Development of ULCOS-Blast Furnace:

Working toward technology demonstration

The ULCOS-BF developments in Europe

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IEAGHG/IETS Iron and steel Industry
CCUS and Process Integration Workshop

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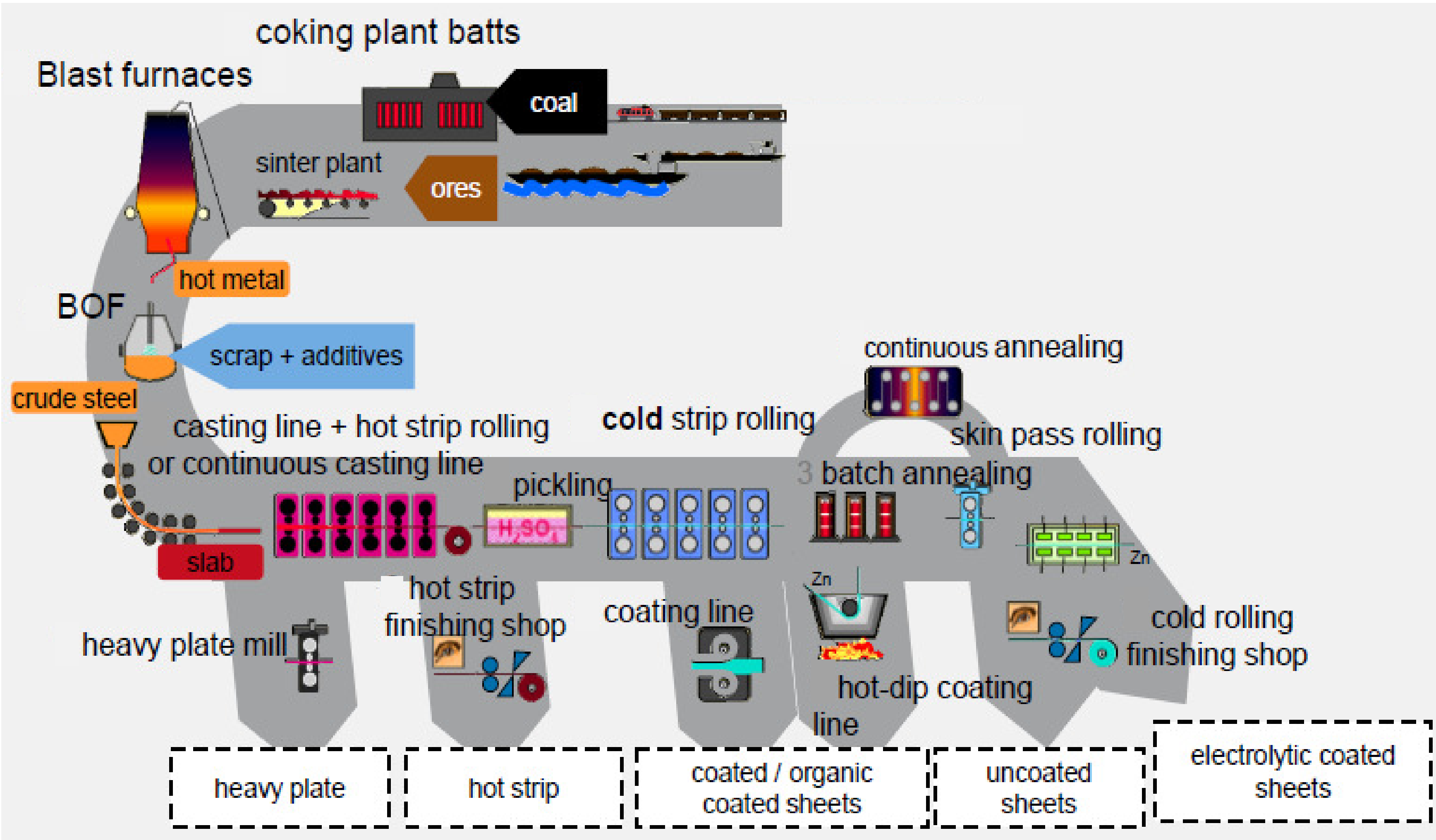
TGRBF: EU project sponsored by the EU

Outline

- Introduction
- ULCOS
- ULCOS BF process concept (TGRBF)
- ULCOS BF Developments
- Demonstration of the ULCOS BF process concept at pilot scale
- ULCOS BF Experimental Blast Furnace results
- CO2 emission reduction
- Next Step and conclusion

