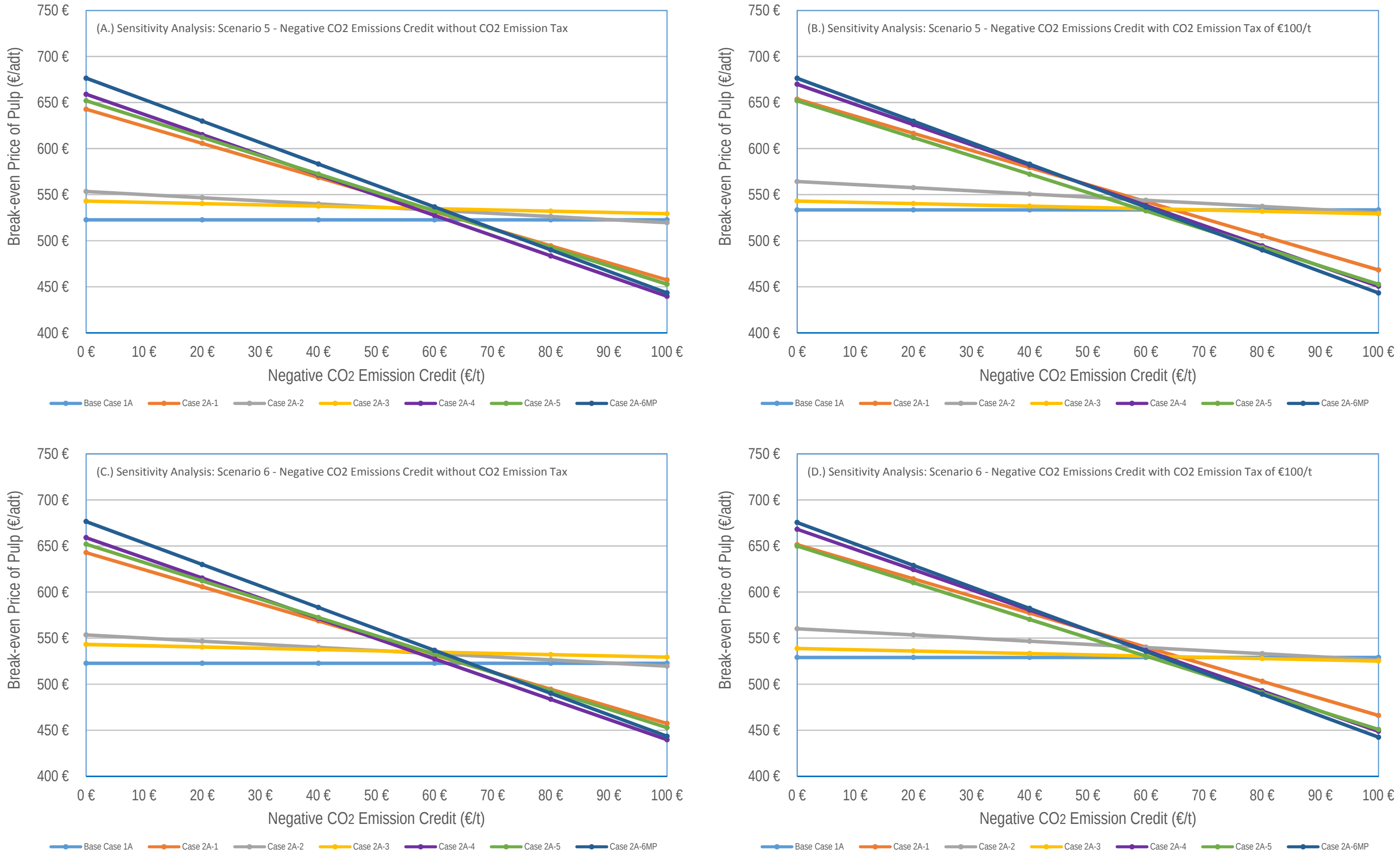
Figures 27(A) to (G): Pulp mill without and with CCS - sensitivity of pulp's break-even price to the electricity selling price and renewable electricity credit (A.) Base Case 1A, (B.) Case 2A-1, (C.) Case 2A-2, (D.) Case 2A-3, (E.) Case 2A-4, (F.) Case 2A-5, and (G.) Case 2A-6MP

Base Number: Wood price (€40/m^3); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)



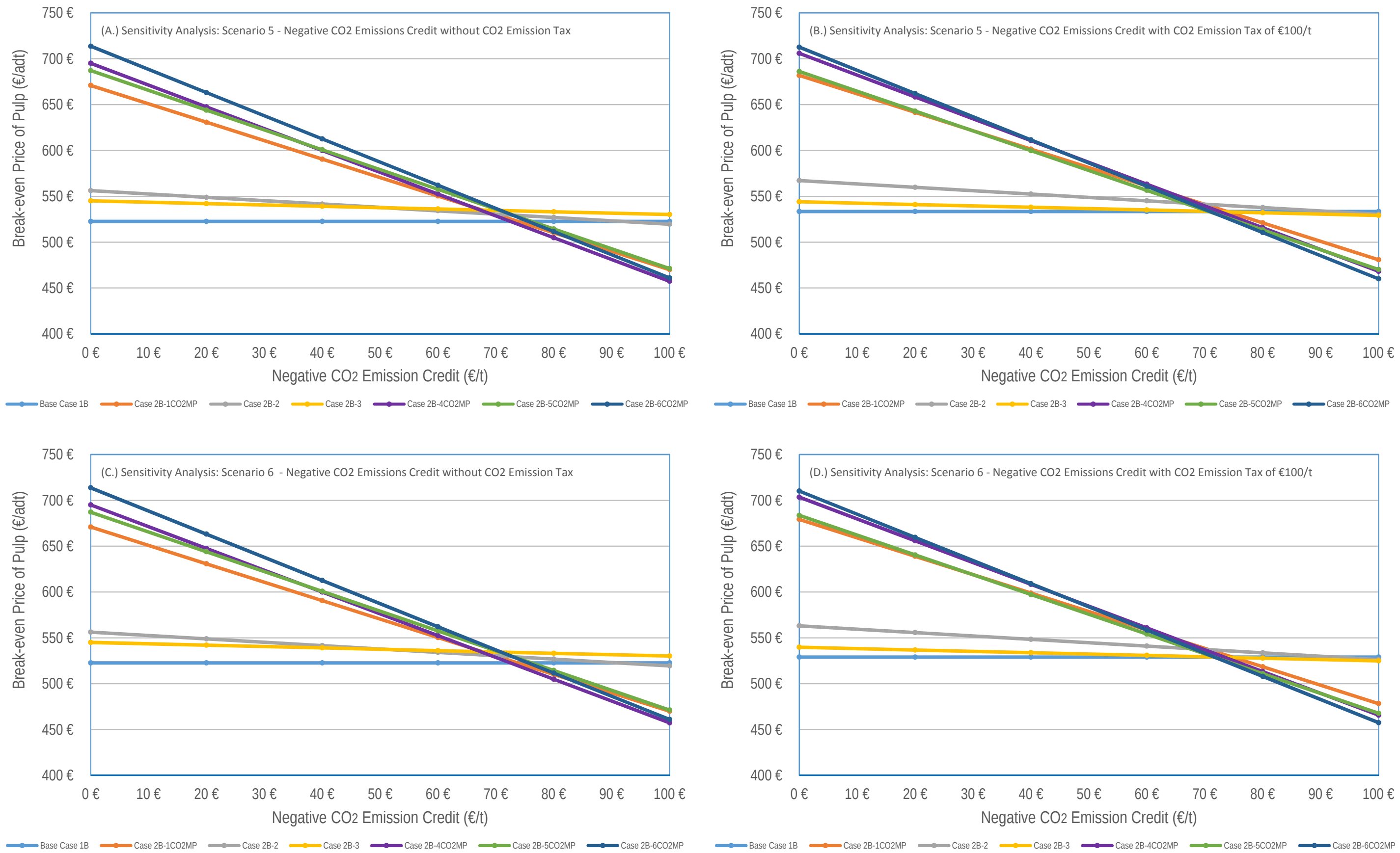
Figures 28(A) to (G): Integrated pulp and board mill without and with CCS - sensitivity of the pulp's break-even price to the electricity selling price and renewable electricity credit (A.) Base Case 1B, (B.) Case 2B-1CO2MP, (C.) Case 2B-2, (D.) Case 2B-3, (E.) Case 2B-4CO2MP, (F.) Case 2B-5CO2MP, and (G.) Case 2B-6CO2MP

Base Number: Wood price (€40/m³); waste wood price (€19/m³), HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)



Figures 29(A) to (D): Pulp mill without and with CCS - sensitivity of pulp's break-even price to the negative CO2 emissions credit (A.) Scenario 5 without CO2 emission tax (B.) Scenario 5 with CO2 emission tax of €100/t , (C.) Scenario 6 without CO2 emission tax and with renewable electricity credit of €4/MWh and (D.) Scenario 6 with CO2 emission tax of €100/t and renewable electricity credit of €4/MWh.

Base Number: Wood price (€40/m^3); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)



Figures 30(A) to (D): Integrated pulp and board mill without and with CCS - sensitivity of the pulp's break-even price to the negative CO2 emissions credit (A.) Scenario 5 without CO2 emission tax (B.) Scenario 5 with CO2 emission tax of €100/t, (C.) Scenario 6 without CO2 emission tax and with renewable electricity credit of €4/MWh and (D.) Scenario 6 with CO2 emission tax of €100/t and renewable electricity credit of €4/MWh.

Base Number: Wood price (€40/m^3); Wood price (€19/m^3); HFO price (€400/t); electricity price (€40/MWh); discount rate (8%); total plant cost (100% of TPC); and CO_2 transport & storage cost (€10/t)

References

[1] Kangas, P.; Kaijaluoto, S. and Santos, S. (2016). CCS in P&P Industry – Reference Plant: Economics Report. Project Report VTT-CR-01301-15. (Part of IEAGHG Report No. 2016-10).

[2] Onarheim, K., Santos, S., and Hankalin, V. (2016). CCS in P&P Industry – CCS Plant: Performance. Project Report VTT-CR-01051-16. (Part of IEAGHG Report No. 2016-10).

[3] IEAGHG. (2014). Criteria for Technical and Economic Assessment of Plants with Low CO_2 Emissions" Version C-6, March 2014.

Annexes

1. Market Pulp Mill without and with CCS - Annual Cash Flow
2. Integrated Pulp and Board Mill without and with CCS - Annual Cash Flow
3. Market Pulp Mill without and with CCS - Annual Operating Expenditure
4. Integrated Pulp and Board Mill without and with CCS – Annual Operating Expenditure
5. Sensitivity Analysis – New Build vs. Retrofit (Base Case 1A & Case 2A-1)
6. Sensitivity Analysis – Year of Retrofit (Case 2A-1)

CCS in P&P industry
Annex I: Market Pulp Mill
Annual Cash Flow

- Annex I-1: Base Case 1A – Market Pulp Mill (Reference Plant)
- Annex I-2: Case 2A-1 – Capture of CO_2 from Flue Gas of Recovery Boiler
- Annex I-3: Case 2A-2 – Capture of CO_2 from Flue Gas of Multi-fuel Boiler
- Annex I-4: Case 2A-3 – Capture of CO_2 from Flue Gas of Lime Kiln
- Annex I-5: Case 2A-4 – Capture of CO_2 from Flue Gases of Recovery Boiler and Multi-fuel Boiler
- Annex I-6: Case 2A-5 – Capture of CO_2 from Flue Gases of Recovery Boiler and Lime Kiln
- Annex I-7: Case 2A-6^{MP} – Capture of CO_2 from Flue Gases of Recovery Boiler, Multi-fuel Boiler and Lime Kiln

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill
Base Case 1A

				2005																									
Period	-3	-2	-1	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	26
Sales				352.32	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	
Selling and Distribution Expenses				-30.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	
Net Sales Revenue (€ milion)				***322.32***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	
Variable Costs				-174.16	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	
GHG Emissions Cost																													
CO2 Transport & Storage Cost																													
Gross Margin (€ milion)				***148.16***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	
Fixed Costs				-60.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	
Net Margin (€ milion)				***87.94***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-189.72	-395.94	-470.57	-143.84	-104.30																								
Working Capital				-37.12																									37.12
Recurring Capital																													
EBITDA (€ Million)	***-189.72***	***-395.94***	***-470.57***	***-93.03***	***28.02***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***37.12***

