Developments of Top Gas Recycle Blast Furnace For Green and Clean Steel Production

The ULCOS-BF developments in Europe

17 January 2024

ICGSI

ir. Jan van der Stel

Together we make the difference

17-18 January 2024 International Conference Green & Sustainable Ironmaking

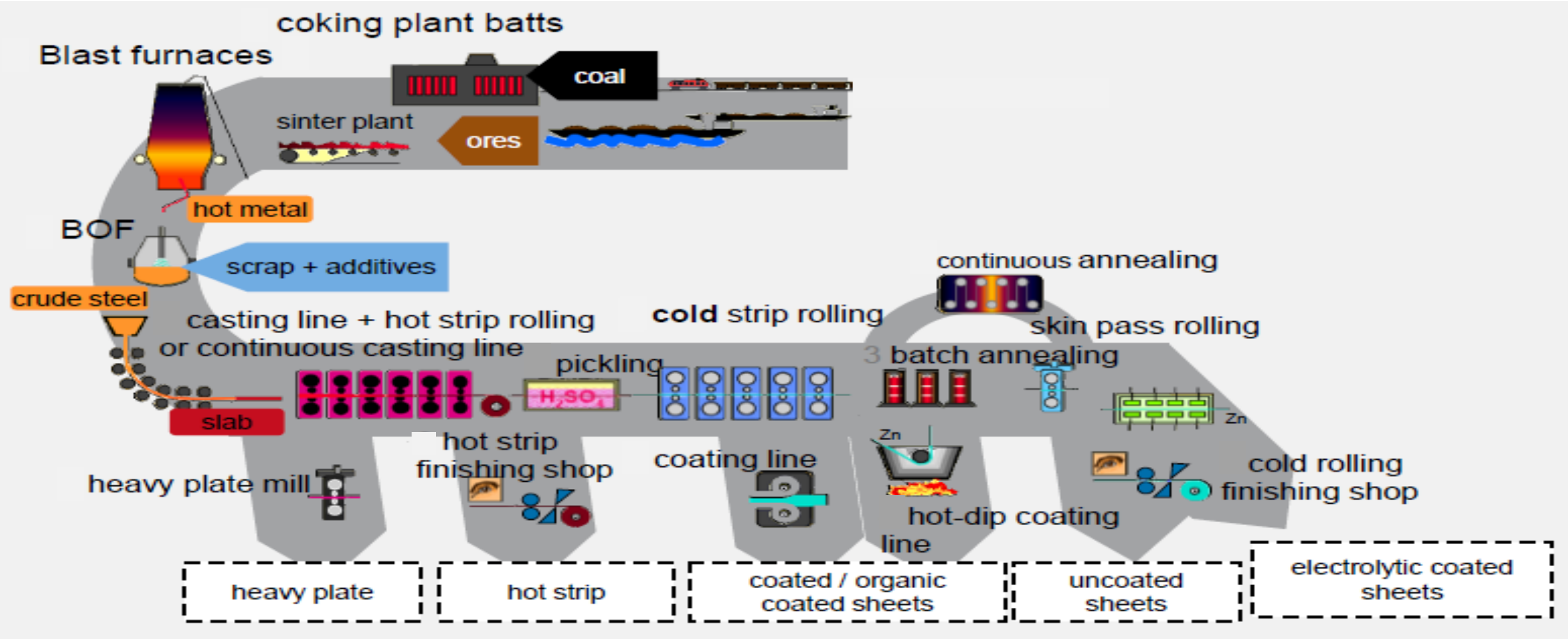
TGRBF: European project sponsored by the EU (2004 – 2014)