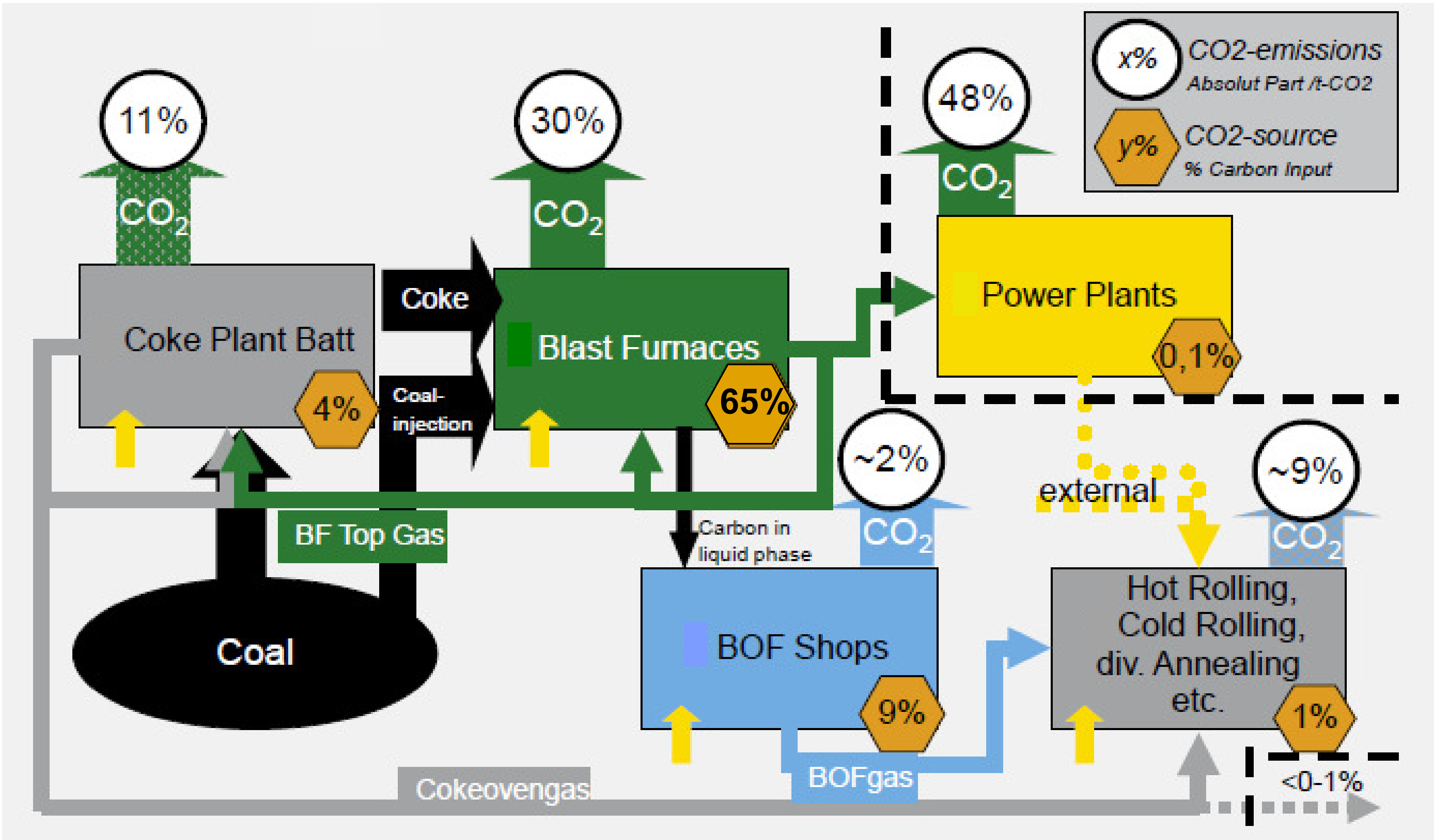
1. Introducion

1.1. An integrated steel mill has numerous facilities to come from ore and coal to steel products



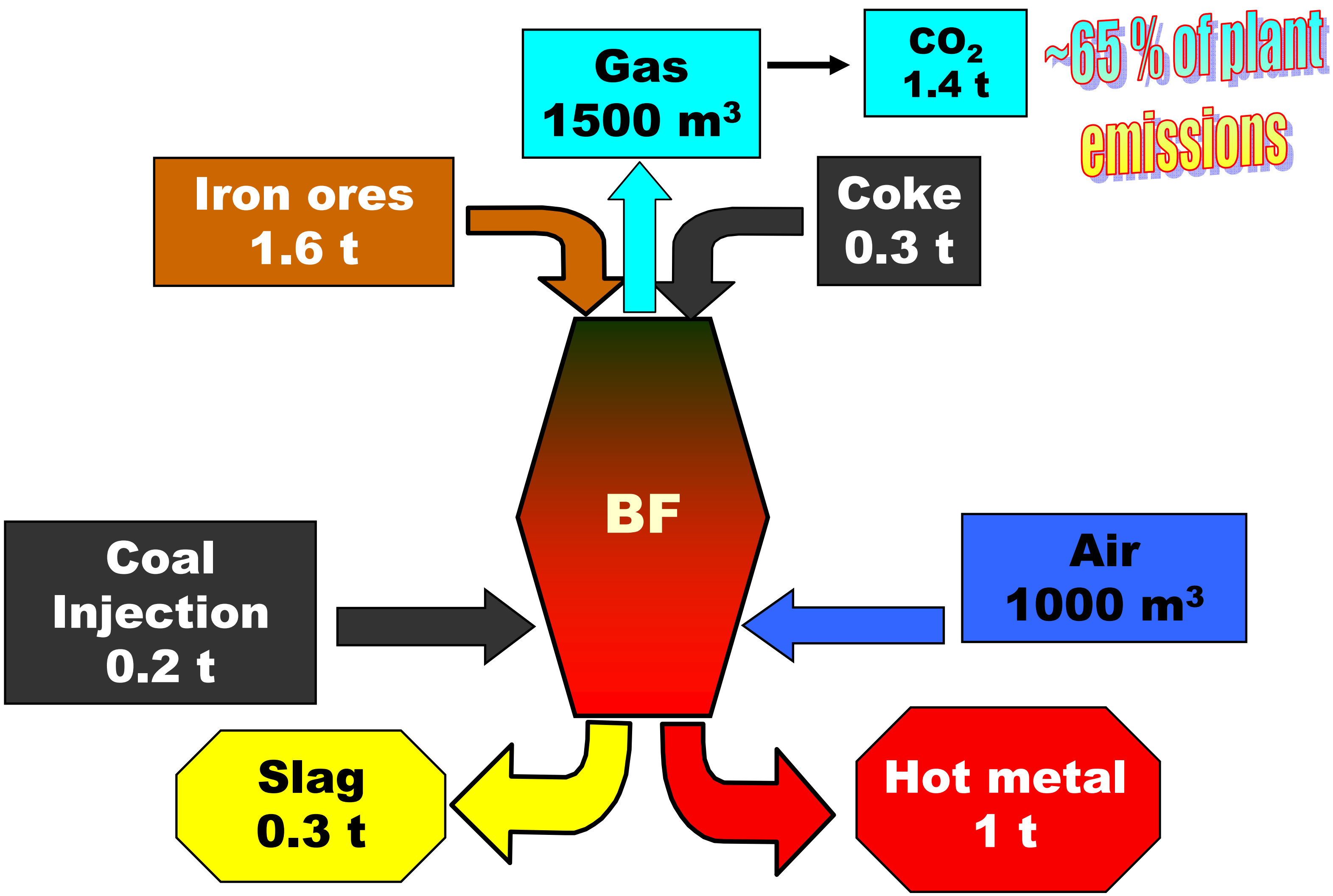
Source: IEA CCS workshop November 2011

1.2. Main CO_2 emitters



Source: IEA CCS workshop November 2011

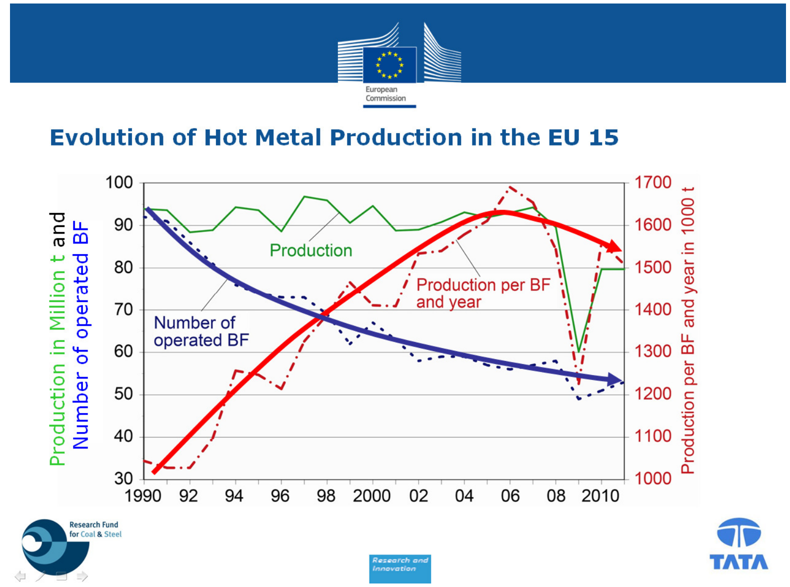
1.3. BF main input & outputs

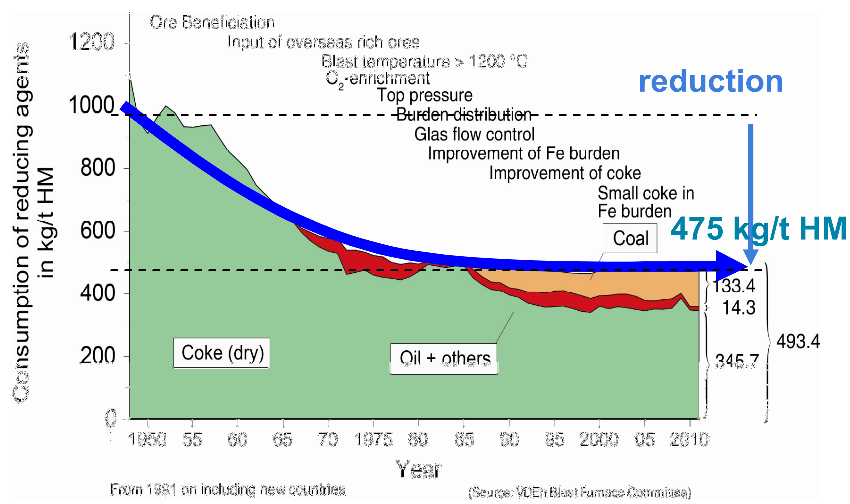


2. ULCOS

2.1. ULCOS – Ultra Low CO2 Steelmaking

- Reducing number of Blast furnaces in Europe
- Increasing productivity
- Increasing CO_2 concentration in the atmosphere
- Close to theoretical minimum regarding reducing agents
- BF is main producer of CO_2 within integrated steel works
- Small possibilities to reduce CO_2 emissions with existing blast furnace operation



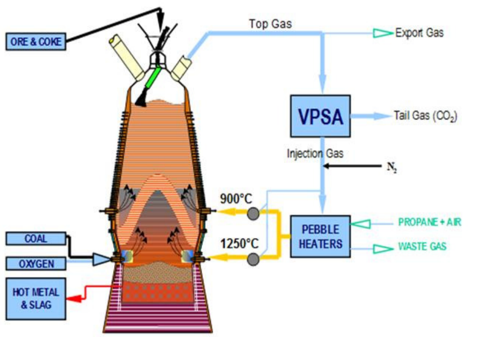


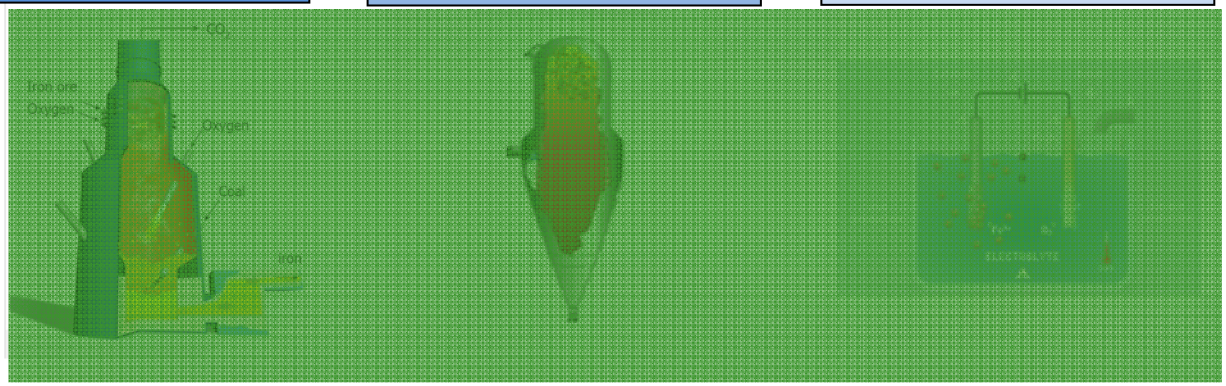
ULCOS – Ultra Low CO2 Steelmaking

- Program launched in 2004
- 48 companies including all major steel producers from 15 European countries
- Aim to reduced CO_2 emissions by more than 50%
- Breakthrough technologies
    - *ULCOS-BF*
    - *HISARNA*
    - *ULCORED*
    - *ULCOWIN/ULCOLYSIS*
- Phase 1 ended in 2010

2.2. ULCOS – Process routes

Coal and sustainable biomass	Natural gas	Electricity





ULCOS BF	Hisarna	ULCORED	ULCOWIN

- Revamped BF/DR
- Brownfield/Greenfield
- CCS technology
- Carbon lean electricity

2.3. The ULCOS project objective

Modification of the conventional blast furnace to reduce the CO2 emission by 50 % per ton of steel

2.4. How can CO_2-emission from the blast furnace be reduced?

1st Recycling of CO/H_2 from blast furnace top gas

2nd Application of Capturing and Storage of CO_2

3rd Use of biomass as a CO_2 neutral carbon source

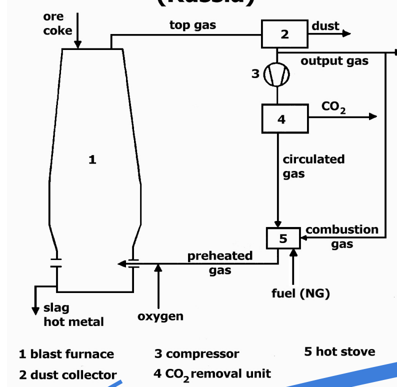
4th Substitution of CO by H_2 as reducing agent

5th Use of C-lean DRI, HBI or LRI

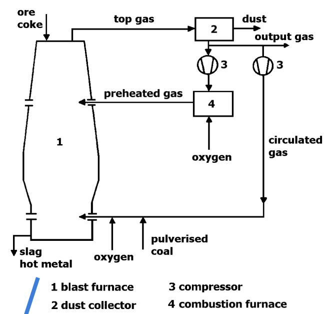
6th Use of C-lean electrical energy

2.5. History of alternative blast furnace processes

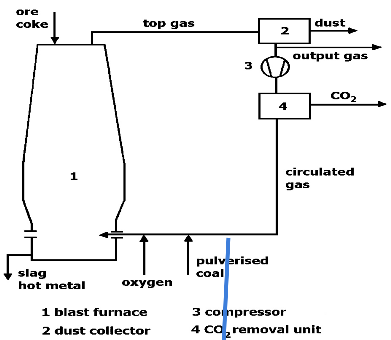
HRG-injection at Toulachermet (Russia)



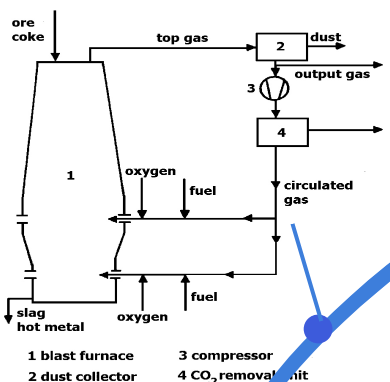
NKK NFBF



Lu NFBF



Fink patent



2004

1985 – 1990 HRG-trials at BF2 with recycling CO2 free topgas Toulachermet (Russia)

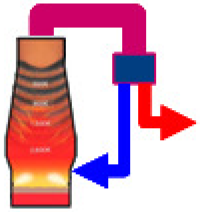
Mid of 80's Development of a NFBF by NKK (Japan)

1984 NFBF-concept of Lu (Canada)

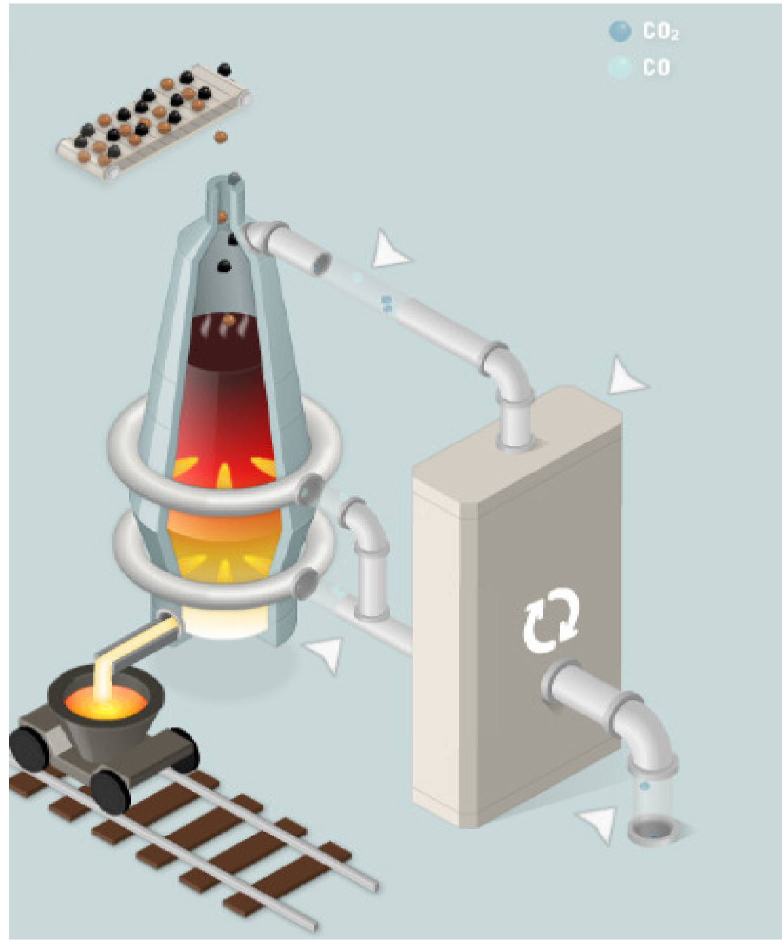
Late 70's Patent of Fink about a NFBF (Germany)