Internal Rate of Return (IRR)	**8.00%**
Discount Rate	8.00%
Net Present Value (NPV) - € Million	**(€ 0.00)**
Levelised Cost of Market Pulp	**€ 522.62**

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill
Case 2A-1

				2005										
Period	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11
Sales & Revenues				352.32	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	540.04	547.84
Selling and Distribution Expenses				-30.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00
Net Sales Revenue (€ milion)				***322.32***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***500.04***	***507.84***
` *Variable Costs*				-174.16	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-240.14	-241.03
GHG Emissions Cost														
CO2 Transport & Storage Cost													-13.31	-14.79
Gross Margin (€ milion)				***148.16***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***246.58***	***252.03***
Fixed Costs				-60.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-78.05	-78.05
Net Margin (€ milion)				***87.94***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***168.53***	***173.98***
Residual Value - Capital Expenditure														
Capital Expenditure	-189.72	-395.94	-470.57	-143.84	-104.30						-150.25	-172.30	-28.03	
Working Capital				-37.12									-4.44	-0.42
Recurring Capital														
EBITDA (€ Million)	***-189.72***	***-395.94***	***-470.57***	***-93.03***	***28.02***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***-17.93***	***-39.97***	***136.06***	***173.56***

Period	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Sales & Revenues	547.84	547.84	547.84	547.84	547.84	547.84	547.84	547.84	547.84	547.84	547.84	547.84	547.84	547.84	
Selling and Distribution Expenses	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	
Net Sales Revenue (€ milion)	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	***507.84***	
Variable Costs	-241.03	-241.03	-241.03	-241.03	-241.03	-241.03	-241.03	-241.03	-241.03	-241.03	-241.03	-241.03	-241.03	-241.03	
GHG Emissions Cost															
CO2 Transport & Storage Cost	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	
Gross Margin (€ milion)	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	***252.03***	
Fixed Costs	-78.05	-78.05	-78.05	-78.05	-78.05	-78.05	-78.05	-78.05	-78.05	-78.05	-78.05	-78.05	-78.05	-78.05	
Net Margin (€ milion)	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	
Residual Value - Capital Expenditure															
Capital Expenditure															
Working Capital															41.98
Recurring Capital															
EBITDA (€ Million)	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***173.98***	***41.98***

Internal Rate of Return (IRR)	**8.00%**						
Discount Rate	**8.00%**						
Net Present Value (NPV) - € Million	**(€ 0.00)**						
		Base Case 1A					
Levelised Cost of Market Pulp	**€ 642.77 per adt of pulp**	**€ 522.62**	**per adt of pulp**	CO2 Avoided	1.848	CAC	€ 65.01

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill

Case 2A-2

				2005																									
Period	-3	-2	-1	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	26
Sales & Revenues				352.32	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	489.14	491.29	491.29	491.29	491.29	491.29	491.29	491.29	491.29	491.29	491.29	491.29	491.29	491.29	491.29	491.29	
Selling and Distribution Expenses				-30.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	
Net Sales Revenue (€ milion)				***322.32***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***449.14***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	***451.29***	
Variable Costs				-174.16	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-233.88	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	-234.07	
GHG Emissions Cost																													
CO2 Transport & Storage Cost													-2.44	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	
Gross Margin (€ milion)				***148.16***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***212.82***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	***214.52***	
Fixed Costs				-60.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	-69.80	
Net Margin (€ milion)				***87.94***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***143.02***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-189.72	-395.94	-470.57	-143.84	-104.30						-44.79	-51.27	-8.35																
Working Capital				-37.12									-1.07	-0.11															38.30
Recurring Capital																													
EBITDA (€ Million)	***-189.72***	***-395.94***	***-470.57***	***-93.03***	***28.02***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***87.53***	***81.05***	***133.61***	***144.61***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***144.72***	***38.30***

Internal Rate of Return (IRR) **8.00%**

Discount Rate **8.00%**

Net Present Value (NPV) - € Million **(€ 0.00)**

Levelised Cost of Market Pulp **€ 553.46 per adt of pulp** Base Case 1A **€ 522.62 per adt of pulp** CO2 Avoided 0.338 CAC € 91.15

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill
Case 2A-3

				2005																									
Period	-3	-2	-1	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	26
Sales & Revenues				352.32	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	482.67	484.11	484.11	484.11	484.11	484.11	484.11	484.11	484.11	484.11	484.11	484.11	484.11	484.11	484.11	484.11	
Selling and Distribution Expenses				-30.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	
Net Sales Revenue (€ milion)				***322.32***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***442.67***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	***444.11***	
Variable Costs				-174.16	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-233.22	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	-233.33	
GHG Emissions Cost																													
CO2 Transport & Storage Cost													-1.77	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	
Gross Margin (€ milion)				***148.16***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***207.68***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	***208.81***	
Fixed Costs				-60.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	-68.59	
Net Margin (€ milion)				***87.94***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***139.09***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-189.72	-395.94	-470.57	-143.84	-104.30						-28.47	-32.61	-5.31																
Working Capital				-37.12									-0.72	-0.07															37.91
Recurring Capital																													
EBITDA (€ Million)	***-189.72***	***-395.94***	***-470.57***	***-93.03***	***28.02***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***103.85***	***99.72***	***133.06***	***140.14***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***140.21***	***37.91***

Internal Rate of Return (IRR)	**8.00%**						
Discount Rate	**8.00%**						
Net Present Value (NPV) - € Million	**(€ 0.00)**		Base Case 1A				
Levelised Cost of Market Pulp	**€ 543.09 per adt of pulp**		**€ 522.62 per adt of pulp**	CO2 Avoided	0.246	CAC	€ 83.13

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill
Case 2A-4

				2005									
Period	-3	-2	-1	1	2	3	4	5	6	7	8	9	10
Sales & Revenues				352.32	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	547.91
Selling and Distribution Expenses				-30.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00
Net Sales Revenue (€ milion)				***322.32***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***507.91***
Variable Costs				-174.16	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-240.27
GHG Emissions Cost													
CO2 Transport & Storage Cost													-15.75
Gross Margin (€ milion)				***148.16***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***251.89***
Fixed Costs				-60.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-79.29
Net Margin (€ milion)				***87.94***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***172.60***
Residual Value - Capital Expenditure													
Capital Expenditure	-189.72	-395.94	-470.57	-143.84	-104.30						-166.98	-191.53	-31.16
Working Capital				-37.12									-5.07
Recurring Capital													
EBITDA (€ Million)	***-189.72***	***-395.94***	***-470.57***	***-93.03***	***28.02***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***-34.66***	***-59.21***	***136.37***

Period	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Sales & Revenues	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	
Selling and Distribution Expenses	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	
Net Sales Revenue (€ milion)	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	***516.59***	
Variable Costs	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	-241.17	
GHG Emissions Cost																
CO2 Transport & Storage Cost	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	
Gross Margin (€ milion)	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	***257.93***	
Fixed Costs	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	-79.29	
Net Margin (€ milion)	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	
Residual Value - Capital Expenditure																
Capital Expenditure																
Working Capital	-0.48															42.68
Recurring Capital																
EBITDA (€ Million)	***178.15***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***178.64***	***42.68***

Internal Rate of Return (IRR) **8.00%**

Discount Rate **8.00%**

Net Present Value (NPV) - € Million **(€ 0.00)**

Levelised Cost of Market Pulp **€ 659.04 per adt of pulp** — Base Case 1A **€ 522.62 per adt of pulp** — CO2 Avoided 2.187 — CAC € 62.38

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill

Case 2A-5

				2005																									
Period	-3	-2	-1	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	26
Sales & Revenues				352.32	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	544.60	552.92	552.92	552.92	552.92	552.92	552.92	552.92	552.92	552.92	552.92	552.92	552.92	552.92	552.92	552.92	
Selling and Distribution Expenses				-30.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	
Net Sales Revenue (€ milion)				***322.32***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***504.60***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	***512.92***	
Variable Costs				-174.16	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-240.41	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	-241.32	
GHG Emissions Cost																													
CO2 Transport & Storage Cost													-15.08	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	
Gross Margin (€ milion)				***148.16***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***249.11***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	***254.84***	
Fixed Costs				-60.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	-78.64	
Net Margin (€ milion)				***87.94***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***170.47***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-189.72	-395.94	-470.57	-143.84	-104.30						-158.18	-181.43	-29.52																
Working Capital				-37.12									-4.81	-0.46															42.39
Recurring Capital																													
EBITDA (€ Million)	***-189.72***	***-395.94***	***-470.57***	***-93.03***	***28.02***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***-25.85***	***-49.10***	***136.14***	***175.74***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***176.20***	***42.39***

Internal Rate of Return (IRR)	**8.00%**						
Discount Rate	**8.00%**						
Net Present Value (NPV) - € Million	**€ 0.00**		Base Case 1A				
Levelised Cost of Market Pulp	**€ 651.99 per adt of pulp**		**€ 522.62 per adt of pulp**	CO2 Avoided	2.095	CAC	€ 61.76

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill
Case 2A-6MP

				2005																								
Period	-3	-2	-1	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	26
Sales & Revenues				352.32	469.76	469.76	469.76	469.76	469.76	469.76	469.76	469.76	554.53	563.95	563.95	563.95	563.95	563.95	563.95	563.95	563.95	563.95	563.95	563.95	563.95	563.95	563.95	563.95	
Selling and Distribution Expenses				-30.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	-40.00	
Net Sales Revenue (€ milion)				***322.32***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***429.76***	***514.53***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	***523.95***	
Variable Costs				-174.16	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-232.22	-242.29	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	-243.41	
GHG Emissions Cost																													
CO2 Transport & Storage Cost													-17.52	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	
Gross Margin (€ milion)				***148.16***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***197.54***	***254.72***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	***261.07***	
Fixed Costs				-60.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-65.22	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	-79.95	
Net Margin (€ milion)				***87.94***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***174.77***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-189.72	-395.94	-470.57	-143.84	-104.30						-175.82	-201.72	-32.81																
Working Capital				-37.12									-5.72	-0.54															43.39
Recurring Capital																													
EBITDA (€ Million)	***-189.72***	***-395.94***	***-470.57***	***-93.03***	***28.02***	***132.33***	***132.33***	***132.33***	***132.33***	***132.33***	***-43.49***	***-69.40***	***136.24***	***180.58***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***181.12***	***43.39***

Internal Rate of Return (IRR) **8.00%**

Discount Rate **8.00%**

Net Present Value (NPV) - € Million **(€ 0.00)**

Base Case 1A

Levelised Cost of Market Pulp **€ 676.49 per adt of pulp** **€ 522.62 per adt of pulp** CO2 Avoided 2.433 CAC € 63.24

CCS in P&P industry
Annex II: Integrated Pulp & Board Mill Annual Cash Flow

- Annex II-1: Base Case 1B – Integrated Pulp & Board Mill (Reference Plant)
- Annex II-2: Case 2B-1^{CO2MP} – Capture of CO_2 from Flue Gas of Recovery Boiler
- Annex II-3: Case 2B-2 – Capture of CO_2 from Flue Gas of Multi-fuel Boiler
- Annex II-4: Case 2B-3 – Capture of CO_2 from Flue Gas of Lime Kiln
- Annex II-5: Case 2B-4^{CO2MP} – Capture of CO_2 from Flue Gases of Recovery Boiler and Multi-fuel Boiler
- Annex II-6: Case 2B-5^{CO2MP} – Capture of CO_2 from Flue Gases of Recovery Boiler and Lime Kiln
- Annex II-7: Case 2B-6^{CO2MP} – Capture of CO_2 from Flue Gases of Recovery Boiler, Multi-fuel Boiler and Lime Kiln

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp and Board Mill
Base Case 1B