Outline

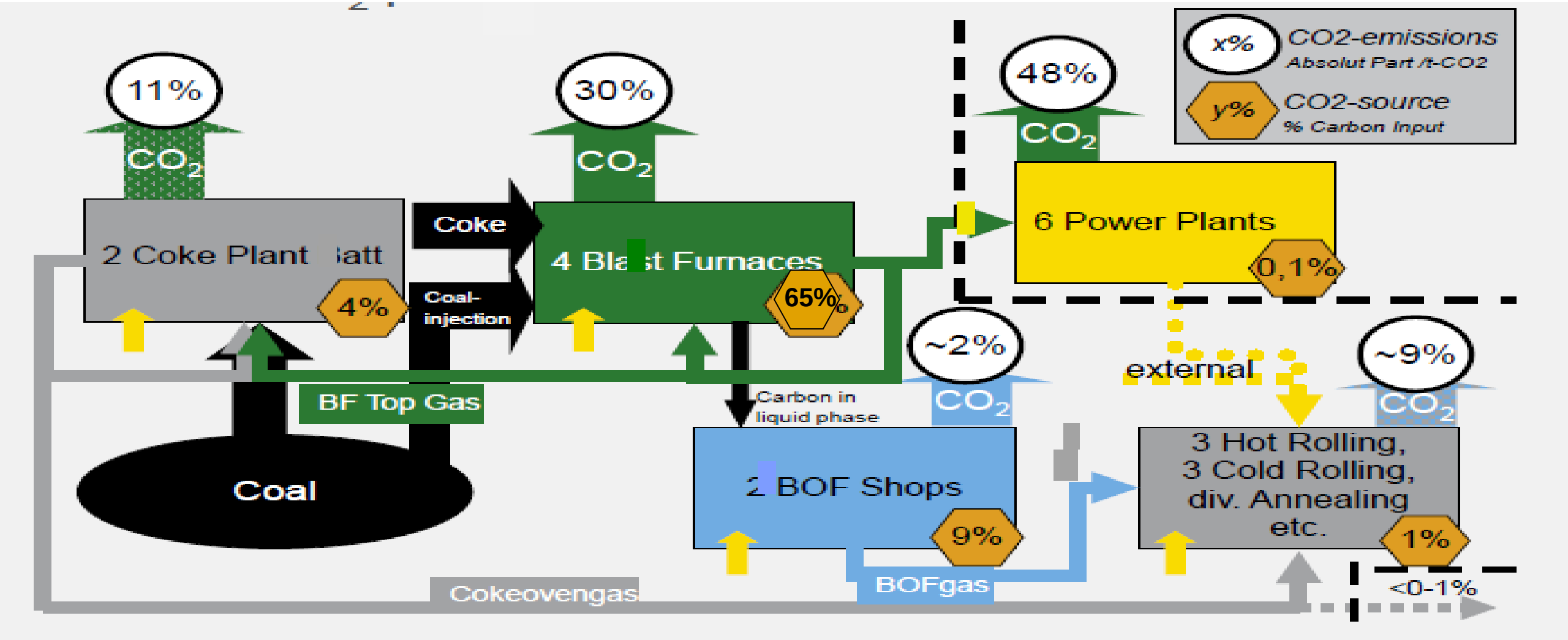
- Introduction
- Ultra Low CO_2 Steelmaking: ULCOS
- Top Gas Recycle Blast Furnace concept (TGRBF)
- ULCOS BF Developments
- Demonstration of the ULCOS BF process concept at pilot scale
- ULCOS BF Experimental Blast Furnace results
- CO2 emission reduction
- Next Step and conclusion