Mid 60's CRM at Cockerill-Seraing (Belgium)

1920 Lance Hot reducing gas injection

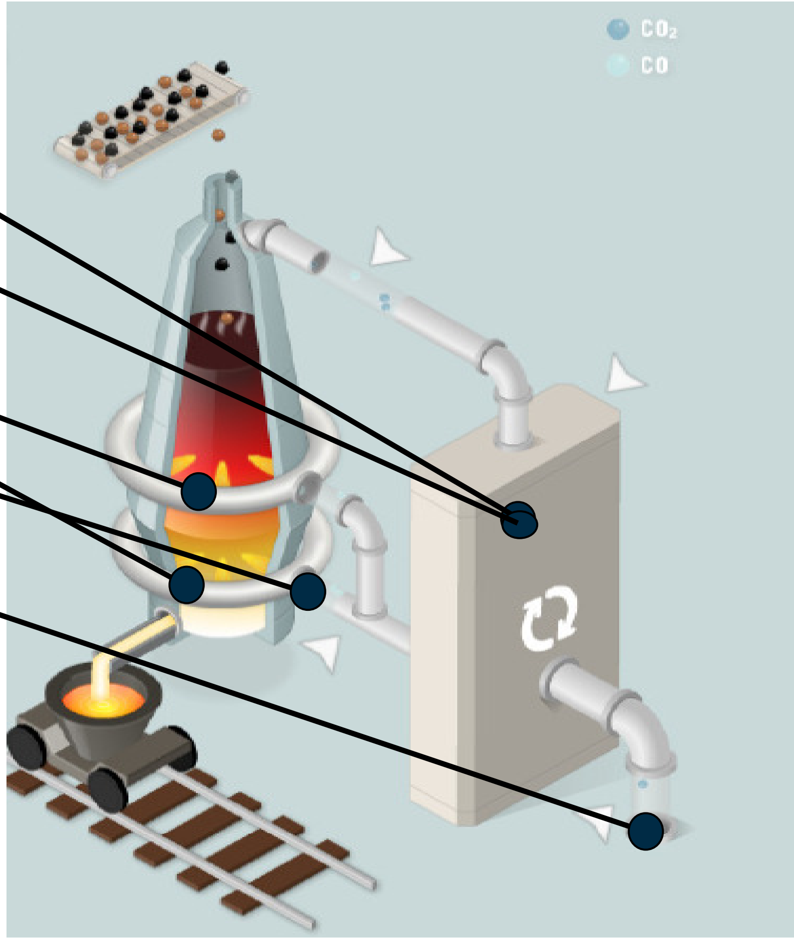


3. ULCOS TGR BF Concept



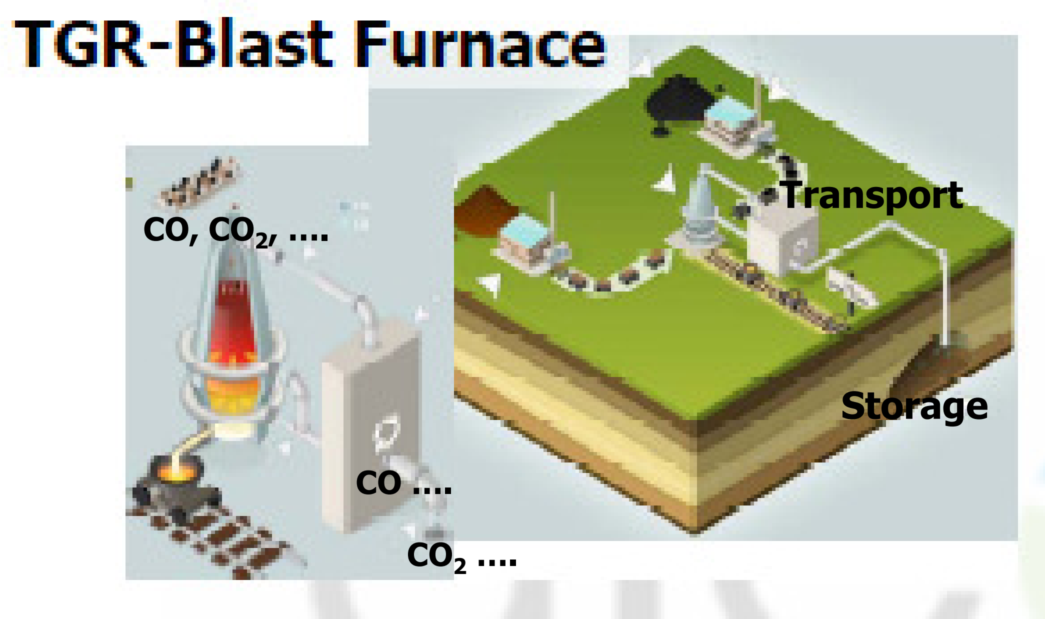
3.1 The ULCOS Top Gas Recycle Blast Furnace Concept

- CO_2 removal from top gas
- Reheating of CO/H_2 gas
- Re-injection of CO/H_2
- Use of pure Oxygen
- Storage of CO_2 possible



The ULCOS Blast Furnace

- Benefits
  - 25 % less carbon usage
  - 60 % CO_2 reduction with CO_2 storage application
  - 35 % coke rate reduction
  - Productivity increase (to be determined)

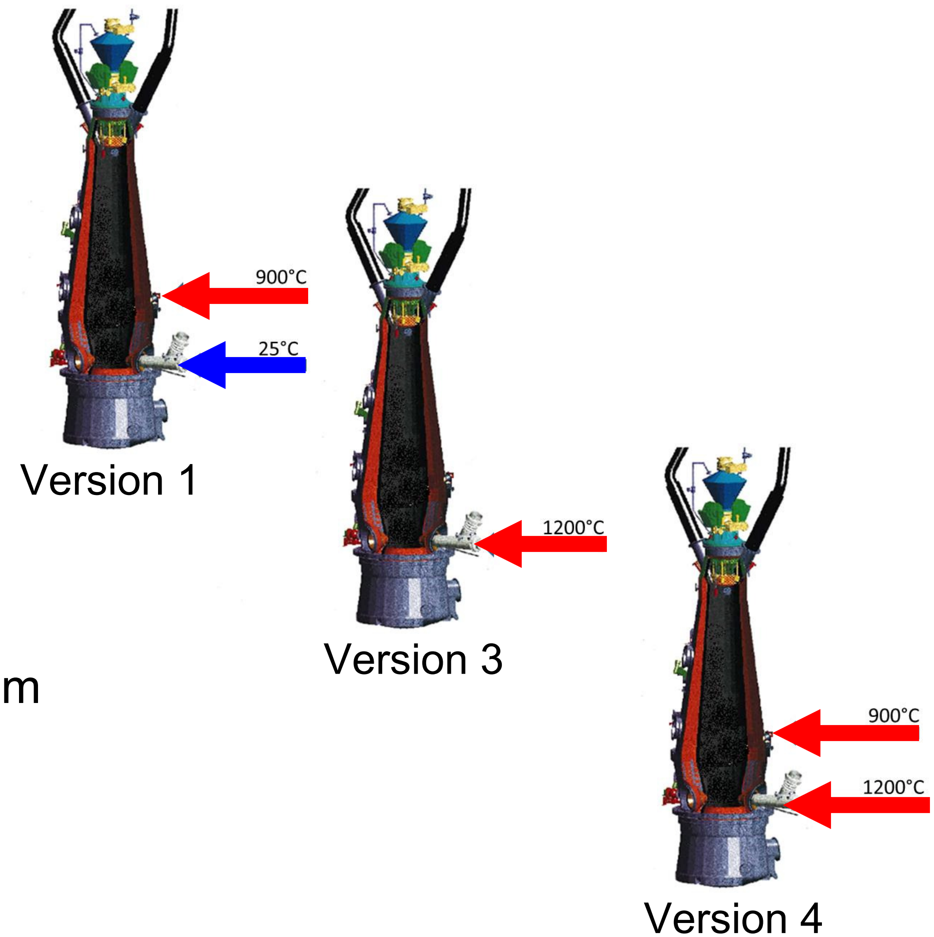


CO2 mitigation | **~25 % at the BF** | **~55-60 % for the whole plant**

4. ULCOS BF Developments

4.1. Tests and planning prior to an Experimental Blast Furnace campaign

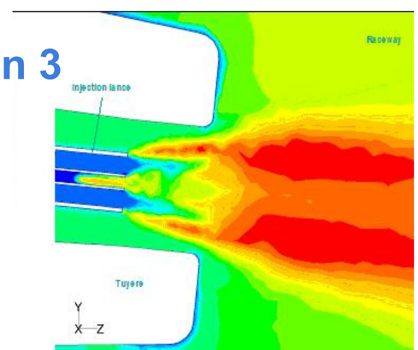
- 4 different ULCOS-BF concepts developed
- Recirculation of blast furnace top gas
- VPSA/PSA operation + CCS
- Injection of decarbonated top gas
  - *Shaft*
  - *Tuyeres*
  - *Temperature*
- Mathematical modelling to find process with highest carbon saving potential
- Process modelling according to data from a commercial European BF
- Laboratory testing