				2005																									
Period	-3	-2	-1	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	26
Sales				520.95	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	
Selling and Distribution Expenses				-42.69	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	
Net Sales Revenue (€ milion)				***478.26***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	
Variable Costs				-293.03	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	
GHG Emissions Cost																													
CO2 Transport & Storage Cost																													
Gross Margin (€ milion)				***185.23***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	
Fixed Costs				-82.98	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	
Net Margin (€ milion)				***102.25***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-223.96	-467.39	-548.51	-168.83	-122.43																								
Working Capital				-61.04																									61.04
Recurring Capital																													
EBITDA (€ Million)	***-223.96***	***-467.39***	***-548.51***	***-127.62***	***34.45***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***61.04***

Internal Rate of Return (IRR)	**8.00%**
Discount Rate	**8.00%**
Net Present Value (NPV) - € Million	**(€ 0.00)**
Levelised Cost of Board	**€ 679.47**
Levelised Cost of Pulp (Base Case 1A)	**€ 522.62**

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-1CO2MP

Period	-3	-2	-1	1 (2005)	2	3	4	5	6	7	8	9	10	11	12
Sales				520.95	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	780.16	789.67	789.67
Selling and Distribution Expenses				-42.69	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92
Net Sales Revenue (€ milion)				***478.26***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***723.24***	***732.75***	***732.75***
Variable Costs				-293.03	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-405.55	-407.20	-407.20
GHG Emissions Cost															
CO2 Transport & Storage Cost													-13.31	-14.79	-14.79
Gross Margin (€ milion)				***185.23***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***304.39***	***310.77***	***310.77***
Fixed Costs				-82.98	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-105.51	-105.51	-105.51
Net Margin (€ milion)				***102.25***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***198.88***	***205.26***	***205.26***
Residual Value - Capital Expenditure															
Capital Expenditure	-223.96	-467.39	-548.51	-168.83	-122.43						-173.69	-200.68	-32.54		
Working Capital				-61.04									-5.53	-0.55	
Recurring Capital															
EBITDA (€ Million)	***-223.96***	***-467.39***	***-548.51***	***-127.62***	***34.45***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***-16.81***	***-43.80***	***160.81***	***204.72***	***205.26***

Period	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Sales	789.67	789.67	789.67	789.67	789.67	789.67	789.67	789.67	789.67	789.67	789.67	789.67	789.67	
Selling and Distribution Expenses	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	
Net Sales Revenue (€ milion)	***732.75***	***732.75***	***732.75***	***732.75***	***732.75***	***732.75***	***732.75***	***732.75***	***732.75***	***732.75***	***732.75***	***732.75***	***732.75***	
Variable Costs	-407.20	-407.20	-407.20	-407.20	-407.20	-407.20	-407.20	-407.20	-407.20	-407.20	-407.20	-407.20	-407.20	
GHG Emissions Cost														
CO2 Transport & Storage Cost	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	-14.79	
Gross Margin (€ milion)	***310.77***	***310.77***	***310.77***	***310.77***	***310.77***	***310.77***	***310.77***	***310.77***	***310.77***	***310.77***	***310.77***	***310.77***	***310.77***	
Fixed Costs	-105.51	-105.51	-105.51	-105.51	-105.51	-105.51	-105.51	-105.51	-105.51	-105.51	-105.51	-105.51	-105.51	
Net Margin (€ milion)	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	
Residual Value - Capital Expenditure														
Capital Expenditure														
Working Capital														67.12
Recurring Capital														
EBITDA (€ Million)	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***205.26***	***67.12***

Internal Rate of Return (IRR)	**8.00%**						
Discount Rate	**8.00%**						
Net Present Value (NPV) - € Million	**(€ 0.00)**	Base Case 1B					
Levelised Cost of Pulp	**€ 670.87**	**€ 522.62**	per adt of pulp	CO2 Avoided	1.800	CAC	€ 82.35
Levelised Cost of Board	**€ 679.47**	**€ 679.47**	per adt of board				

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-2

Period	-3	-2	-1	1 (2005)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Sales				520.95	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	714.02	716.17	716.17	716.17	716.17	716.17	716.17	716.17	716.17	716.17	716.17	716.17	716.17	716.17	716.17	716.17	
Selling and Distribution Expenses				-42.69	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	
Net Sales Revenue (€ milion)				***478.26***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***657.10***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	***659.25***	
Variable Costs				-293.03	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-392.39	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	-392.58	
GHG Emissions Cost																													
CO2 Transport & Storage Cost													-2.44	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	-2.71	
Gross Margin (€ milion)				***185.23***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***262.27***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	***263.97***	
Fixed Costs				-82.98	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	-94.68	
Net Margin (€ milion)				***102.25***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***167.59***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-223.96	-467.39	-548.51	-168.83	-122.43						-44.84	-51.32	-8.36																
Working Capital				-61.04									-1.07	-0.11															62.22
Recurring Capital																													
EBITDA (€ Million)	***-223.96***	***-467.39***	***-548.51***	***-127.62***	***34.45***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***112.04***	***105.56***	***158.16***	***169.18***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***169.29***	***62.22***

Internal Rate of Return (IRR)	**8.00%**						
Discount Rate	**8.00%**						
Net Present Value (NPV) - € Million	**(€ 0.00)**						
		Base Case 1B					
Levelised Cost of Pulp (Case 2A-2)	**€ 556.25**	**€ 522.62**	per adt of pulp	CO2 Avoided	0.367	CAC	€ 91.76
Levelised Cost of Board	**€ 679.47**	**€ 679.47**	per adt of board				

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-3

				2005																								
Period	-3	-2	-1	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	26
Sales				520.95	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	707.55	708.99	708.99	708.99	708.99	708.99	708.99	708.99	708.99	708.99	708.99	708.99	708.99	708.99	708.99	708.99	
Selling and Distribution Expenses				-42.69	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	
Net Sales Revenue (€ milion)				***478.26***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***650.63***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	***652.07***	
Variable Costs				-293.03	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-391.72	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	-391.84	
GHG Emissions Cost																													
CO2 Transport & Storage Cost													-1.77	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	-1.97	
Gross Margin (€ milion)				***185.23***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***257.13***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	***258.26***	
Fixed Costs				-82.98	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	-93.48	
Net Margin (€ milion)				***102.25***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***163.65***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-223.96	-467.39	-548.51	-168.83	-122.43						-28.52	-32.65	-5.32																
Working Capital				-61.04									-0.72	-0.07															61.84
Recurring Capital																													
EBITDA (€ Million)	***-223.96***	***-467.39***	***-548.51***	***-127.62***	***34.45***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***128.36***	***124.23***	***157.61***	***164.71***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***164.78***	***61.84***

Internal Rate of Return (IRR)	**8.00%**						
Discount Rate	8.00%						
Net Present Value (NPV) - € Million	**(€ 0.00)**	Base Case 1B					
Levelised Cost of Pulp (Base Case 1A)	**€ 545.02**	**€ 522.62**	per adt of pulp	CO2 Avoided	0.267	CAC	€ 83.96
Levelised Cost of Board	**€ 679.47**	**€ 679.47**	per adt of board				

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-4CO2MP

				2005																									
Period	-3	-2	-1	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	26
Sales				520.95	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	795.38	806.58	806.58	806.58	806.58	806.58	806.58	806.58	806.58	806.58	806.58	806.58	806.58	806.58	806.58	806.58	
Selling and Distribution Expenses				-42.69	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	
Net Sales Revenue (€ milion)				***478.26***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***738.46***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	***749.66***	
Variable Costs				-293.03	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-410.61	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	-412.83	
GHG Emissions Cost																													
CO2 Transport & Storage Cost		0.60											-15.75	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	-17.50	
Gross Margin (€ milion)				***185.23***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***312.10***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	***319.34***	
Fixed Costs				-82.98	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	-107.30	
Net Margin (€ milion)				***102.25***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***204.80***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-223.96	-467.39	-548.51	-168.83	-122.43						-197.90	-228.69	-37.08																
Working Capital				-61.04									-6.67	-0.66															68.38
Recurring Capital																													
EBITDA (€ Million)	***-223.96***	***-467.39***	***-548.51***	***-127.62***	***34.45***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***-41.02***	***-71.81***	***161.05***	***211.38***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***212.04***	***68.38***

Internal Rate of Return (IRR)	**8.00%**						
Discount Rate	**8.00%**						
Net Present Value (NPV) - € Million	**(€ 0.00)**	**Base Case 1B**					
Levelised Cost of Pulp	**€ 695.00**	**€ 522.62**	per adt of pulp	CO2 Avoided	2.055	CAC	€ 83.88
Levelised Cost of Board	**€ 679.47**	**€ 679.47**	per adt of board				

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-5CO2MP

Period	-3	-2	-1	1 (2005)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Sales				520.95	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	790.35	800.98	800.98	800.98	800.98	800.98	800.98	800.98	800.98	800.98	800.98	800.98	800.98	800.98	800.98	800.98	
Selling and Distribution Expenses				-42.69	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	
Net Sales Revenue (€ milion)				***478.26***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***733.43***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	***744.06***	
Variable Costs				-293.03	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-409.38	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	-411.46	
GHG Emissions Cost																													
CO2 Transport & Storage Cost													-15.08	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	-16.76	
Gross Margin (€ milion)				***185.23***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***308.96***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	***315.85***	
Fixed Costs				-82.98	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	-106.57	
Net Margin (€ milion)				***102.25***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***202.39***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-223.96	-467.39	-548.51	-168.83	-122.43						-187.98	-217.22	-35.22																
Working Capital				-61.04									-6.35	-0.63															68.02
Recurring Capital																													
EBITDA (€ Million)	***-223.96***	***-467.39***	***-548.51***	***-127.62***	***34.45***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***-31.10***	***-60.34***	***160.82***	***208.64***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***209.27***	***68.02***

Internal Rate of Return (IRR)	**8.00%**						
Discount Rate	**8.00%**						
Net Present Value (NPV) - € Million	**(€ 0.00)**						
		Base Case 1B					
Levelised Cost of Pulp	**€ 687.03**	**€ 522.62**	per adt of pulp	CO2 Avoided	1.972	CAC	€ 83.36
Levelised Cost of Board	**€ 679.47**	**€ 679.47**	per adt of board (Base Case 1B)				

Cash Flow (€ Million) - EBITDA Basis

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-6CO2MP

				2005																									
Period	-3	-2	-1	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	26
Sales				520.95	694.60	694.60	694.60	694.60	694.60	694.60	694.60	694.60	807.91	820.50	820.50	820.50	820.50	820.50	820.50	820.50	820.50	820.50	820.50	820.50	820.50	820.50	820.50	820.50	
Selling and Distribution Expenses				-42.69	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	-56.92	
Net Sales Revenue (€ milion)				***478.26***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***637.68***	***750.99***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	***763.58***	
Variable Costs				-293.03	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-390.70	-417.99	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	-421.02	
GHG Emissions Cost																													
CO2 Transport & Storage Cost													-17.52	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	-19.47	
Gross Margin (€ milion)				***185.23***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***246.98***	***315.48***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	***323.09***	
Fixed Costs				-82.98	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-90.10	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	-108.08	
Net Margin (€ milion)				***102.25***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***207.40***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	
Residual Value - Capital Expenditure																													
Capital Expenditure	-223.96	-467.39	-548.51	-168.83	-122.43						-208.32	-240.79	-39.03																
Working Capital				-61.04									-7.77	-0.77															69.59
Recurring Capital																													
EBITDA (€ Million)	***-223.96***	***-467.39***	***-548.51***	***-127.62***	***34.45***	***156.88***	***156.88***	***156.88***	***156.88***	***156.88***	***-51.44***	***-83.91***	***160.59***	***214.24***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***215.01***	***69.59***

Internal Rate of Return (IRR)	**8.00%**						
Discount Rate	**8.00%**						
Net Present Value (NPV) - € Million	**(€ 0.00)**	**Base Case 1B**					
Levelised Cost of Pulp	**€ 713.59**	**€ 522.62**	per adt of pulp	CO2 Avoided	2.164	CAC	€ 88.27
Levelised Cost of Board	**€ 679.47**	**€ 679.47**	per adt of board				