Introducion

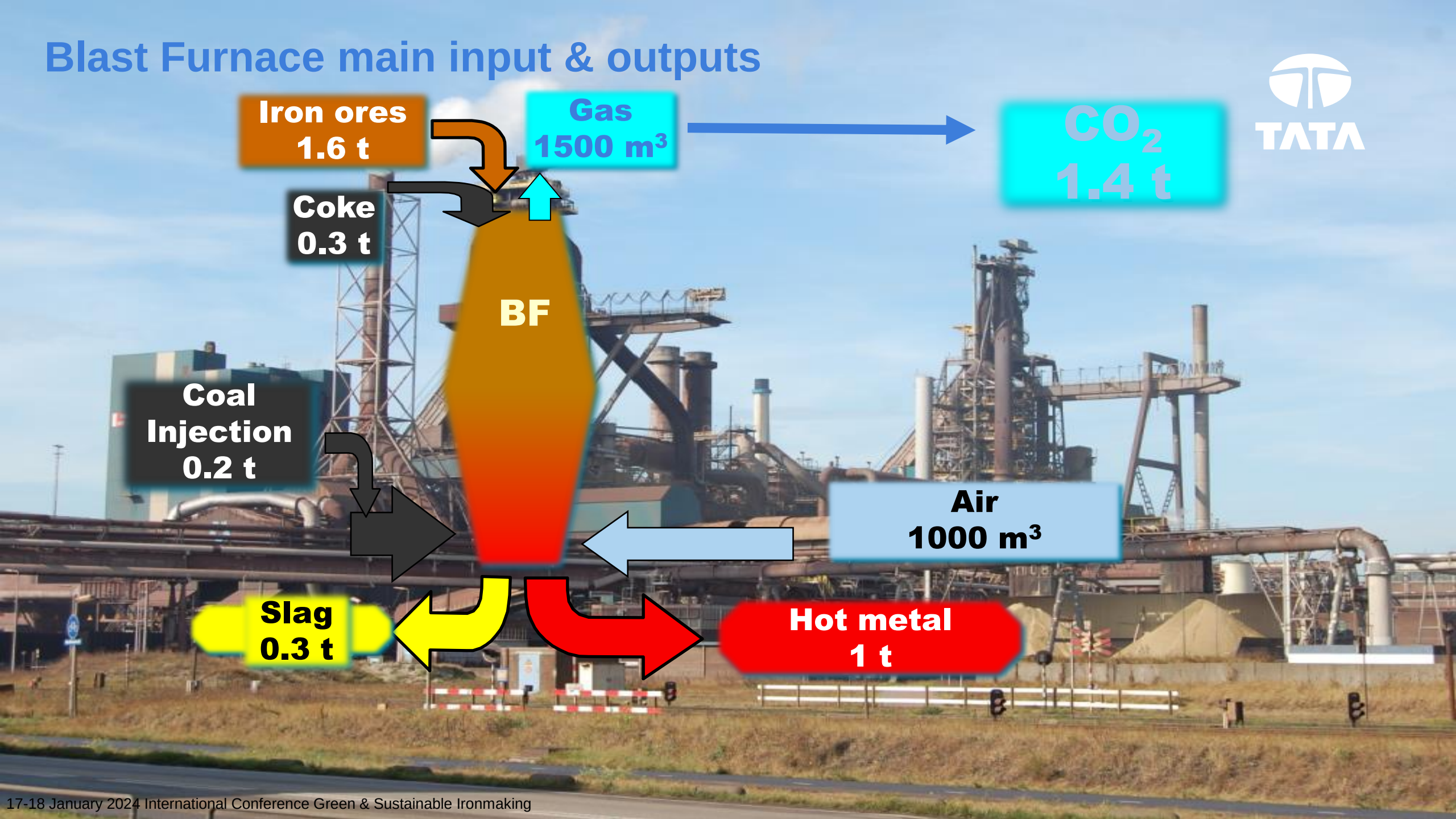
An integrated steel mill has numerous facilities to come from ore and coal to steel products