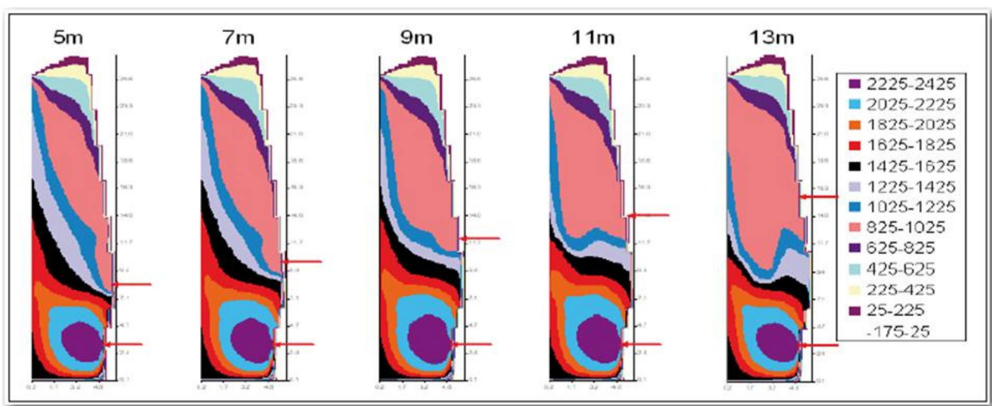


4.2. Tests and planning prior to an Experimental Blast Furnace campaign

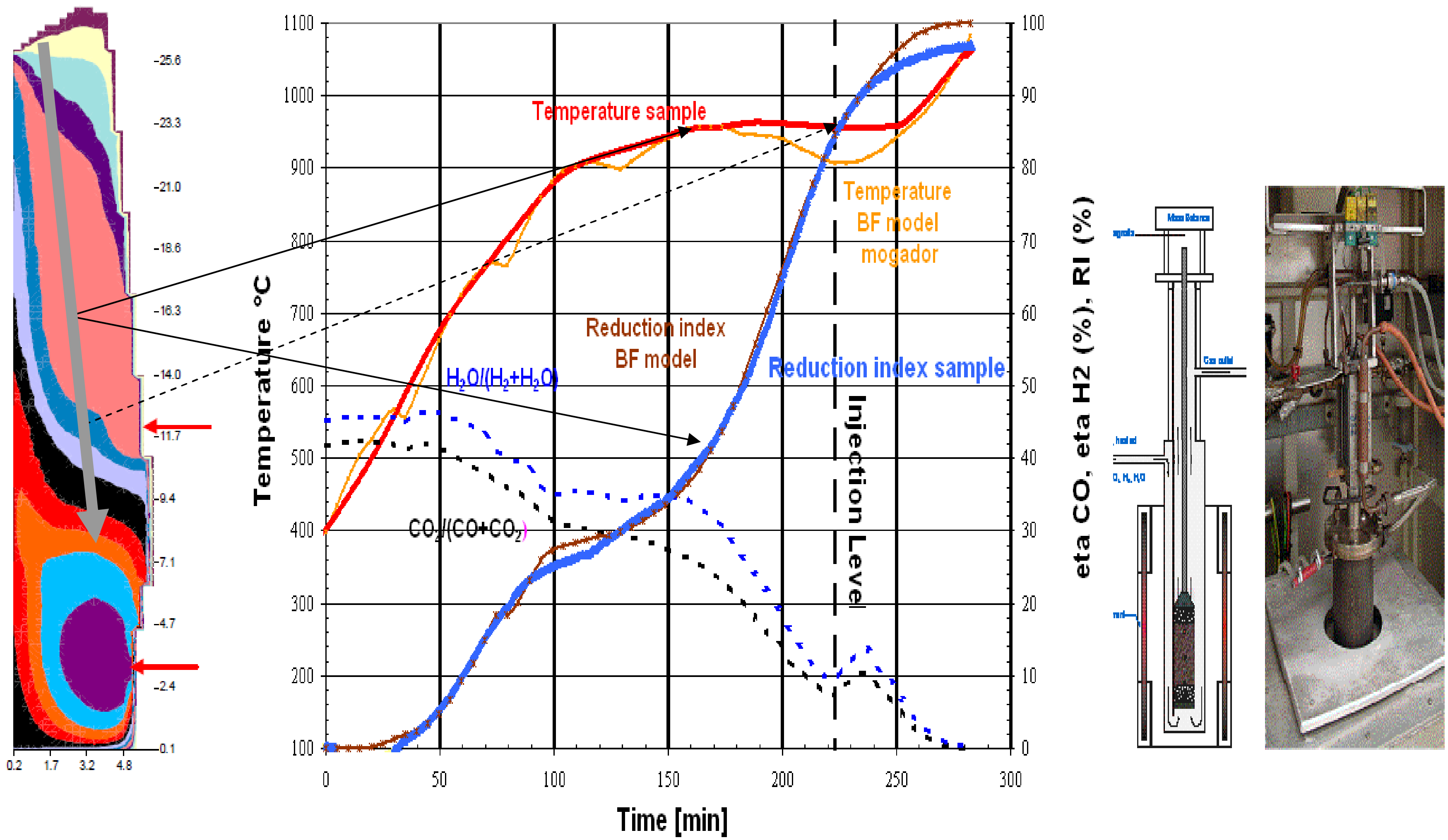
	Version 1	Version 3	Version 4
Gas temperature Shaft tuyeres Hearth tuyeres	 900°C 25°C	 1200°C	 900°C 1200°C
Gas distribution Shaft tuyeres Hearth tuyeres	 80% 20%	 100%	Optimized according to process
Concerns	Small raceways Tuyere design	PCI combustion at low RAFT	Effect and position of shaft injection
Calculated c-savings (%)	21	25	26

Version 3



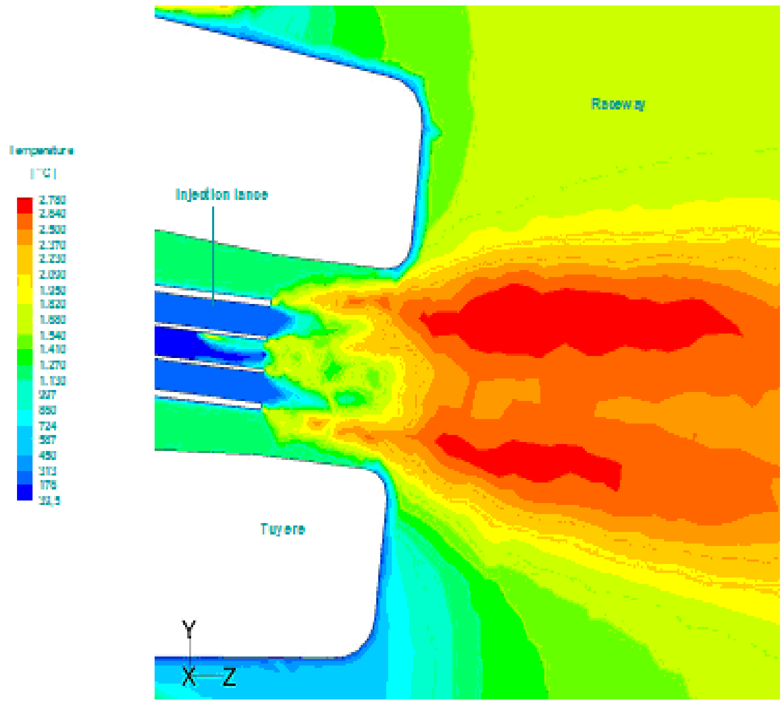


4.3. Developments
Behaviour of existing raw materials

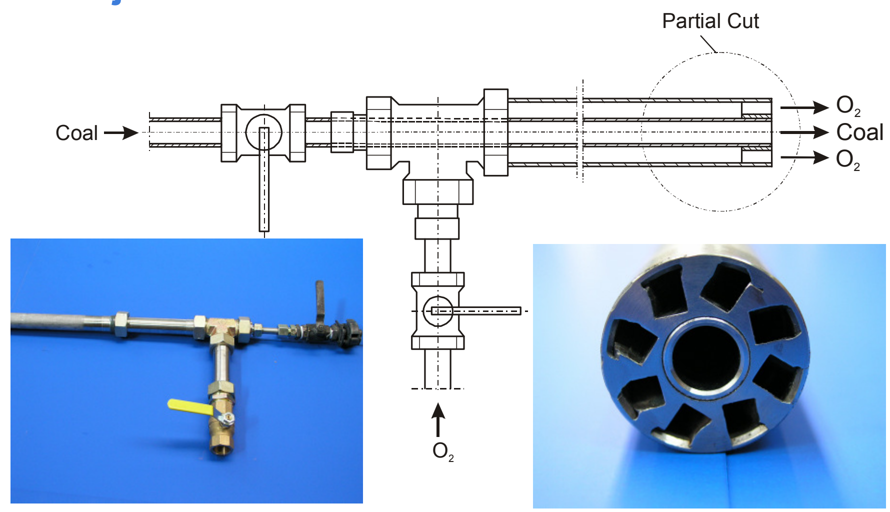


4.3. Developments
Raceway conditions and tuyere design

Temperature distribution in the tuyere and raceway region (version 4)



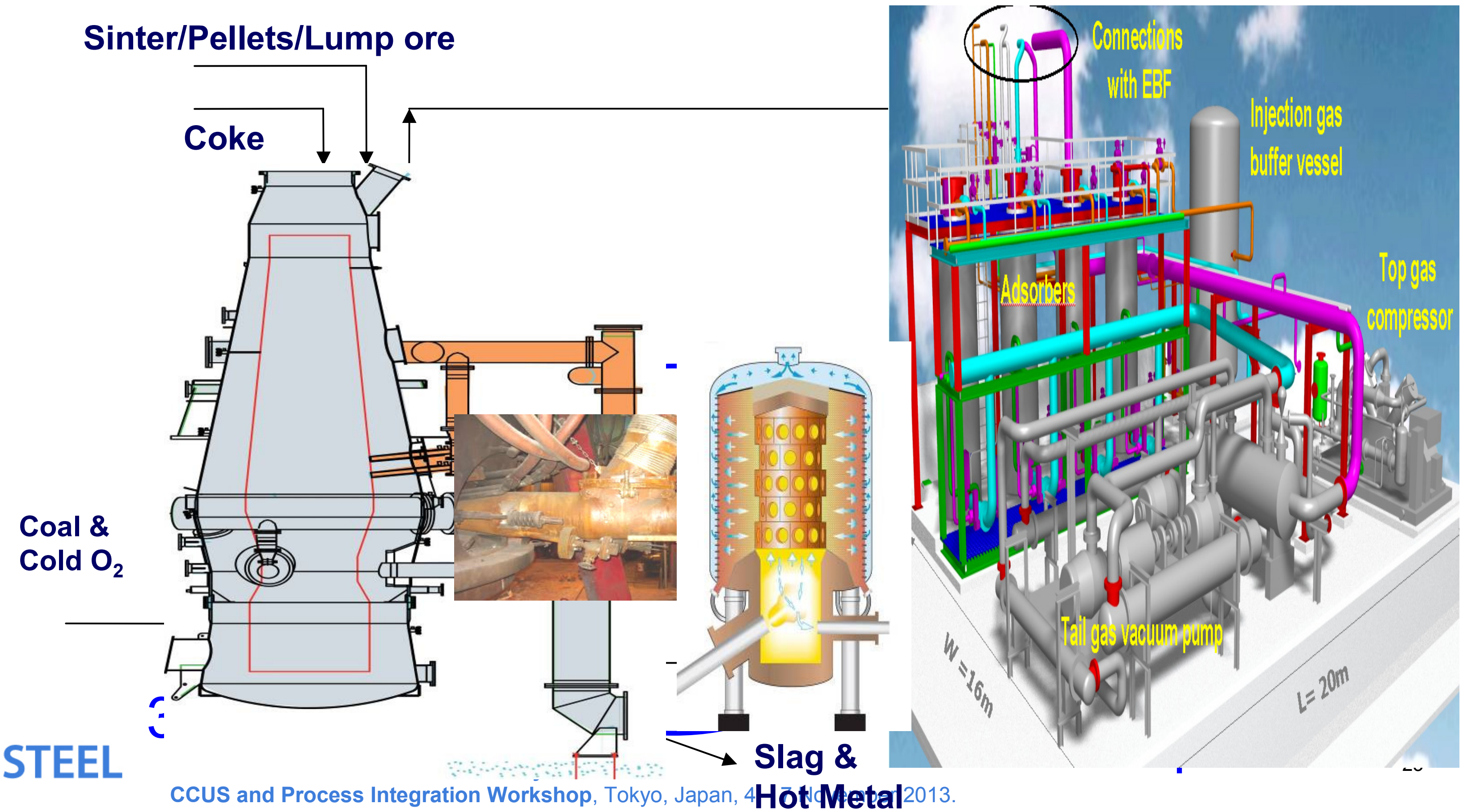
Lance design for coal and oxygen injection