CCS in P&P industry
Annex III: Market Pulp Mill
Annual Operating Expenditure

- Annex III-1: Base Case 1A – Market Pulp Mill (Reference Plant)
- Annex III-2: Case 2A-1 – Capture of CO_2 from Flue Gas of Recovery Boiler
- Annex III-3: Case 2A-2 – Capture of CO_2 from Flue Gas of Multi-fuel Boiler
- Annex III-4: Case 2A-3 – Capture of CO_2 from Flue Gas of Lime Kiln
- Annex III-5: Case 2A-4 – Capture of CO_2 from Flue Gases of Recovery Boiler and Multi-fuel Boiler
- Annex III-6: Case 2A-5 – Capture of CO_2 from Flue Gases of Recovery Boiler and Lime Kiln
- Annex III-7: Case 2A-6^{MP} – Capture of CO_2 from Flue Gases of Recovery Boiler, Multi-fuel Boiler and Lime Kiln

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill
Base Case 1A

	Base Number €'000/y	Period	-3	-2	-1	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
1. Fixed Cost ('000)																														
1a. Direct Labour	€ *7,200.00*					7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00
1b. Indirect Labour Cost	€ *2,880.00*					2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ *20,000.00*					15,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00
1d. Maintenance	€ *35,139.50*					35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50
	Total (Fixed O&M Cost)					**€ 60,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**
2. Variable Cost ('000)																														
2a. Raw Materials	***€ 185,600.00***																													
Wood	*185,600.00*					139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	-																													
CTMP	-																													
Filler	-																													
Coating	-																													
2b. Chemicals	***€ 27,250.40***																													
NaOH	*11,011.20*					8,258.40	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20
H2O2	*2,960.00*					2,220.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	*840.00*					630.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	*499.20*					374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	*800.00*					600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	*9,800.00*					7,350.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	*700.00*					525.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	*640.00*					480.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
2c. Utilities	***€ 6,646.07***																													
Cooling Water	*5,177.23*					3,882.92	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23
Process Water	*1,308.69*					981.52	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69
Boiler Feed Water Make Up	*160.14*					120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14
2d. Fuel Cost	***€ 11,200.00***																													
HFO	*11,200.00*					8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	***€ 1,521.92***																													
Rejects from Brown Stock Handling	*72.00*					54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	*0.80*					0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	*40.00*					30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	*13.60*					10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	*60.00*					45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	*55.44*					41.58	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill	-																													
Waste Water Effluent Discharge	*1,280.08*					960.06	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08
	Total (Variable O&M Cost)					**€ 174,163.80**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**
3. Revenues ('000)																														
3a. Board	€ -																													
3b. Electrcity Export (Import) to the Grid	€ *36,068.80*					27,051.60	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80
3c. CTO	€ *15,600.00*					11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
	Total (Additional Revenues)					**€ 38,751.60**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**
4. GHG Emissions Cost ('000)																														
4a. CO2 Emission Tax	€ -																													
4b. CO2 Emission Tax Credit	€ -																													
4c. Renewable Energy Credit	€ -																													
	Total (GHG Emissions Cost)																													
5. CO2 Transport & Storage ('000)																														
5a. CO2 Transport & Storage	€ -																													
	Total (CO2 Transport & Storage)																													

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill

Case 2A-1

	Base Number €'000/y	Period -3	-2	-1	2005 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
1. Fixed Cost ('000)																													
1a. Direct Labour	€ 7,200.00				7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00
1b. Indirect Labour Cost	€ 2,880.00				2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 20,000.00				15,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41	22,782.41
1d. Maintenance	€ 35,139.50				35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34	43,507.34
	Total (Fixed O&M Cost)				**€ 60,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**	**€ 78,049.75**
2. Variable Cost ('000)																													
2a. Raw Materials	***€ 185,600.00***																												
Wood	*185,600.00*				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	-																												
CTMP	-																												
Filler	-																												
Coating	-																												
2b. Chemicals	***€ 27,250.40***																												
NaOH	*11,011.20*				8,258.40	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,075.16	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26	11,082.26
H2O2	*2,960.00*				2,220.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	*840.00*				630.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	*499.20*				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	*800.00*				600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	*9,800.00*				7,350.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	*700.00*				525.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	*640.00*				480.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
MEA (Make Up)	-													2,583.67	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74
2c. Utilities	***€ 6,646.07***																												
Cooling Water	*5,177.23*				3,882.92	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	9,962.12	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77	10,493.77
Process Water	*1,308.69*				981.52	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,374.07	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34	1,381.34
Boiler Feed Water Make Up	*160.14*				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	179.57	181.73	181.73	181.73	181.73	181.73	181.73	181.73	181.73	181.73	181.73	181.73	181.73	181.73	181.73	181.73
2d. Fuel Cost	***€ 11,200.00***																												
HFO	*11,200.00*				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	***€ 1,521.92***																												
Rejects from Brown Stock Handling	*72.00*				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	*0.80*				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	*40.00*				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	*13.60*				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	*60.00*				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	*55.44*				41.58	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill	-																												
MEA Sludge	-													303.02	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69
Waste Water Effluent Discharge	*1,280.08*				960.06	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,385.69	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42	1,397.42
	Total (Variable O&M Cost)				**€ 174,163.80**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 240,144.34**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**	**€ 241,025.00**
3. Revenues ('000)																													
3b. Electrcity Export (Import) to the Grid	€ 36,068.80				27,051.60	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	19,829.92	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60	18,025.60
3c. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
	Total (Additional Revenues)				**€ 38,751.60**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 35,429.92**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**	**€ 33,625.60**
4. GHG Emissions Cost ('000)																													
4a. CO2 Emission Tax	€ -																												
4b. CO2 Emission Tax Credit	€ -																												
4c. Renewable Electricity Credit	€ -																												
4d. Bio-CCS Credit	€ -																												
	Total (GHG Emissions Cost)																												
5. CO2 Transport & Storage ('000)																													
5a. CO2 Transport & Storage	€ 14,787.00													13,308.30	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00
	Total (CO2 Transport & Storage)													**€ 13,308.30**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill
Case 2A-2

Period	Base Number €'000/y	-3	-2	-1	1 (2005)	2	3	4	5	6	7	8	9
1. Fixed Cost ('000)													
1a. Direct Labour	€ 7,200.00				7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00
1b. Indirect Labour Cost	€ 2,880.00				2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 20,000.00				15,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00
1d. Maintenance	€ 35,139.50				35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50
Total (Fixed O&M Cost)					**€ 60,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**
2. Variable Cost ('000)													
2a. Raw Materials	***€ 185,600.00***												
Wood	*185,600.00*				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	-												
CTMP	-												
Filler	-												
Coating	-												
2b. Chemicals	***€ 27,250.40***												
NaOH	*11,011.20*				8,258.40	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20
H2O2	*2,960.00*				2,220.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	*840.00*				630.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	*499.20*				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	*800.00*				600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	*9,800.00*				7,350.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	*700.00*				525.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	*640.00*				480.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
MEA (Make Up)	-												
2c. Utilities	***€ 6,646.07***												
Cooling Water	*5,177.23*				3,882.92	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23
Process Water	*1,308.69*				981.52	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69
Boiler Feed Water Make Up	*160.14*				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14
2d. Fuel Cost	***€ 11,200.00***												
HFO	*11,200.00*				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	***€ 1,521.92***												
Rejects from Brown Stock Handling	*72.00*				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	*0.80*				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	*40.00*				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	*13.60*				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	*60.00*				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	*55.44*				41.58	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill	-												
MEA Sludge	-												
Waste Water Effluent Discharge	*1,280.08*				960.06	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08
Total (Variable O&M Cost)					**€ 174,163.80**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**
3. Revenues ('000)													
3a. Electrcity Export (Import) to the Grid	€ 36,068.80				27,051.60	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)					**€ 38,751.60**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**
4. GHG Emissions Cost ('000)													
4a. CO2 Emission Tax	€ -												
4b. CO2 Emission Tax Credit	€ -												
4c. Renewable Electricity Credit	€ -												
4d. Bio-CCS Credit	€ -												
Total (GHG Emissions Cost)													
5. CO2 Transport & Storage ('000)													
5a. CO2 Transport & Storage	€ 2,706.58												
Total (CO2 Transport & Storage)													

Period	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)																
1a. Direct Labour	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00
1b. Indirect Labour Cost	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50	20,829.50
1d. Maintenance	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01	37,628.01
Total (Fixed O&M Cost)	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**	**€ 69,797.51**
2. Variable Cost ('000)																
2a. Raw Materials																
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP																
CTMP																
Filler																
Coating																
2b. Chemicals																
NaOH	11,022.92	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22	11,024.22
H2O2	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
MEA (Make Up)	473.56	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17
2c. Utilities																
Cooling Water	6,256.17	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05	6,376.05
Process Water	1,318.65	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75	1,319.75
Boiler Feed Water Make Up	163.58	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96
2d. Fuel Cost																
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal																
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill																
MEA Sludge	55.54	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71
Waste Water Effluent Discharge	1,311.13	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58	1,314.58
Total (Variable O&M Cost)	**€ 233,882.58**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**	**€ 234,067.49**
3. Revenues ('000)																
3a. Electrcity Export (Import) to the Grid	33,242.08	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00	32,928.00
3b. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	**€ 48,842.08**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**	**€ 48,528.00**
4. GHG Emissions Cost ('000)																
4a. CO2 Emission Tax																
4b. CO2 Emission Tax Credit																
4c. Renewable Electricity Credit																
4d. Bio-CCS Credit																
Total (GHG Emissions Cost)																
5. CO2 Transport & Storage ('000)																
5a. CO2 Transport & Storage	2,435.92	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58
Total (CO2 Transport & Storage)	**€ 2,435.92**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**	**€ 2,706.58**

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill

Case 2A-3

	Base Number €'000/y	Period -3	-2	-1	1 (2005)	2	3	4	5	6	7	8	9
1. Fixed Cost ('000)													
1a. Direct Labour	€ 7,200.00				7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00
1b. Indirect Labour Cost	€ 2,880.00				2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 20,000.00				15,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00
1d. Maintenance	€ 35,139.50				35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50
Total (Fixed O&M Cost)					€ 60,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50
2. Variable Cost ('000)													
2a. Raw Materials	€ 185,600.00												
Wood	185,600.00				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	-												
CTMP	-												
Filler	-												
Coating	-												
2b. Chemicals	€ 27,250.40												
NaOH	11,011.20				8,258.40	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20
H2O2	2,960.00				2,220.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	840.00				630.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	499.20				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	800.00				600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	9,800.00				7,350.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	700.00				525.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	640.00				480.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
MEA (Make Up)	-												
2c. Utilities	€ 6,646.07												
Cooling Water	5,177.23				3,882.92	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23
Process Water	1,308.69				981.52	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69
Boiler Feed Water Make Up	160.14				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14
2d. Fuel Cost	€ 11,200.00												
HFO	11,200.00				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	€ 1,521.92												
Rejects from Brown Stock Handling	72.00				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	55.44				41.58	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill	-												
MEA Sludge	-												
Waste Water Effluent Discharge	1,280.08				960.06	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08
Total (Variable O&M Cost)					€ 174,163.80	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40
3. Revenues ('000)													
3b. Electrcity Export (Import) to the Grid	€ 36,068.80				27,051.60	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80
3c. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)					€ 38,751.60	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80
4. GHG Emissions Cost ('000)													
4a. CO2 Emission Tax	€ -												
4b. CO2 Emission Tax Credit	€ -												
4c. Renewable Electricity Credit	€ -												
4d. Bio-CCS Credit	€ -												
Total (GHG Emissions Cost)													
5. CO2 Transport & Storage ('000)													
5a. CO2 Transport & Storage	€ 1,970.08												
Total (CO2 Transport & Storage)													

	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)																
1a. Direct Labour	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00	8,100.00
1b. Indirect Labour Cost	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00	3,240.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29	20,527.29
1d. Maintenance	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30	36,727.30
Total (Fixed O&M Cost)	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58	€ 68,594.58
2. Variable Cost ('000)																
2a. Raw Materials																
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP																
CTMP																
Filler																
Coating																
2b. Chemicals																
NaOH	11,019.33	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23	11,020.23
H2O2	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
MEA (Make Up)	328.57	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08
2c. Utilities																
Cooling Water	5,784.54	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02	5,852.02
Process Water	1,312.01	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38	1,312.38
Boiler Feed Water Make Up	162.50	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76
2d. Fuel Cost																
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal																
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill																
MEA Sludge	38.54	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82
Waste Water Effluent Discharge	1,291.43	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69	1,292.69
Total (Variable O&M Cost)	€ 233,217.96	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02	€ 233,329.02
3. Revenues ('000)																
3b. Electrcity Export (Import) to the Grid	34,240.00	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80	34,036.80
3c. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	€ 49,840.00	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80	€ 49,636.80
4. GHG Emissions Cost ('000)																
4a. CO2 Emission Tax																
4b. CO2 Emission Tax Credit																
4c. Renewable Electricity Credit																
4d. Bio-CCS Credit																
Total (GHG Emissions Cost)																
5. CO2 Transport & Storage ('000)																
5a. CO2 Transport & Storage	1,773.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08
Total (CO2 Transport & Storage)	€ 1,773.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08	€ 1,970.08