Main CO_2 emitters



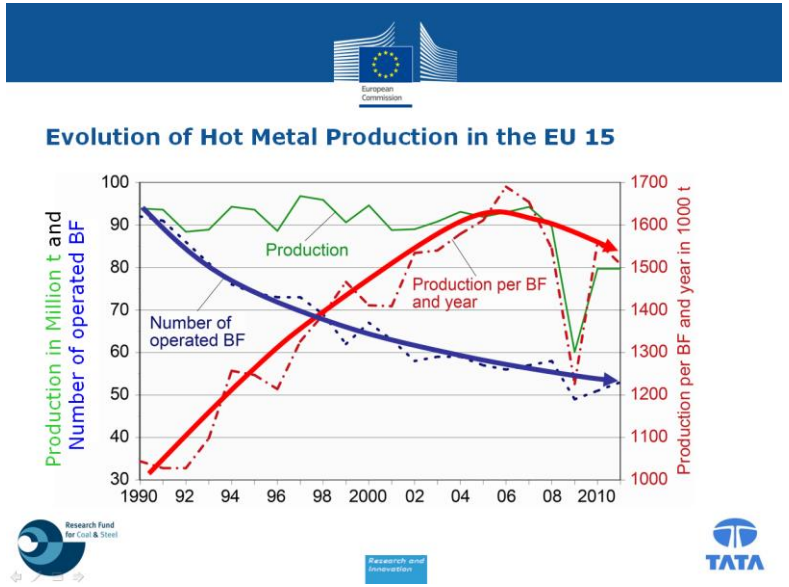
Blast Furnace main input & outputs

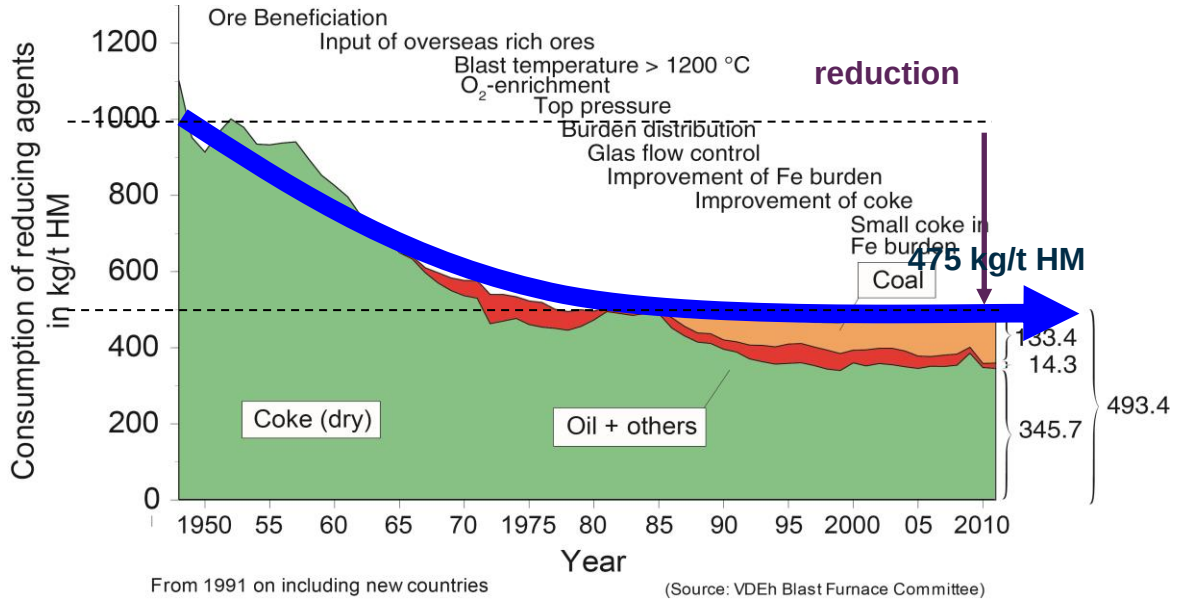


ULCOS

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
- Blast Furnace is main producer of CO_2 within integrated steel works
- Small possibilities to reduce CO_2 emissions with existing blast furnace operation