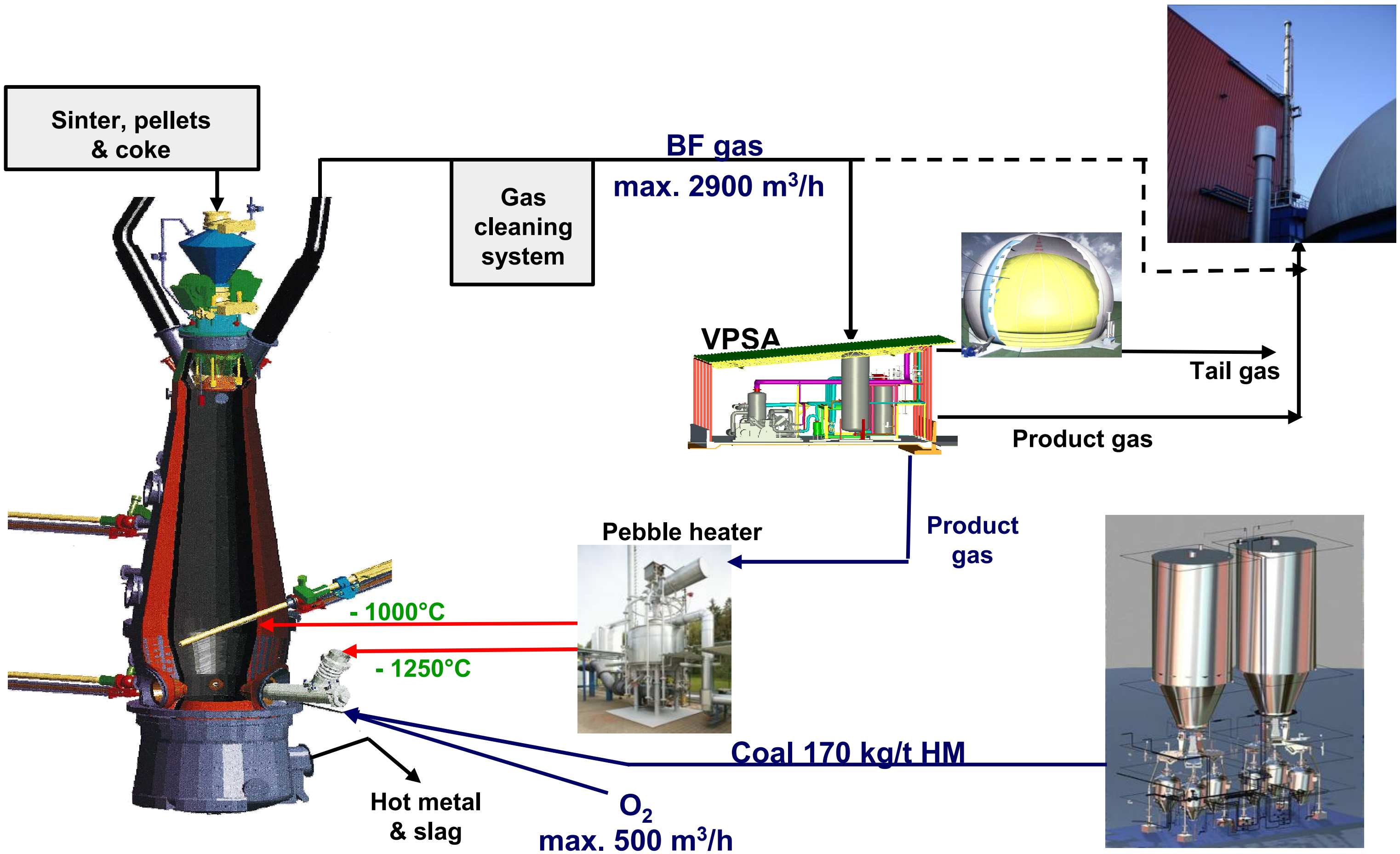
Test results at the TS single tuyere rig (TTC)

4.4. Preparations prior to the ULCOS trials

- Extensive **HAZOP** studies
- Erection of an **PSA/VPSA** plant on site – Air Liquide
- **Modification** of existing EBF equipment
- Installation of **new** EBF **equipment**
- ***Simulated*** ULCOS-BF operation using cold nitrogen
- ***Training*** of personnel



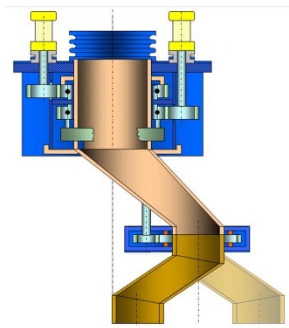
4.5. The ULCOS Blast Furnace concept at EBF in Luleå

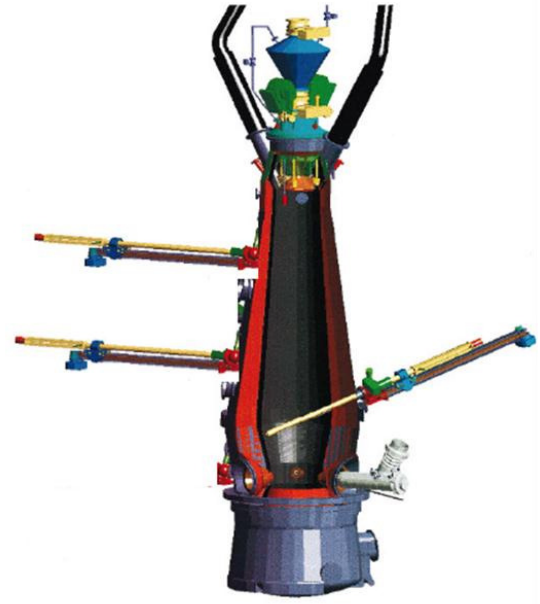


5. ULCOS BF EBF Campaigns

5.1. LKAB Experimental Blast Furnace, EBF

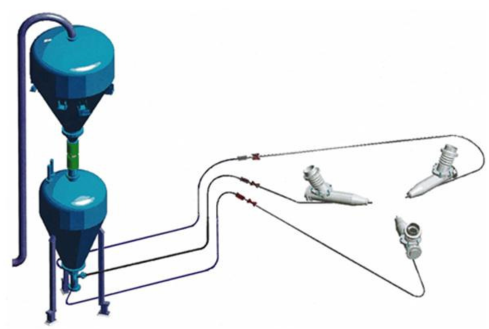
Production	36 tHM/day
Fuel rate	~540 kg/tHM
Injectants	Coal, oil, gas, etc.
Top pressure	1,2 barG
Blast temp.	1200°C
Oxygen in blast	21-40%
Tuyeres	3
Hearth diameter	1,2m
Working volume	9m^3



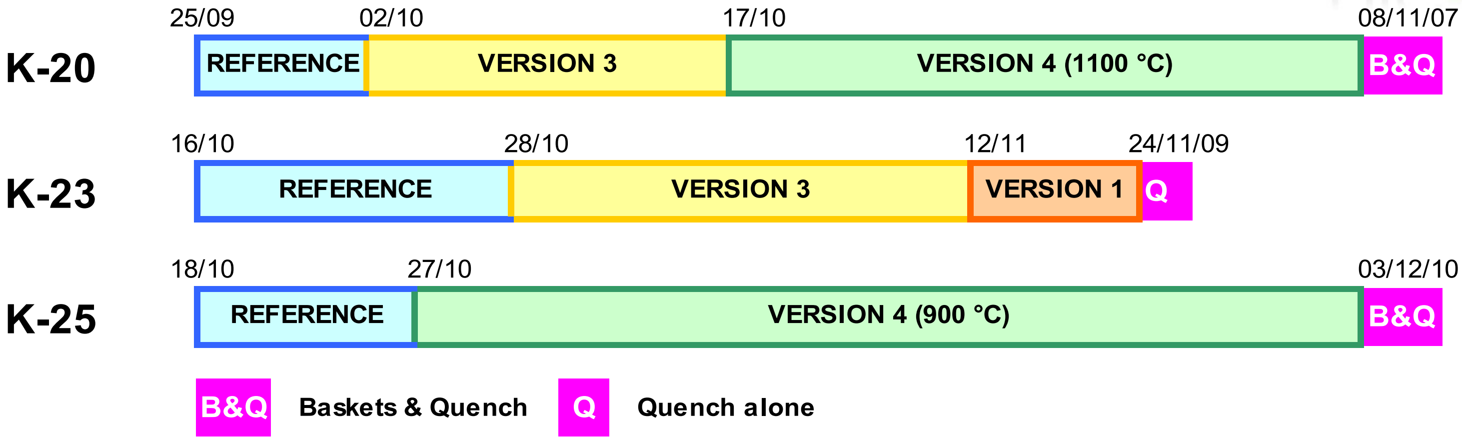


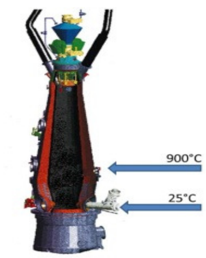
Flexible sampling possibilities

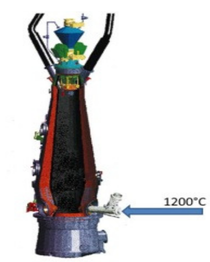
- *In-burden probes*
- *Basket samples*
- *Quench and Excavation*

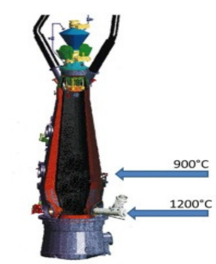


5.2. Operating successful trials







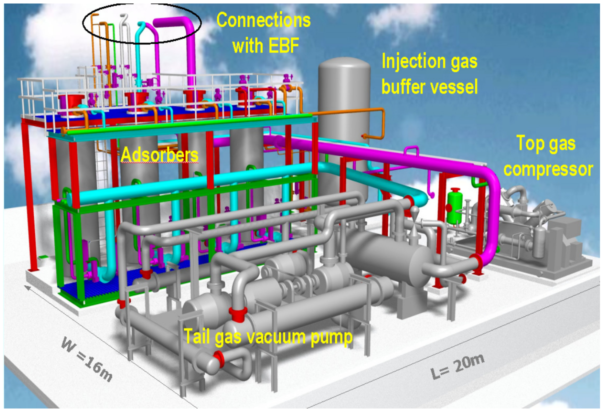


- 3 ULCOS BF trials operated in the EBF in 2007, 2009 and 2010
- Varied BF operation tested:
  - *Amount of recirculated gas;*
  - *Coal injection (130 and 170 kg/tHM);*
  - *Distribution (70% Ruukki sinter / 30% LKab pellets);*
  - *Temperature;*
- Quenching and excavation of the blast furnace shaft after each campaign;
- Process evaluation of blast furnace and VPSA/PSA unit
- Metallurgical and mechanical testing of burden material samp

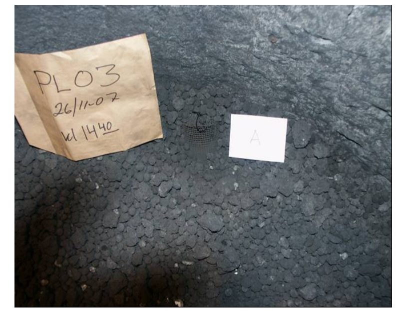
6. ULCOS BF EBF Results

6.1. Blast Furnace and VPSA results

- No safety issue recorded.
- The EBF operation was very smooth :
  - constant productivity (*production was not an aim)*
  - smooth burden descent
  - good hot metal quality
  - high thermal stability
  - nearly no equipment failure
  - BF recovery after shut-downs was easy
- VPSA operated without any failure and with the required gas quality:
  - Recycling ratios up to 90% were possible;
  - It always provided the required gas amount and the required gas quality (CO_2 < 3%);
  - The CO recovery was 88 %.
- Good connection between EBF and VPSA