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill

Case 2A-4

	Base Number €'000/y	Period	-3	-2	-1	2005 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
1. Fixed Cost ('000)																														
1a. Direct Labour	€ 7,200.00					7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00
1b. Indirect Labour Cost	€ 2,880.00					2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 20,000.00					15,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27	23,092.27
1d. Maintenance	€ 35,139.50					35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91	44,436.91
Total (Fixed O&M Cost)						€ 60,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17	€ 79,289.17
2. Variable Cost ('000)																														
2a. Raw Materials	€ 185,600.00																													
Wood	185,600.00					139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	-																													
CTMP	-																													
Filler	-																													
Coating	-																													
2b. Chemicals	€ 27,250.40																													
NaOH	11,011.20					8,258.40	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,086.86	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27	11,095.27
H2O2	2,960.00					2,220.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	840.00					630.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	499.20					374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	800.00					600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	9,800.00					7,350.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	700.00					525.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	640.00					480.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
MEA (Make Up)	-														3,058.19	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99
2c. Utilities	€ 6,646.07																													
Cooling Water	5,177.23					3,882.92	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	9,512.55	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25	9,994.25
Process Water	1,308.69					981.52	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,380.13	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07	1,388.07
Boiler Feed Water Make Up	160.14					120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	182.12	184.56	184.56	184.56	184.56	184.56	184.56	184.56	184.56	184.56	184.56	184.56	184.56	184.56	184.56	184.56
2d. Fuel Cost	€ 11,200.00																													
HFO	11,200.00					8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	€ 1,521.92																													
Rejects from Brown Stock Handling	72.00					54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80					0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00					30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60					10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00					45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	55.44					41.58	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill	-																													
MEA Sludge	-														358.68	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53
Waste Water Effluent Discharge	1,280.08					960.06	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,413.63	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47	1,428.47
Total (Variable O&M Cost)						€ 174,163.80	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 240,273.19	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17	€ 241,168.17
3. Revenues ('000)																														
3a. Electrcity Export (Import) to the Grid	€ 36,068.80					27,051.60	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	15,989.44	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40	13,758.40
3b. CTO	€ 15,600.00					11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)						€ 38,751.60	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 31,589.44	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40	€ 29,358.40
4. GHG Emissions Cost ('000)																														
4a. CO2 Emission Tax	€ -																													
4b. CO2 Emission Tax Credit	€ -																													
4c. Renewable Electricity Credit	€ -																													
4d. Bio-CCS Credit	€ -																													
Total (GHG Emissions Cost)																														
5. CO2 Transport & Storage ('000)																														
5a. CO2 Transport & Storage	€ 17,496.00														15,746.40	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00
Total (CO2 Transport & Storage)															€ 15,746.40	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill

Case 2A-5

2005

Period	Base Number €'000/y	-3	-2	-1	1	2	3	4	5	6	7	8	9
1. Fixed Cost ('000)													
1a. Direct Labour	€ 7,200.00				7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00
1b. Indirect Labour Cost	€ 2,880.00				2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 20,000.00				15,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00
1d. Maintenance	€ 35,139.50				35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50
Total (Fixed O&M Cost)					€ 60,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50	€ 65,219.50
2. Variable Cost ('000)													
2a. Raw Materials	€ 185,600.00												
Wood	185,600.00				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	-												
CTMP	-												
Filler	-												
Coating	-												
2b. Chemicals	€ 27,250.40												
NaOH	11,011.20				8,258.40	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20
H2O2	2,960.00				2,220.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	840.00				630.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	499.20				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	800.00				600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	9,800.00				7,350.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	700.00				525.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	640.00				480.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
MEA (Make Up)	-												
2c. Utilities	€ 6,646.07												
Cooling Water	5,177.23				3,882.92	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23
Process Water	1,308.69				981.52	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69
Boiler Feed Water Make Up	160.14				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14
2d. Fuel Cost	€ 11,200.00												
HFO	11,200.00				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	€ 1,521.92												
Rejects from Brown Stock Handling	72.00				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	55.44				41.58	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill	-												
MEA Sludge	-												
Waste Water Effluent Discharge	1,280.08				960.06	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08
Total (Variable O&M Cost)					€ 174,163.80	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40	€ 232,218.40
3. Revenues ('000)													
3a. Electrcity Export (Import) to the Grid	€ 36,068.80				27,051.60	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)					€ 38,751.60	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80	€ 51,668.80
4. GHG Emissions Cost ('000)													
4a. CO2 Emission Tax	€ -												
4b. CO2 Emission Tax Credit	€ -												
4c. Renewable Electricity Credit	€ -												
4d. Bio-CCS Credit	€ -												
Total (GHG Emissions Cost)													
5. CO2 Transport & Storage ('000)													
5a. CO2 Transport & Storage	€ 16,759.22												
Total (CO2 Transport & Storage)													

Period	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)																
1a. Direct Labour	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00
1b. Indirect Labour Cost	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17	22,929.17
1d. Maintenance	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55	43,953.55
Total (Fixed O&M Cost)	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72	€ 78,642.72
2. Variable Cost ('000)																
2a. Raw Materials																
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP																
CTMP																
Filler																
Coating																
2b. Chemicals																
NaOH	11,083.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28	11,091.28
H2O2	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
MEA (Make Up)	2,913.31	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01
2c. Utilities																
Cooling Water	9,834.71	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21	10,352.21
Process Water	1,376.80	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36	1,384.36
Boiler Feed Water Make Up	181.73	184.13	184.13	184.13	184.13	184.13	184.13	184.13	184.13	184.13	184.13	184.13	184.13	184.13	184.13	184.13
2d. Fuel Cost																
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal																
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill																
MEA Sludge	341.68	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65
Waste Water Effluent Discharge	1,396.89	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87	1,409.87
Total (Variable O&M Cost)	€ 240,409.44	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55	€ 241,319.55
3. Revenues ('000)																
3a. Electrcity Export (Import) to the Grid	17,759.20	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80	15,724.80
3b. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	€ 33,359.20	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80	€ 31,324.80
4. GHG Emissions Cost ('000)																
4a. CO2 Emission Tax																
4b. CO2 Emission Tax Credit																
4c. Renewable Electricity Credit																
4d. Bio-CCS Credit																
Total (GHG Emissions Cost)																
5. CO2 Transport & Storage ('000)																
5a. CO2 Transport & Storage	15,083.30	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22
Total (CO2 Transport & Storage)	€ 15,083.30	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in a Market Pulp Mill

Case 2A-6MP

					2005																								
	Base Number €'000/y	Period -3	-2	-1	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
1. Fixed Cost ('000)																													
1a. Direct Labour	€ 7,200.00				7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00	8,400.00
1b. Indirect Labour Cost	€ 2,880.00				2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	2,880.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00	3,360.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 20,000.00				15,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84	23,255.84
1d. Maintenance	€ 35,139.50				35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	35,139.50	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56	44,933.56
	Total (Fixed O&M Cost)				**€ 60,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 65,219.50**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**	**€ 79,949.40**
2. Variable Cost ('000)																													
2a. Raw Materials	***€ 185,600.00***																												
Wood	*185,600.00*				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	-																												
CTMP	-																												
Filler	-																												
Coating	-																												
2b. Chemicals	***€ 27,250.40***																												
NaOH	*11,011.20*				8,258.40	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,011.20	11,094.99	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30	11,104.30
H2O2	*2,960.00*				2,220.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00	2,960.00
MgSO4	*840.00*				630.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00	840.00
CaO	*499.20*				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	*800.00*				600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
NaClO3	*9,800.00*				7,350.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00	9,800.00
Methanol	*700.00*				525.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
Talc	*640.00*				480.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00	640.00
MEA (Make Up)	-													3,386.72	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03
2c. Utilities	***€ 6,646.07***																												
Cooling Water	*5,177.23*				3,882.92	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	5,177.23	11,135.54	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57	11,797.57
Process Water	*1,308.69*				981.52	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,308.69	1,384.97	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44	1,393.44
Boiler Feed Water Make Up	*160.14*				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	185.61	188.44	188.44	188.44	188.44	188.44	188.44	188.44	188.44	188.44	188.44	188.44	188.44	188.44	188.44	188.44
2d. Fuel Cost	***€ 11,200.00***																												
HFO	*11,200.00*				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	***€ 1,521.92***																												
Rejects from Brown Stock Handling	*72.00*				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	*0.80*				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	*40.00*				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	*13.60*				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	*60.00*				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	*55.44*				41.58	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
Rejects from Board Mill	-																												
MEA Sludge	-													397.21	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34
Waste Water Effluent Discharge	*1,280.08*				960.06	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,280.08	1,427.42	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79	1,443.79
	Total (Variable O&M Cost)				**€ 174,163.80**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 232,218.40**	**€ 242,293.49**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**	**€ 243,412.95**
3. Revenues ('000)																													
3a. Electrcity Export (Import) to the Grid	€ 36,068.80				27,051.60	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	36,068.80	10,048.00	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80	7,156.80
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
	Total (Additional Revenues)				**€ 38,751.60**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 51,668.80**	**€ 25,648.00**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**	**€ 22,756.80**
4. GHG Emissions Cost ('000)																													
4a. CO2 Emission Tax	€ -																												
4b. CO2 Emission Tax Credit	€ -																												
4c. Renewable Electricity Credit	€ -																												
4d. Bio-CCS Credit	€ -																												
	Total (GHG Emissions Cost)																												
5. CO2 Transport & Storage ('000)																													
5a. CO2 Transport & Storage	€ 19,465.75													17,519.18	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75	19,465.75
	Total (CO2 Transport & Storage)													**€ 17,519.18**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**	**€ 19,465.75**

CCS in P&P industry

Annex IV: Integrated Pulp & Board Mill Annual Operating Expenditure

- Annex IV-1: Base Case 1B – Integrated Pulp & Board Mill (Reference Plant)
- Annex IV-2: Case 2B-1^{CO2MP} – Capture of CO_2 from Flue Gas of Recovery Boiler
- Annex IV-3: Case 2B-2 – Capture of CO_2 from Flue Gas of Multi-fuel Boiler
- Annex IV-4: Case 2B-3 – Capture of CO_2 from Flue Gas of Lime Kiln
- Annex IV-5: Case 2B-4^{CO2MP} – Capture of CO_2 from Flue Gases of Recovery Boiler and Multi-fuel Boiler
- Annex IV-6: Case 2B-5^{CO2MP} – Capture of CO_2 from Flue Gases of Recovery Boiler and Lime Kiln
- Annex IV-7: Case 2B-6^{CO2MP} – Capture of CO_2 from Flue Gases of Recovery Boiler, Multi-fuel Boiler and Lime Kiln