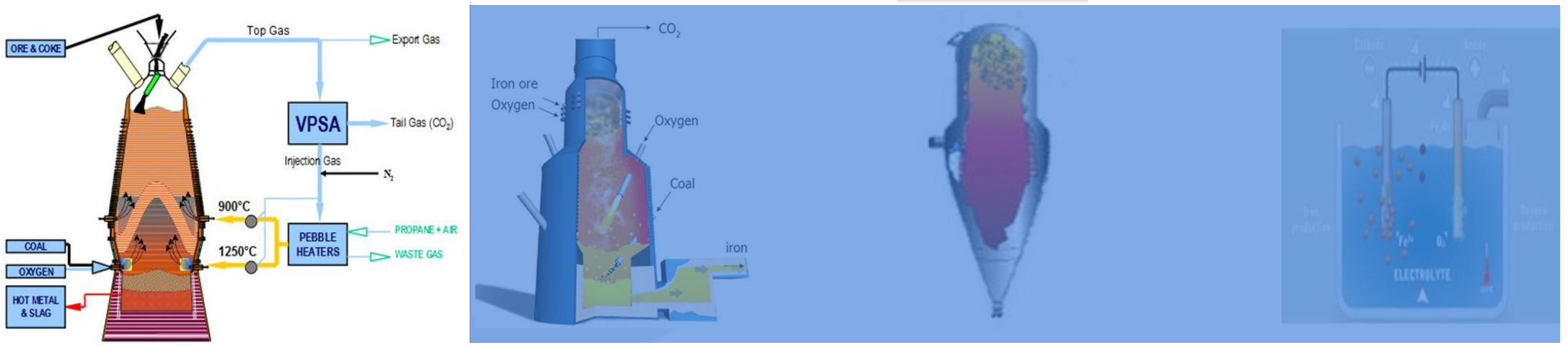


ULCOS – Ultra Low CO2 Steelmaking

- 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
  - *ULCOSBF: TGRBF*
  - *HISARNA*
  - *ULCORED*
  - *ULCOWIN/ULCOLYSIS*
- Phase 1 ended in 2010
- Cooperation ended in 2014

ULCOS – Process routes

Coal and sustainable biomass	Natural gas	Electricity



ULCOS BF HISARNA	ULCORED	ULCOWIN

- Revamped Blast Furnace / DR
- Brownfield / Greenfield
- CCS technology
- Carbon lean electricity

The ULCOS project objective

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

How can CO_2-emission from blast furnace be reduced?

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

2nd Application of Capturing and Storage of CO_2

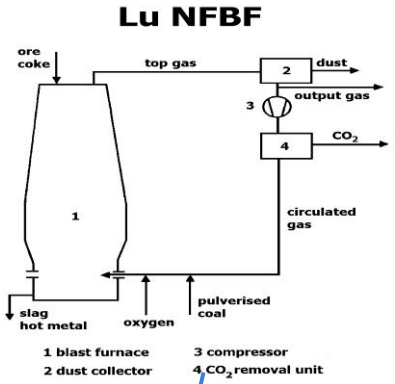
3rd Use of biomass as a CO_2 neutral carbon source

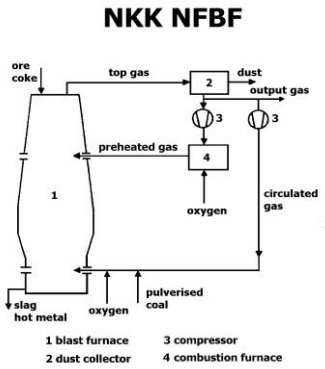
4th Substitution of CO by H_2 as reducing agent

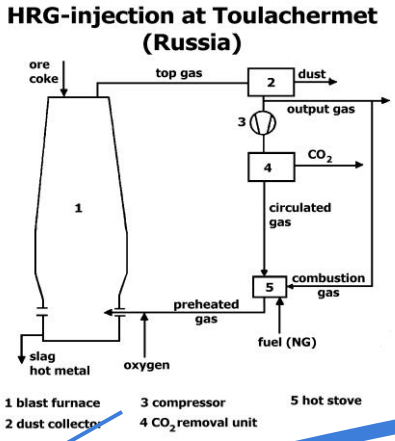
5th Use of C-lean DRI, HBI or LRI

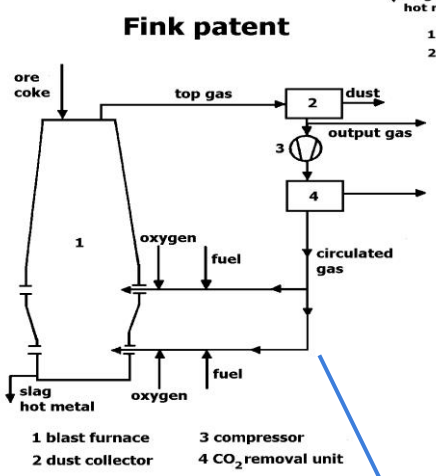
6th Use of C-lean electrical energy

History of alternative blast furnace processes









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)