6.2. Evaluation of process and equipment
Excavation of the Experimental BF

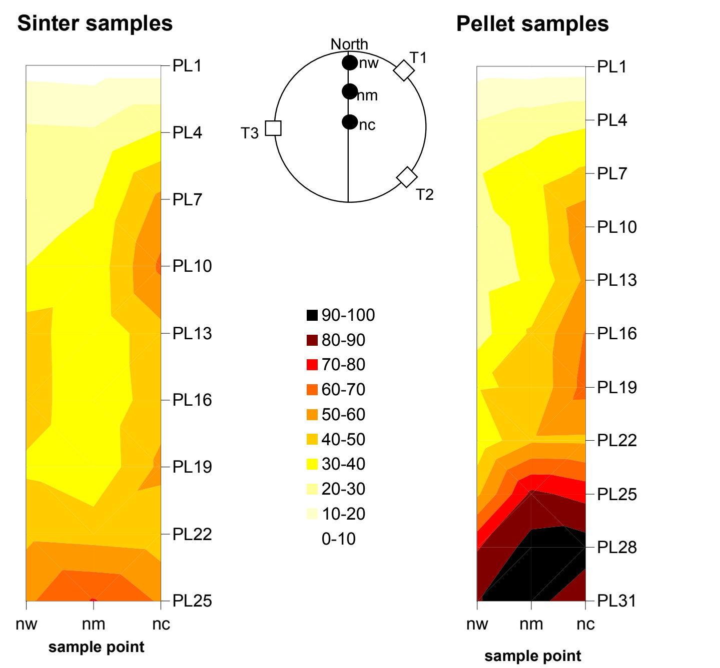


Reduction profile:

- centre working furnace

Similar behavior as in conventional BF:

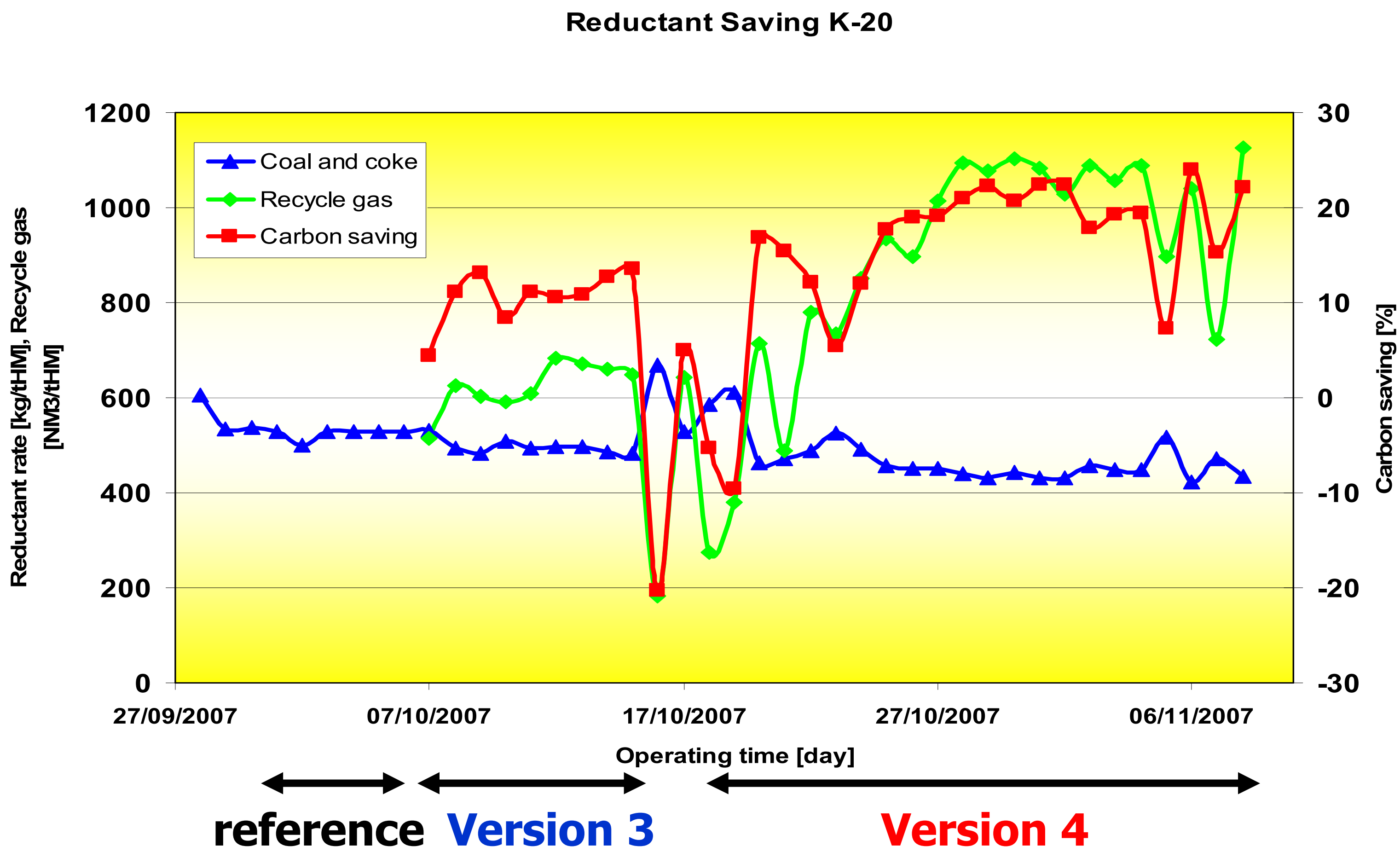
- Strength index shows linear trend with reduction degree;
- sinter disintegration

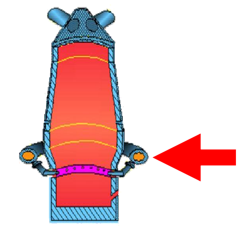


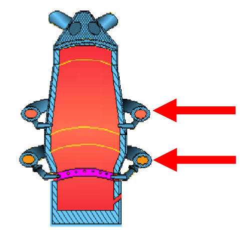
Reduction degree of sinter and pellet samples north-axis