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp and Board Mill

Base Case 1B

	Base Number €'000/y	Period -3	-2	-1	2005 1	2	3	4	5	6	7	8	9	10	11	12
1. Fixed Cost ('000)																
1a. Direct Labour	€ 14,400.00				14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00
1b. Indirect Labour	€ 5,760.00				5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 28,460.00				21,345.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00
1d. Maintenance	€ 41,478.80				41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80
Total (Fixed O&M Cost)					€ 82,983.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80
2. Variable Cost ('000)																
2a. Raw Materials	€ 345,915.56															
Wood	185,600.00				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78				41,383.33	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78				69,733.33	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00				4,320.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00				4,800.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals	€ 26,206.78															
NaOH	10,712.30				8,034.22	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30
H2O2	2,809.04				2,106.78	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88				625.41	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00				577.50	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00				6,982.50	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00				498.75	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36				455.52	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
2c. Utilities	€ 5,583.75															
Cooling Water (m3)	3,779.40				2,834.55	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40
Process Water (m3)	1,644.35				1,233.26	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35
Boiler Feed Water Make Up (m3)	160.00				120.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
2d. Fuel Cost	€ 11,200.00															
HFO	11,200.00				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	€ 1,796.13															
Rejects from Brown Stock Handling	72.00				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18				38.39	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Waste Water Effluent Discharge	1,518.55				1,138.91	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55
Total (Variable O&M Cost)					€ 293,026.67	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22
3. Revenues ('000)																
3a. Electrcity Export (Import) to the Grid	€ 21,312.00				15,984.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)					€ 27,684.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00
4. GHG Emissions Cost ('000)																
4a. CO2 Emission Tax	€ -															
4b. CO2 Emission Tax Credit	€ -															
4c. Renewable Energy Credit	€ -															
Total (GHC Emission Cost)																
5. CO2 Transport & Storage ('000)																
5a. CO2 Transport & Storage	€ -															
Total (CO2 Transport & Storage)																

	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)													
1a. Direct Labour	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00
1b. Indirect Labour	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00
1d. Maintenance	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80
Total (Fixed O&M Cost)	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80
2. Variable Cost ('000)													
2a. Raw Materials													
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals													
NaOH	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30
H2O2	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
2c. Utilities													
Cooling Water (m3)	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40
Process Water (m3)	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35
Boiler Feed Water Make Up (m3)	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
2d. Fuel Cost													
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal													
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Waste Water Effluent Discharge	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55
Total (Variable O&M Cost)	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22	€ 390,702.22
3. Revenues ('000)													
3a. Electrcity Export (Import) to the Grid	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00
3b. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00
4. GHG Emissions Cost ('000)													
4a. CO2 Emission Tax													
4b. CO2 Emission Tax Credit													
4c. Renewable Energy Credit													
Total (GHC Emission Cost)													
5. CO2 Transport & Storage ('000)													
5a. CO2 Transport & Storage													
Total (CO2 Transport & Storage)													

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-1CO2MP

Period	Base Number €'000/y	-3	-2	-1	2005 1	2	3	4	5	6	7	8	9	10
1. Fixed Cost ('000)														
1a. Direct Labour	€ 14,400.00				14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	16,200.00
1b. Indirect Labour	€ 5,760.00				5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	6,480.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 28,460.00				21,345.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	31,676.43
1d. Maintenance	€ 41,478.80				41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	51,149.03
Total (Fixed O&M Cost)					**€ 82,983.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 105,505.46**
2. Variable Cost ('000)														
2a. Raw Materials	**€ 345,915.56**													
Wood	*185,600.00*				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	*55,177.78*				41,383.33	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	*92,977.78*				69,733.33	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	*5,760.00*				4,320.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	*6,400.00*				4,800.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals	**€ 26,206.78**													
NaOH	*10,712.30*				8,034.22	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,776.26
H2O2	*2,809.04*				2,106.78	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	*833.88*				625.41	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	*499.20*				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	*770.00*				577.50	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	*9,310.00*				6,982.50	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	*665.00*				498.75	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	*607.36*				455.52	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	*-*													2,583.67
2c. Utilities	**€ 5,583.89**													
Cooling Water (m3)	*3,779.40*				2,834.55	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	8,656.22
Process Water (m3)	*1,644.35*				1,233.26	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,709.73
Boiler Feed Water Make Up (m3)	*160.14*				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	190.01
2d. Fuel Cost	**€ 11,200.00**													
HFO	*11,200.00*				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
Waste Wood / Forrest Residues	*-*													6,795.85
2e. Waste Processing & Disposal	**€ 1,796.13**													
Rejects from Brown Stock Handling	*72.00*				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	*0.80*				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	*40.00*				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	60.33
Dregs	*13.60*				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	*60.00*				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	*51.18*				38.39	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	*40.00*				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	*-*													303.02
Waste Water Effluent Discharge	*1,518.55*				1,138.91	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,624.16
Total (Variable O&M Cost)					**€ 293,026.77**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 405,546.87**
3. Revenues ('000)														
3a. Electrcity Export (Import) to the Grid	€ 21,312.00				15,984.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	8,354.92
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)					**€ 27,684.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 23,954.92**
4. GHG Emissions Cost ('000)														
4a. CO2 Emission Tax	€ -													
4b. CO2 Emission Tax Credit	€ -													
4c. Renewable Electricity Credit	€ -													
4d. Bio-CCS Credit	€ -													
Total (GHC Emission Cost)														
5. CO2 Transport & Storage ('000)														
5a. CO2 Transport & Storage	€ 14,787.00													13,308.30
Total (CO2 Transport & Storage)														**€ 13,308.30**

Period	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)															
1a. Direct Labour	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00
1b. Indirect Labour	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43	31,676.43
1d. Maintenance	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03	51,149.03
Total (Fixed O&M Cost)	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**	**€ 105,505.46**
2. Variable Cost ('000)															
2a. Raw Materials															
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals															
NaOH	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36	10,783.36
H2O2	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74	2,870.74
2c. Utilities															
Cooling Water (m3)	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09	9,198.09
Process Water (m3)	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99	1,716.99
Boiler Feed Water Make Up (m3)	193.33	193.33	193.33	193.33	193.33	193.33	193.33	193.33	193.33	193.33	193.33	193.33	193.33	193.33	193.33
2d. Fuel Cost															
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
Waste Wood / Forrest Residues	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94	7,550.94
2e. Waste Processing & Disposal															
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	62.59	62.59	62.59	62.59	62.59	62.59	62.59	62.59	62.59	62.59	62.59	62.59	62.59	62.59	62.59
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69	336.69
Waste Water Effluent Discharge	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89	1,635.89
Total (Variable O&M Cost)	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**	**€ 407,196.26**
3. Revenues ('000)															
3a. Electrcity Export (Import) to the Grid	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25	6,915.25
3b. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**	**€ 22,515.25**
4. GHG Emissions Cost ('000)															
4a. CO2 Emission Tax															
4b. CO2 Emission Tax Credit															
4c. Renewable Electricity Credit															
4d. Bio-CCS Credit															
Total (GHC Emission Cost)															
5. CO2 Transport & Storage ('000)															
5a. CO2 Transport & Storage	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00	14,787.00
Total (CO2 Transport & Storage)	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**	**€ 14,787.00**

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-2

	Base Number €'000/y	Period	-3	-2	-1	1	2	3	4	5	6	7	8	9
1. Fixed Cost ('000)														
1a. Direct Labour	€ 14,400.00					14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00
1b. Indirect Labour	€ 5,760.00					5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 28,460.00					21,345.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00
1d. Maintenance	€ 41,478.80					41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80
	Total (Fixed O&M Cost)					€ 82,983.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80
2. Variable Cost ('000)														
2a. Raw Materials	€ 345,915.56													
Wood	185,600.00					139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78					41,383.33	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78					69,733.33	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00					4,320.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00					4,800.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals	€ 26,206.78													
NaOH	10,712.30					8,034.22	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30
H2O2	2,809.04					2,106.78	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88					625.41	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20					374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00					577.50	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00					6,982.50	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00					498.75	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36					455.52	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	-													
2c. Utilities	€ 5,583.89													
Cooling Water	3,779.40					2,834.55	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40
Process Water	1,644.35					1,233.26	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35
Boiler Feed Water Make Up	160.14					120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14
2d. Fuel Cost	€ 11,200.00													
HFO	11,200.00					8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	€ 1,796.13													
Rejects from Brown Stock Handling	72.00					54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80					0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00					30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60					10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00					45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18					38.39	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00					30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	-													
Waste Water Effluent Discharge	1,518.55					1,138.91	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55
	Total (Variable O&M Cost)					€ 293,026.77	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36
3. Revenues ('000)														
3a. Electrcity Export (Import) to the Grid	€ 21,312.00					15,984.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00
3b. CTO	€ 15,600.00					11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
	€ 36,912.00					€ 27,684.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00
4. GHG Emissions Cost ('000)														
4a. CO2 Emission Tax	€ -													
4b. CO2 Emission Tax Credit	€ -													
4c. Renewable Electricity Credit	€ -													
4d. Bio-CCS Credit	€ -													
	Total (GHC Emission Cost)													
5. CO2 Transport & Storage ('000)														
5a. CO2 Transport & Storage	€ 2,706.58													
	Total (CO2 Transport & Storage)													

	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)																
1a. Direct Labour	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00
1b. Indirect Labour	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30	29,290.30
1d. Maintenance	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71	43,969.71
Total (Fixed O&M Cost)	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01	€ 94,680.01
2. Variable Cost ('000)																
2a. Raw Materials																
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals																
NaOH	10,724.02	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32	10,725.32
H2O2	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	473.56	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17	526.17
2c. Utilities																
Cooling Water	4,881.80	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29	5,004.29
Process Water	1,654.30	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41	1,655.41
Boiler Feed Water Make Up	163.58	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96	163.96
2d. Fuel Cost																
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal																
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	55.54	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71	61.71
Waste Water Effluent Discharge	1,549.60	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05	1,553.05
Total (Variable O&M Cost)	€ 392,390.01	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52	€ 392,577.52
3. Revenues ('000)																
3a. Electrcity Export (Import) to the Grid	18,374.40	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00	18,048.00
3b. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
	€ 33,974.40	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00	€ 33,648.00
4. GHG Emissions Cost ('000)																
4a. CO2 Emission Tax																
4b. CO2 Emission Tax Credit																
4c. Renewable Electricity Credit																
4d. Bio-CCS Credit																
Total (GHC Emission Cost)																
5. CO2 Transport & Storage ('000)																
5a. CO2 Transport & Storage	2,435.92	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58	2,706.58
Total (CO2 Transport & Storage)	€ 2,435.92	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58	€ 2,706.58

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-3

	Base Number €'000/y	Period -3	-2	-1	1 (2005)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)																													
1a. Direct Labour	€ 14,400.00				14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00	15,300.00
1b. Indirect Labour	€ 5,760.00				5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00	6,120.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 28,460.00				21,345.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09	28,988.09
1d. Maintenance	€ 41,478.80				41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00	43,069.00
	Total (Fixed O&M Cost)				**€ 82,983.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 90,098.80**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**	**€ 93,477.08**
2. Variable Cost ('000)																													
2a. Raw Materials	***€ 345,915.56***																												
Wood	*185,600.00*				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	*55,177.78*				41,383.33	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	*92,977.78*				69,733.33	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	*5,760.00*				4,320.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	*6,400.00*				4,800.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals	***€ 26,206.78***																												
NaOH	*10,712.30*				8,034.22	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,720.43	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33	10,721.33
H2O2	*2,809.04*				2,106.78	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	*833.88*				625.41	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	*499.20*				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	*770.00*				577.50	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	*9,310.00*				6,982.50	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	*665.00*				498.75	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	*607.36*				455.52	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	-													328.57	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08	365.08
2c. Utilities	***€ 5,583.89***																												
Cooling Water	*3,779.40*				2,834.55	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	4,408.65	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57	4,478.57
Process Water	*1,644.35*				1,233.26	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,647.67	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04	1,648.04
Boiler Feed Water Make Up	*160.14*				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	162.50	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76	162.76
2d. Fuel Cost	***€ 11,200.00***																												
HFO	*11,200.00*				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
2e. Waste Processing & Disposal	***€ 1,796.13***																												
Rejects from Brown Stock Handling	*72.00*				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	*0.80*				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	*40.00*				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	*13.60*				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	*60.00*				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	*51.18*				38.39	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	*40.00*				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	-													38.54	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82	42.82
Waste Water Effluent Discharge	*1,518.55*				1,138.91	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,529.89	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15	1,531.15
	Total (Variable O&M Cost)				**€ 293,026.77**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 390,702.36**	**€ 391,723.87**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**	**€ 391,837.37**
3. Revenues ('000)																													
3a. Electrcity Export (Import) to the Grid	€ 21,312.00				15,984.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	19,372.32	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80	19,156.80
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
	Total (Additional Revenues)				**€ 27,684.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 36,912.00**	**€ 34,972.32**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**	**€ 34,756.80**
4. GHG Emissions Cost ('000)																													
4a. CO2 Emission Tax	€ -																												
4b. CO2 Emission Tax Credit	€ -																												
4c. Renewable Electricity Credit	€ -																												
4d. Bio-CCS Credit	€ -																												
	Total (GHC Emission Cost)																												
5. CO2 Transport & Storage ('000)																													
5a. CO2 Transport & Storage	€ 1,970.08													1,773.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08	1,970.08
	Total (CO2 Transport & Storage)													**€ 1,773.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**	**€ 1,970.08**