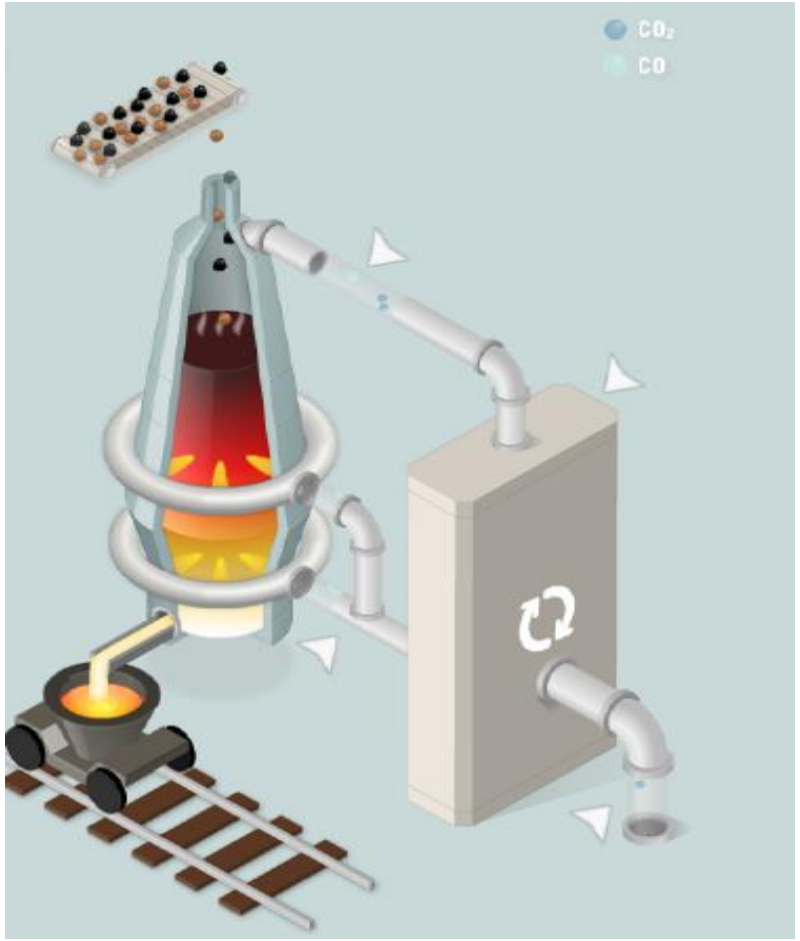
1984 NFBF-concept of Lu (Canada)