6.3. Evaluation of process and equipment K-20 results:

reductant rate, recycled gas injection and carbon saving

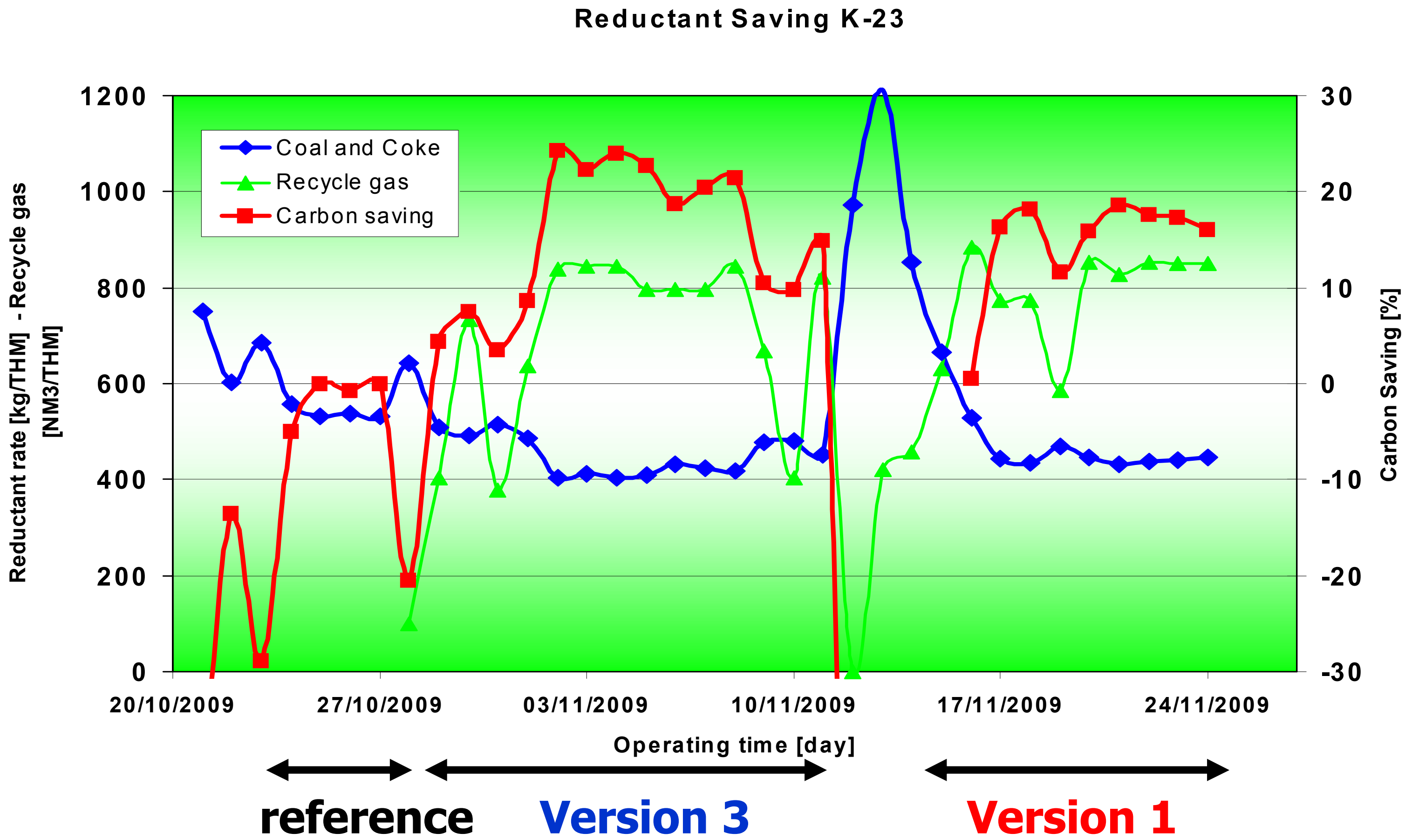


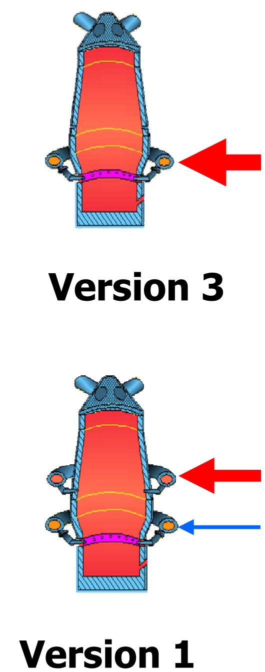




6.3. Evaluation of process and equipment K-23 results:

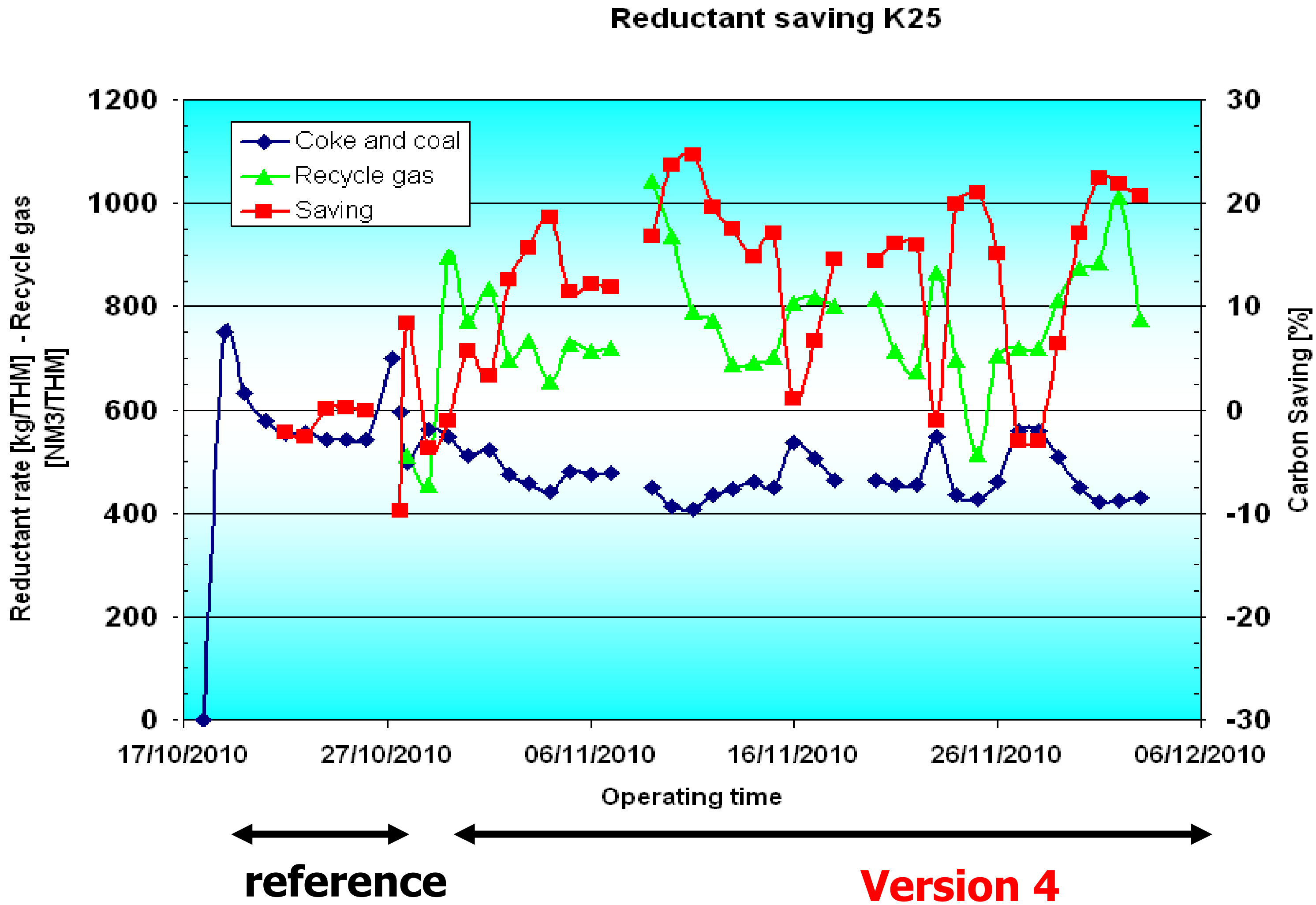
reductant rate, recycled gas injection and carbon saving

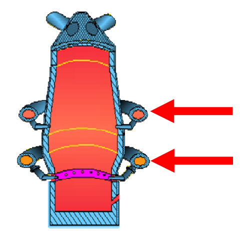




6.3. Evaluation of process and equipment K-25 results:

reductant rate, recycled gas injection and carbon saving

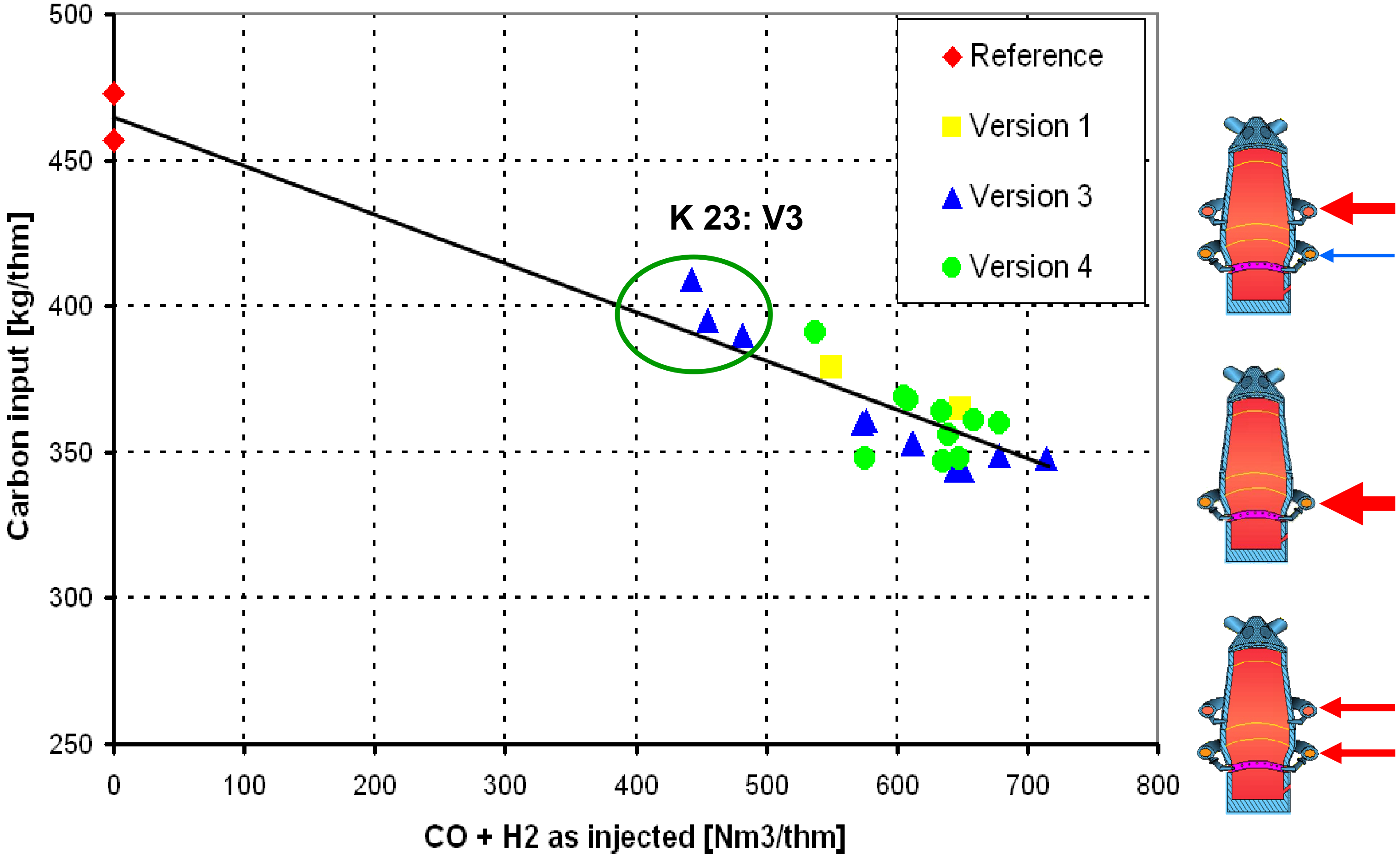




Version 4

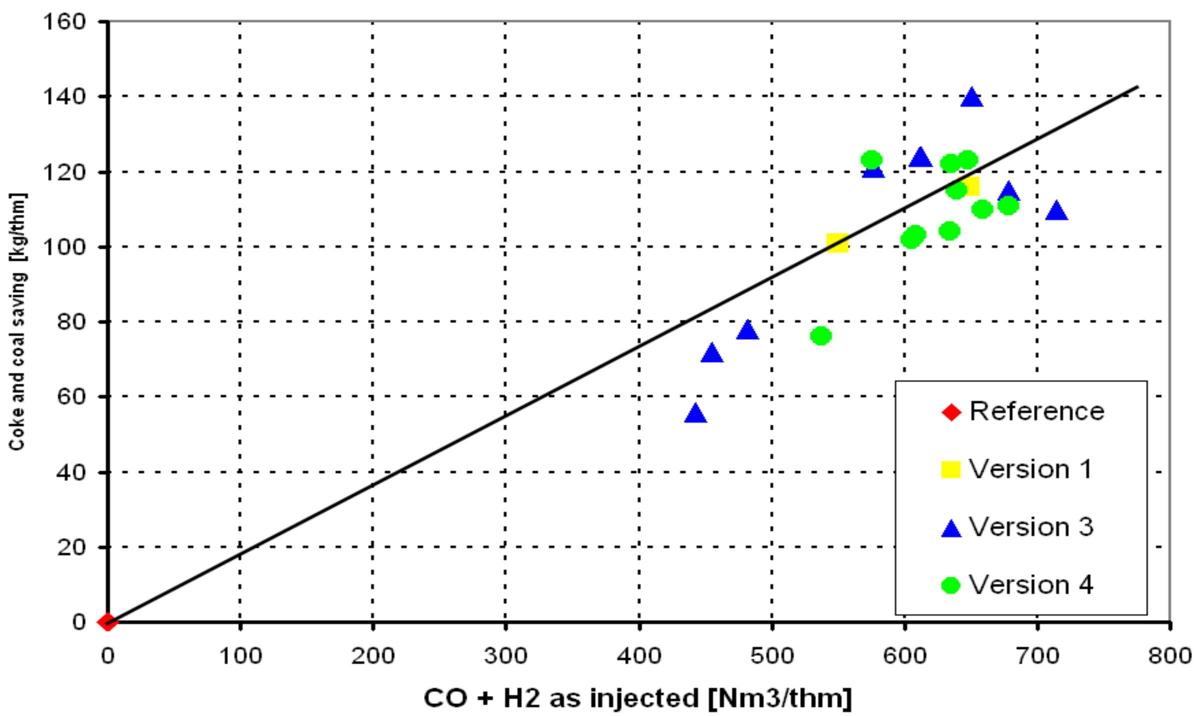
7. CO_2 Emission Reduction

7.1. BF Results:
Carbon input and gas injection



7.1. BF results: Carbon savings

	Version 1	Version 3	Version 4
Carbon saving (%)	20	23	24
Recycling ratio (%)	85	87	90