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-4CO2MP

	Base Number €'000/y	-3	-2	-1	1	2	3	4	5	6	7	8	9
1. Fixed Cost ('000)													
1a. Direct Labour	€ 14,400.00				14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00
1b. Indirect Labour	€ 5,760.00				5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 28,460.00				21,345.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00
1d. Maintenance	€ 41,478.80				41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80
Total (Fixed O&M Cost)					€ 82,983.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80
2. Variable Cost ('000)													
2a. Raw Materials	€ 345,915.56												
Wood	185,600.00				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78				41,383.33	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78				69,733.33	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00				4,320.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00				4,800.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals	€ 26,206.78												
NaOH	10,712.30				8,034.22	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30
H2O2	2,809.04				2,106.78	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88				625.41	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00				577.50	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00				6,982.50	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00				498.75	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36				455.52	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	-												
2c. Utilities	€ 5,583.89												
Cooling Water (m3)	3,779.40				2,834.55	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40
Process Water (m3)	1,644.35				1,233.26	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35
Boiler Feed Water Make Up (m3)	160.14				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14
2d. Fuel Cost	€ 11,200.00												
HFO	11,200.00				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
Waste Wood / Forrest Residues	-												
2e. Waste Processing & Disposal	€ 1,796.13												
Rejects from Brown Stock Handling	72.00				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Dregs	13.60				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18				38.39	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	-												
Waste Water Effluent Discharge	1,518.55				1,138.91	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55
Total (Variable O&M Cost)					€ 293,026.77	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36
3. Revenues ('000)													
3a. Electrcity Export (Import) to the Grid	€ 21,312.00				15,984.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)					€ 27,684.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00
4. GHG Emissions Cost ('000)													
4a. CO2 Emission Tax	€ -												
4b. CO2 Emission Tax Credit	€ -												
4c. Renewable Electricity Credit	€ -												
4d. Negative CO2 Emission Credit	€ -												
Total (GHC Emission Cost)													
5. CO2 Transport & Storage ('000)													
5a. CO2 Transport & Storage	€ 17,496.00												
Total (CO2 Transport & Storage)													

	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)																
1a. Direct Labour	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00
1b. Indirect Labour	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87	32,124.87
1d. Maintenance	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34	52,494.34
Total (Fixed O&M Cost)	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20	€ 107,299.20
2. Variable Cost ('000)																
2a. Raw Materials																
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals																
NaOH	10,787.96	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37	10,796.37
H2O2	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	3,058.19	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99	3,397.99
2c. Utilities																
Cooling Water (m3)	9,364.75	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35	9,985.35
Process Water (m3)	1,715.78	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72	1,723.72
Boiler Feed Water Make Up (m3)	198.35	202.60	202.60	202.60	202.60	202.60	202.60	202.60	202.60	202.60	202.60	202.60	202.60	202.60	202.60	202.60
2d. Fuel Cost																
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
Waste Wood / Forrest Residues	10,559.70	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00	11,733.00
2e. Waste Processing & Disposal																
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	71.60	75.11	75.11	75.11	75.11	75.11	75.11	75.11	75.11	75.11	75.11	75.11	75.11	75.11	75.11	75.11
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	358.68	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53	398.53
Waste Water Effluent Discharge	1,652.09	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93	1,666.93
Total (Variable O&M Cost)	€ 410,614.72	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20	€ 412,827.20
3. Revenues ('000)																
3a. Electrcity Export (Import) to the Grid	7,535.59	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88	6,004.88
3b. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	€ 23,135.59	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88	€ 21,604.88
4. GHG Emissions Cost ('000)																
4a. CO2 Emission Tax																
4b. CO2 Emission Tax Credit																
4c. Renewable Electricity Credit																
4d. Negative CO2 Emission Credit																
Total (GHC Emission Cost)																
5. CO2 Transport & Storage ('000)																
5a. CO2 Transport & Storage	15,746.40	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00	17,496.00
Total (CO2 Transport & Storage)	€ 15,746.40	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00	€ 17,496.00

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-5CO2MP

	Base Number €'000/y	Period -3	-2	-1	2005 1	2	3	4	5	6	7	8	9	10
1. Fixed Cost ('000)														
1a. Direct Labour	€ 14,400.00				14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	16,200.00
1b. Indirect Labour	€ 5,760.00				5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	6,480.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 28,460.00				21,345.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	31,941.15
1d. Maintenance	€ 41,478.80				41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	51,949.13
Total (Fixed O&M Cost)					€ 82,983.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 106,570.28
2. Variable Cost ('000)														
2a. Raw Materials	€ 345,915.56													
Wood	185,600.00				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78				41,383.33	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78				69,733.33	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00				4,320.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00				4,800.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals	€ 26,206.78													
NaOH	10,712.30				8,034.22	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,784.38
H2O2	2,809.04				2,106.78	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88				625.41	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00				577.50	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00				6,982.50	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00				498.75	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36				455.52	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	-													2,913.31
2c. Utilities	€ 5,583.89													
Cooling Water (m3)	3,779.40				2,834.55	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	8,896.94
Process Water (m3)	1,644.35				1,233.26	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,712.45
Boiler Feed Water Make Up (m3)	160.14				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	197.07
2d. Fuel Cost	€ 11,200.00													
HFO	11,200.00				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
Waste Wood / Forrest Residues	-													9,984.67
2e. Waste Processing & Disposal	€ 1,796.13													
Rejects from Brown Stock Handling	72.00				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	69.88
Dregs	13.60				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18				38.39	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	-													341.68
Waste Water Effluent Discharge	1,518.55				1,138.91	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,635.36
Total (Variable O&M Cost)					€ 293,026.77	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 409,383.35
3. Revenues ('000)														
3a. Electrcity Export (Import) to the Grid	€ 21,312.00				15,984.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	7,791.63
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)					€ 27,684.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 23,391.63
4. GHG Emissions Cost ('000)														
4a. CO2 Emission Tax	€ -													
4b. CO2 Emission Tax Credit	€ -													
4c. Renewable Electricity Credit	€ -													
4d. Negative CO2 Emission Credit	€ -													
Total (GHC Emission Cost)														
5. CO2 Transport & Storage ('000)														
5a. CO2 Transport & Storage	€ 16,759.22													15,083.30
Total (CO2 Transport & Storage)														€ 15,083.30

	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)															
1a. Direct Labour	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00
1b. Indirect Labour	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15	31,941.15
1d. Maintenance	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13	51,949.13
Total (Fixed O&M Cost)	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28	€ 106,570.28
2. Variable Cost ('000)															
2a. Raw Materials															
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals															
NaOH	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38	10,792.38
H2O2	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01	3,237.01
2c. Utilities															
Cooling Water (m3)	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55	9,465.55
Process Water (m3)	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02	1,720.02
Boiler Feed Water Make Up (m3)	201.18	201.18	201.18	201.18	201.18	201.18	201.18	201.18	201.18	201.18	201.18	201.18	201.18	201.18	201.18
2d. Fuel Cost															
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
Waste Wood / Forrest Residues	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07	11,094.07
2e. Waste Processing & Disposal															
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	73.19	73.19	73.19	73.19	73.19	73.19	73.19	73.19	73.19	73.19	73.19	73.19	73.19	73.19	73.19
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65	379.65
Waste Water Effluent Discharge	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33	1,648.33
Total (Variable O&M Cost)	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02	€ 411,459.02
3. Revenues ('000)															
3a. Electrcity Export (Import) to the Grid	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37	6,289.37
3b. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37	€ 21,889.37
4. GHG Emissions Cost ('000)															
4a. CO2 Emission Tax															
4b. CO2 Emission Tax Credit															
4c. Renewable Electricity Credit															
4d. Negative CO2 Emission Credit															
Total (GHC Emission Cost)															
5. CO2 Transport & Storage ('000)															
5a. CO2 Transport & Storage	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22	16,759.22
Total (CO2 Transport & Storage)	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22	€ 16,759.22

Operating Expenditure

Techno-Economic Evaluation of Deploying CCS in an Integrated Pulp & Board Mill
Case 2B-6CO2MP

	Base Number €'000/y	Period -3	-2	-1	1 (2005)	2	3	4	5	6	7	8	9	10
1. Fixed Cost ('000)														
1a. Direct Labour	€ 14,400.00				14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	14,400.00	16,200.00
1b. Indirect Labour	€ 5,760.00				5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	6,480.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	€ 28,460.00				21,345.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	28,460.00	32,317.84
1d. Maintenance	€ 41,478.80				41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	41,478.80	53,079.20
Total (Fixed O&M Cost)					€ 82,983.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 90,098.80	€ 108,077.04
2. Variable Cost ('000)														
2a. Raw Materials	€ 345,915.56													
Wood	185,600.00				139,200.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78				41,383.33	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78				69,733.33	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00				4,320.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00				4,800.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals	€ 26,206.78													
NaOH	10,712.30				8,034.22	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,712.30	10,796.09
H2O2	2,809.04				2,106.78	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88				625.41	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20				374.40	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00				577.50	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00				6,982.50	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00				498.75	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36				455.52	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	-													3,386.72
2c. Utilities	€ 5,583.89													
Cooling Water (m3)	3,779.40				2,834.55	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	3,779.40	10,987.74
Process Water (m3)	1,644.35				1,233.26	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,644.35	1,720.62
Boiler Feed Water Make Up (m3)	160.14				120.11	160.14	160.14	160.14	160.14	160.14	160.14	160.14	160.14	210.04
2d. Fuel Cost	€ 11,200.00													
HFO	11,200.00				8,400.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
Waste Wood / Forrest Residues	-													15,891.82
2e. Waste Processing & Disposal	€ 1,796.13													
Rejects from Brown Stock Handling	72.00				54.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80				0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	87.55
Dregs	13.60				10.20	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00				45.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18				38.39	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00				30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	-													397.21
Waste Water Effluent Discharge	1,518.55				1,138.91	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,518.55	1,665.89
Total (Variable O&M Cost)					€ 293,026.77	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 390,702.36	€ 417,991.29
3. Revenues ('000)														
3a. Electrcity Export (Import) to the Grid	€ 21,312.00				15,984.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	21,312.00	7,706.08
3b. CTO	€ 15,600.00				11,700.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)					€ 27,684.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 36,912.00	€ 23,306.08
4. GHG Emissions Cost ('000)														
4a. CO2 Emission Tax	€ -													
4b. CO2 Emission Tax Credit	€ -													
4c. Renewable Electricity Credit	€ -													
4d. Negative CO2 Emission Credit	€ -													
Total (GHC Emission Cost)														
5. CO2 Transport & Storage ('000)														
5a. CO2 Transport & Storage	€ 19,468.22													17,521.40
Total (CO2 Transport & Storage)														€ 17,521.40