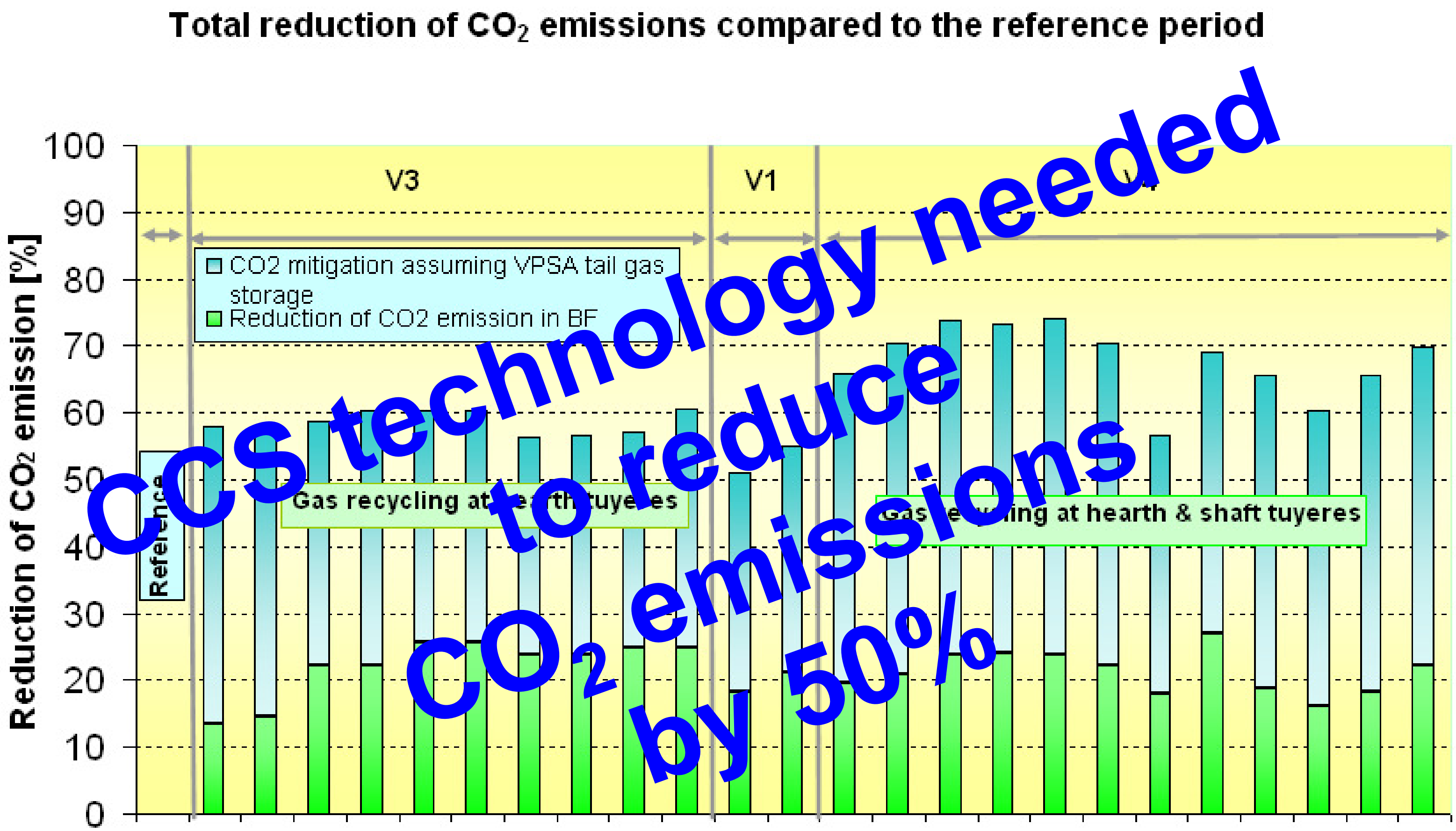


The <u>carbon savings</u> are:

- In terms of (coke + coal): up to 140 kg/thm
- In terms of carbon: up to 129 kg/thm
- Results are in agreement with model calculations
- In terms of coal and coke usage: up to 24%

7.2. CO_2 emission reduction

- Reduced emissions by 23% in version 4 for EBF case
- Evaluation of VPSA/PSA + CCS indicates possible reduction of CO_2 emissions by up to 50%



8. Next steps and Conclusion

8.1. Scale up to industrial

The campaigns showed the possibilities of the Top Gas Recycling Blast Furnace for:

- Industrial operating point
- Safe closed loop operation
- Gas preheating
- Topgas de-CO_2
- Thermal control
- Reduction of ores in the shaft
- Low coke rates

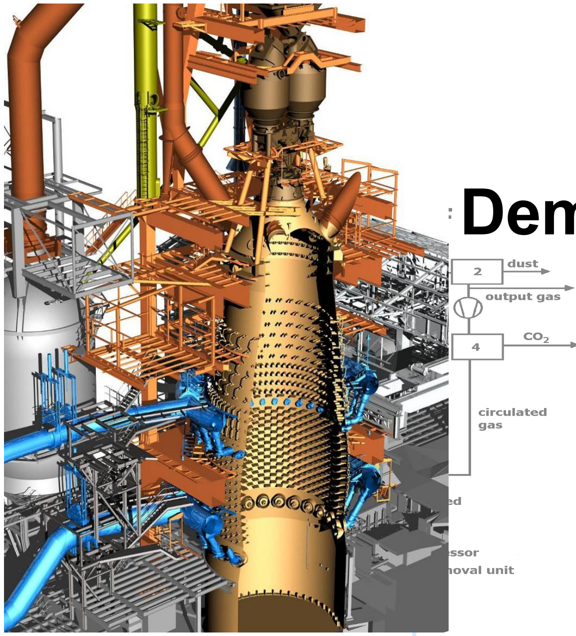
Special attention for:

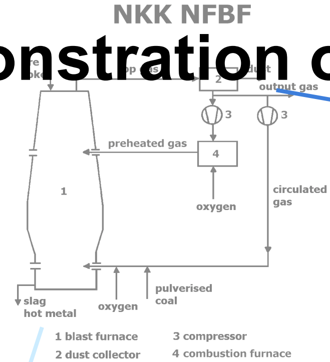
- Tuyere technology
  (product gas + Oxygen + Coal)
- Shaft gas injection, distribution of gas over radius
- Product gas heating

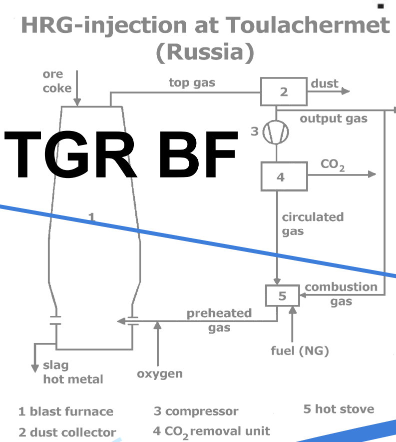
8.2. Next steps

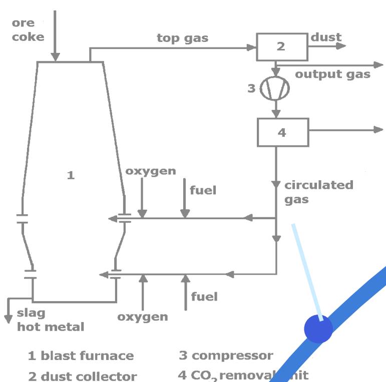
- ULCOS phase II
- Demonstrator plant on industrial scale for version 4
    - *In a production Blast Furnace in Europe*
- CCS storage of CO_2 should be included for the tests at demonstrator scale

Demonstration of TGR BF









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Mid of 80's Development of a NFBF by NKK (Japan)

1984 NFBF-concept of Lu (Canada)

2007 – 2010 BF Campaigns with the CCS concept

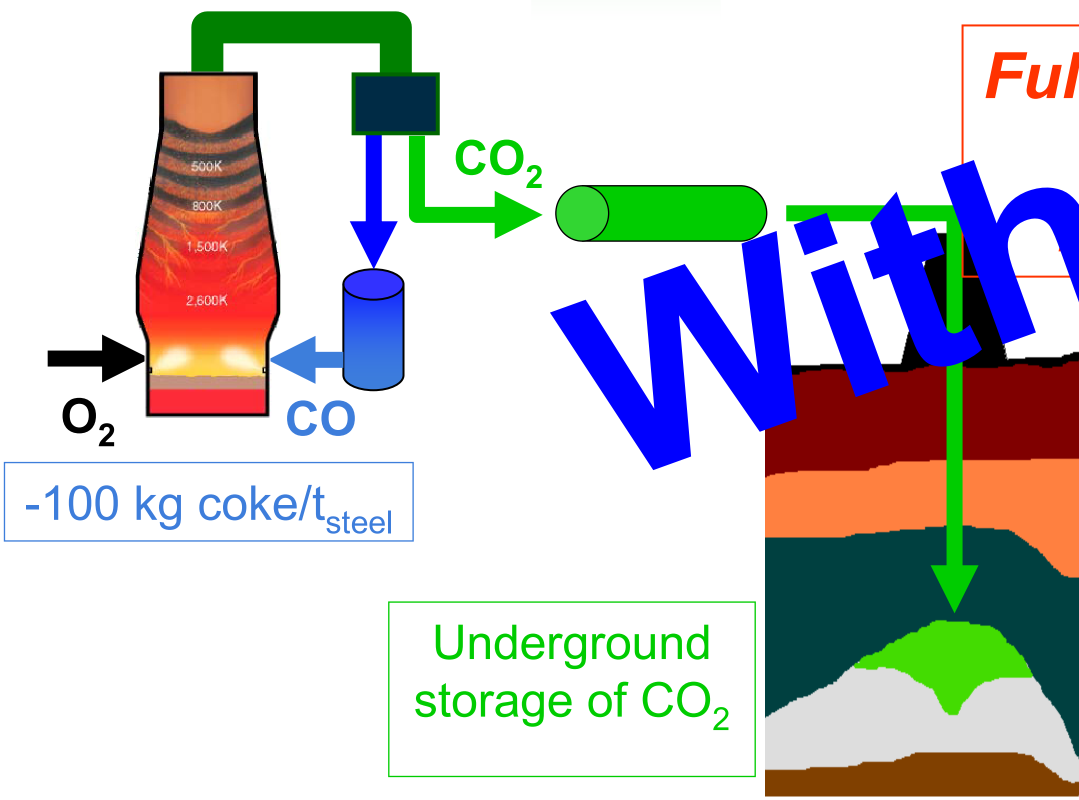
Late 70's Patent of Fink about a NFBF (Germany)

Mid 60's CRM at Cockerill-Seraing (Belgium)

1920 Lance Hot reducing gas injection

8.3. Outlook – ULCOS II

CO_2 emissions of the steel plant: **- 60%**

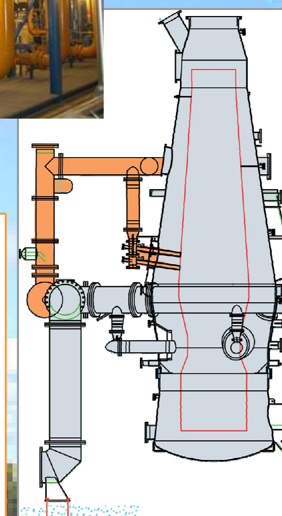


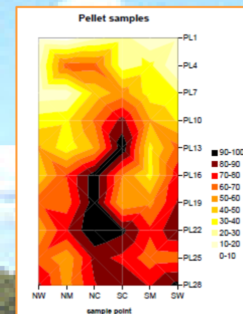
Full CCS demonstrator in Florange, NER-300 proposal

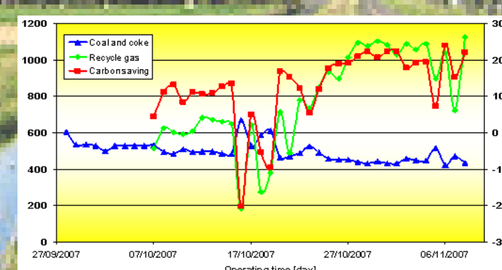
Withdrawn

Conclusions ULCOS TGR BF Developments

- It has been possible to apply the Top Gas Recycling Blast Furnace process concept at the EBF;
- No <u>safety issue</u> has been recorded with the new process;
- The EBF and VPSA operations were smooth with good results;
  - *High recycling ratios;*
  - *Closed loop operation;*
  - *Gas quality according to set values.*
- Three different blast furnace concepts has been developed;
- Achieved results close to modelled expected values
- The Carbon savings were up to 24 %;
- The VPSA plant was able to remove CO_2 efficiently from BF topgas;
- Campaigns showed that conventional burden material can be used;
- Calculations for industrial applications indicate that a reduction of CO_2 over 50%/tHRC could be achievable;
- Next step for technological developments:
  Demonstrator plant on industrial scale for version 4 on a full Production Blast Furnace







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Thank you for your attention

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