	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Fixed Cost ('000)															
1a. Direct Labour	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00	16,200.00
1b. Indirect Labour	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00	6,480.00
1c. Other Fixed Cost (incl. Insurance & Local Taxes)	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84	32,317.84
1d. Maintenance	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20	53,079.20
Total (Fixed O&M Cost)	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04	€ 108,077.04
2. Variable Cost ('000)															
2a. Raw Materials															
Wood	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00	185,600.00
BHKP	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78	55,177.78
CTMP	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78	92,977.78
Filler	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00	5,760.00
Coating	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00	6,400.00
2b. Chemicals															
NaOH	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40	10,805.40
H2O2	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04	2,809.04
MgSO4	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88	833.88
CaO	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20	499.20
H2SO4	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00	770.00
NaClO3	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00	9,310.00
Methanol	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00	665.00
Talc	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36	607.36
MEA	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03	3,763.03
2c. Utilities															
Cooling Water (m3)	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66	11,788.66
Process Water (m3)	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10	1,729.10
Boiler Feed Water Make Up (m3)	215.58	215.58	215.58	215.58	215.58	215.58	215.58	215.58	215.58	215.58	215.58	215.58	215.58	215.58	215.58
2d. Fuel Cost															
HFO	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00	11,200.00
Waste Wood / Forrest Residues	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58	17,657.58
2e. Waste Processing & Disposal															
Rejects from Brown Stock Handling	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00	72.00
Residues from CTO Production	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Bottom & Fly Ash	92.83	92.83	92.83	92.83	92.83	92.83	92.83	92.83	92.83	92.83	92.83	92.83	92.83	92.83	92.83
Dregs	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Slaker Grit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Rejects from Pulp Dryer	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18	51.18
Rejects from Board Mill	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
MEA Sludge for Disposal	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34	441.34
Waste Water Effluent Discharge	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26	1,682.26
Total (Variable O&M Cost)	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40	€ 421,023.40
3. Revenues ('000)															
3a. Electrcity Export (Import) to the Grid	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31	6,194.31
3b. CTO	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00	15,600.00
Total (Additional Revenues)	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31	€ 21,794.31
4. GHG Emissions Cost ('000)															
4a. CO2 Emission Tax															
4b. CO2 Emission Tax Credit															
4c. Renewable Electricity Credit															
4d. Negative CO2 Emission Credit															
Total (GHC Emission Cost)															
5. CO2 Transport & Storage ('000)															
5a. CO2 Transport & Storage	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22	19,468.22
Total (CO2 Transport & Storage)	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22	€ 19,468.22

CCS in P&P industry
Annex V: Sensitivity Analysis – New Build vs. Retrofit
(Summary of Results – Economic Evaluation)

Annex VI: Sensitivity Analysis – New Build vs. Retrofit

(Summary of Results – Economic Evaluation)

1. INTRODUCTION

The evaluation of the cost of pulp production and cost of CO_2 avoided for a greenfield market pulp mill identical to Base Case 1A and Case 2A-1 where CO_2 is captured from the Recovery Boiler flue gas are summarised in this annex.

In the main report, it was assumed that that the pulp mill is retrofitted with CCS ten years after the start-up. In this annex, preliminary assessment were made if the changes required by the pulp mill to install the CCS facilities has been included in the development of a greenfield pulp mill.

The results presented in this analysis should be considered preliminary and less accurate as compared to the analysis made in the main report. Thus, the accuracy of the results should be within the definition of AACE Class V (with an accuracy range of -30% to +50%).

2. CAPITAL COST

Table A5-1 presents the total plant cost (TPC) and total capital requirement (TCR) for the market pulp mill built in 2005 and 2015. Similarly, this table also presented the TPC and TCR for Case 2A-1 where pulp mill is retrofitted with CCS after 10 years of operation and Case 2A-1-GF for a greenfield pulp mill with CCS.

Table A5-1: Summary of results – TPC and TCR

	Year of Plant Commissioning or Year of Retrofit	Total Plant Cost - Pulp Mill / Changes to Mill (million €)	Total Plant Cost - CO_2 Capture Plant (million €)	Total Plant Cost CO_2 Compression (million €)	Project Contingency (million €)	Total Plant Cost - TPC (million €)	Total Capital Requirement - TCR (million €)
Base Case 1A	2005	798.50	-	-	79.85	878.35	1,341.50
Case 2A-1	2015	10.55	227.92	14.48	25.29	278.24	355.44
Base Case 1A-GF	2015	998.00	-	-	99.80	1097.80	1649.70
Case 2A-1-GF	2015	996.74	227.92	14.48	123.91	1363.05	2021.63

The capital cost for the market pulp mill (Base Case 1A and Base Case 1A-GF) is based on the estimated developed by VTT (as presented in Section 3 - Table 2).

On the other hand, the capital cost for the market pulp mill retrofitted with CCS is based on the estimates developed by VTT (as shown in Section 3 – Table 3).

Whilst the capital cost for the market pulp mill with CCS built in 2015 (Case 2A-1-GF) is based on the estimates used in Base Case 1A-GF and Case 2A-1 with the capital cost required to modify the recovery boiler, steam turbine island, and waste water treatment plant included.

3. ANNUAL O&M COST

The study assumed a real constant money for the discounted cash flow analysis (i.e. without any inflation or any escalation considered). In this regard, annual O&M cost should have the same values as presented in the main report (See Section 4).

4. SUMMARY OF RESULTS

Table A5-2 presents the break-even price of the pulp and CO_2 avoided cost for all cases evaluated.

From the results, it could be surmised that the pulp's break-even price is higher by 7% for the greenfield option (Case 2A-1-GF) as compared to the pulp's break-even price for the retrofit option (Case 2A-1). This is expected as this reflects the higher capital cost of the pulp mill as estimated in 2015 vs. the capital cost estimated in 2005 (consequently having a higher break-even price for the market pulp – i.e. Base Case 1A vs. Base Case 1A-GF).

On the other hand, the cost of CO_2 avoided is slightly lower for the greenfield option as compared to the retrofit option by 3%.

Table A6-2: Summary of results – Break-Even Price of Pulp (after retrofit) and CO_2 Avoided Cost

	Year of Plant Commissioning or Year of Retrofit	Break-Even Price of Pulp (€/adt)	CO_2 Avoided Cost* (€/t)	% Change (as compared to Case 2A-1)
Base Case 1A	2005	522.6 €	-	-
Case 2A-1	2015	642.8 €	65.0 €	-
Base Case 1A-GF	2015	571.9 €	-	-
Case 2A-1-GF	2015	688.0 €	62.9 €	-3.3%

*Amount of CO2 avoided for all Case 2A-1 is around 1.85 t/adt

CCS in P&P industry

Annex VI: Sensitivity Analysis - Year of Retrofit

(Summary of Results – Economic Evaluation)

Annex VI: Sensitivity Analysis - Year of Retrofit

(Summary of Results – Economic Evaluation)

1. INTRODUCTION

The influence of the moment of retrofitting the CO_2 capture facilities on the cost of pulp production and cost of CO_2 avoided for Case 2A-1 where CO_2 is captured from the Recovery Boiler flue gas is summarised in this annex.

In the main report, it was assumed that that pulp mill is retrofitted with CCS ten years after the start-up. In this annex, assessment were made to evaluate the impact on the break-even price of the pulp and associated CO_2 avoided cost when the CCS facilities are retrofitted 5 years earlier or 5 years later.

The results presented in this analysis should be considered preliminary and less accurate as compared to the analysis made in the main report. Thus, the accuracy of the results should be within the definition of AACE Class V (with an accuracy range of -30% to +50%).

2. CAPITAL COST

The total plant cost (TPC) and total capital requirement (TCR) are presented of the CCS facilities retrofitted in 2010, 2015 and 2020 are presented Table A6-1.

Table A6-1: Summary of results – TPC and TCR

	Year of Retrofit	Total Plant Cost - Pulp Mill / Changes to Mill (million €)	Total Plant Cost - CO_2 Capture Plant (million €)	Total Plant Cost CO_2 Compression (million €)	Project Contingency (million €)	Total Plant Cost - TPC (million €)	Total Capital Requirement - TCR (million €)
Base Case 1A	-	798.50	-	-	79.85	878.35	1,341.50
Case 2A-1-R2010	2010	10.38	224.17	14.24	24.88	273.66	349.47
Case 2A-1	2015	10.55	227.92	14.48	25.29	278.24	355.44
Case 2A-1-R2020	2020	11.62	251.03	15.94	27.86	306.44	391.61

The capital cost of the CCS were adjusted based on the Chemical Engineering Plant Cost Index. For 2010, the CEPCI index is based on actual values reported in the Chemical Engineering Journal [1]. Whilst for 2020, the CEPCI index is estimated based on the following correlation [2]:

$$\text{CEPCI}(n) = 340.7 * \exp\left(0.54*\sum_{k=2013}^{n} i_k\right) + 1.64 * \text{Price of oil}(n) + 107$$

Where the forecast for the CEPCI index for the year up to 2020 is correlated to the projected oil price (reported by EIA) and US prime interest rate (reported by US Federal Reserve Bank).

Assuming a low oil price scenario, the CEPCI index for 2020 is estimated at around 617. The projection for the CEPCI index up to 2020 could be illustrated in Figure A6-1.

The projected CEPCI index value for 2020 is reported to be within +/-5% of the actual CEPCI index values [2, 3]

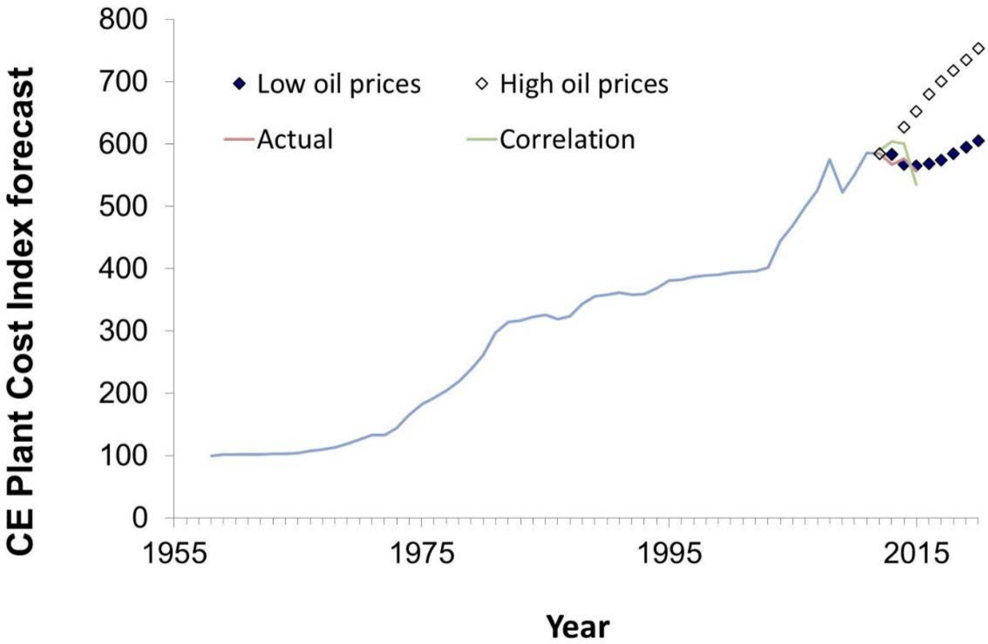


Figure A6-1: Chemical Engineering Plant Cost Index – Forecast for 2016 to 2020 [2]

3. ANNUAL O&M COST

The study assumed a real constant money for the discounted cash flow analysis (i.e. without any inflation or price escalation considered). In this regard, annual O&M cost should have the same values as presented in the main report (See Section 4).

The only difference is the start-up year for the operation of the CCS facilities. This means that additional O&M cost due to the retrofit of CCS will only be included starting on 5th, 10th and 15th years after the start-up of the pulp mill for all the retrofit cases respectively.

4. SUMMARY OF RESULTS

Table A6-2 presents the calculated break-even price and CO_2 avoided cost for all cases evaluated.

From the results, it could be surmised that a five year earlier retrofit lowers the cost of avoided CO_2 by around 5% (as compared to Year 10 retrofit), whereas a "delay" in the retrofit increases the cost of avoided CO_2 by 17%.

Table A6-2: Summary of results – Break-Even Price of Pulp (after retrofit) and CO_2 Avoided Cost

	Year of Retrofit	Break-Even Price of Pulp (€/adt)	CO_2 Avoided Cost* (€/t)	% Change (as compared to retrofit on year 10)
Base Case 1A	-	522.6 €	-	-
Case 2A-1-R2010	2010	636.6 €	61.7 €	-5.1%
Case 2A-1	2015	642.8 €	65.0 €	-
Case 2A-1-R2020	2020	663.3 €	76.1 €	+17.1%

*Amount of CO2 avoided for all Case 2A-1 is around 1.85 t/adt

5. REFERENCES

[1] CEPCI Index (2015). *Chemical Engineering Magazine.*

[2] Mignard, D. (2014). **Correlating the Chemical Engineering Plant Cost Index with Macro-Economics Indicators.** *Journal of Chemical Engineering Research and Design.* Vol. 92, pp. 285-294.

[3] Mignard, D. – personal communication.