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

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

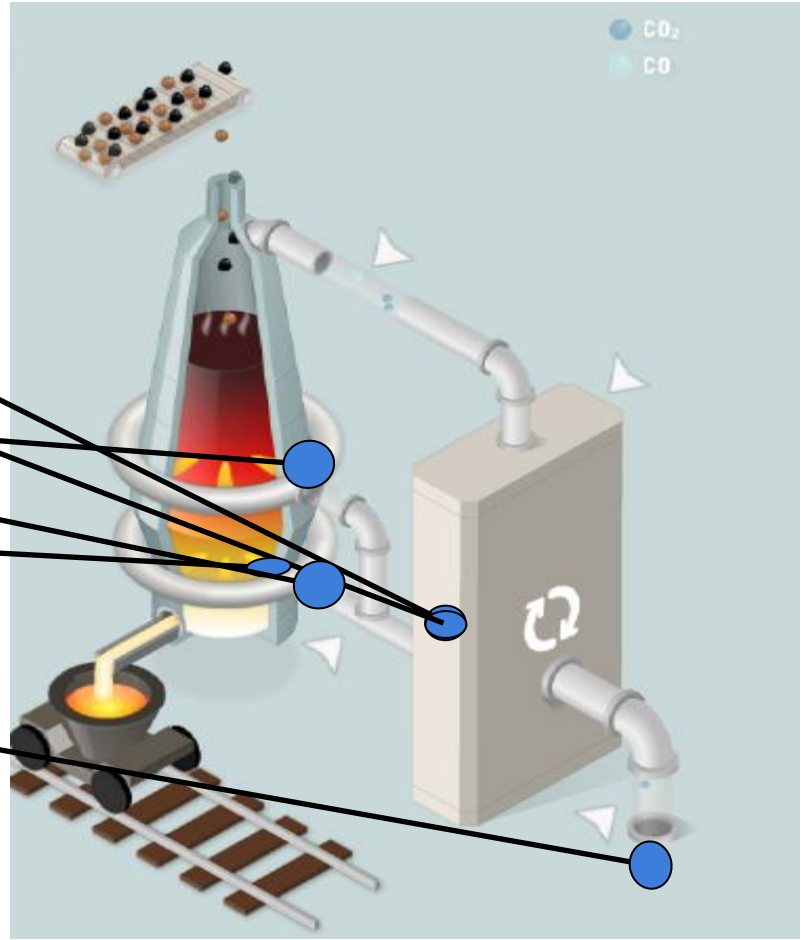
1920 Lance Hot reducing gas injection

TGR BF Concept



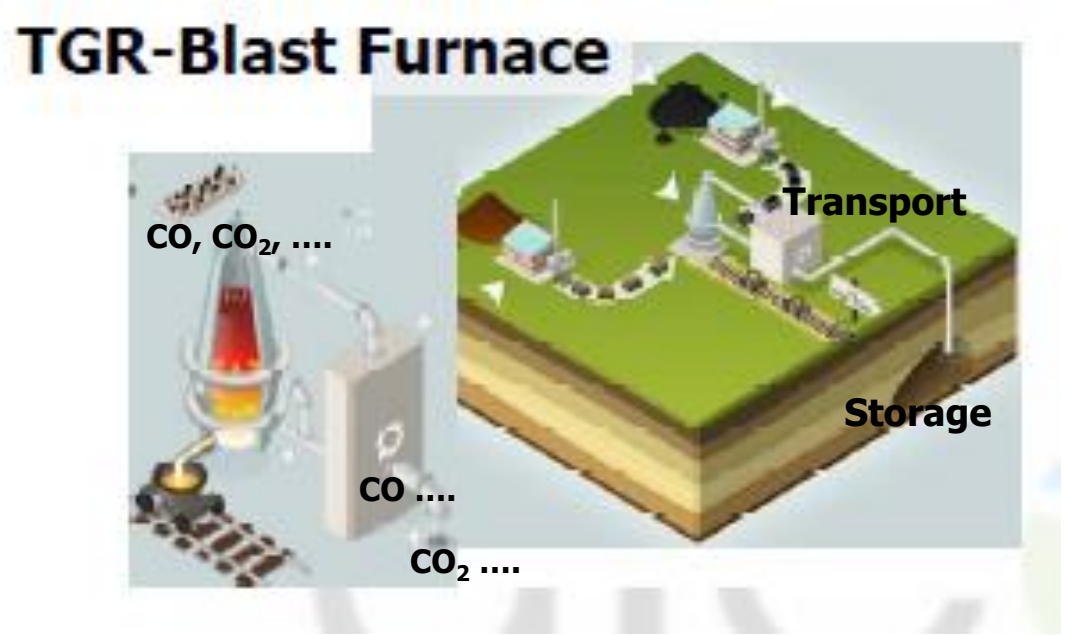
The ULCOS Top Gas Recycle Blast Furnace Concept

- 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

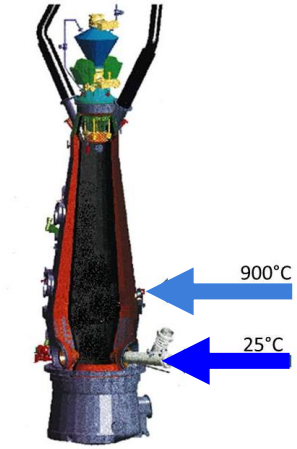


CO2 mitigation | **~25 % at the BF** | **~55-60 % for the whole plant**

ULCOS TGRBF Developments

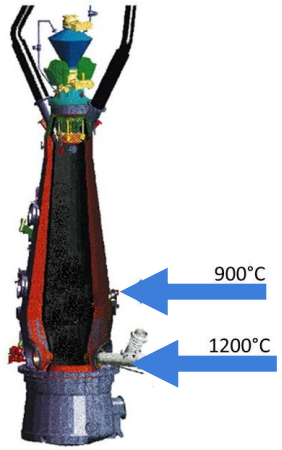
Tests prior to the Experimental Blast Furnace campaign

- Recirculation of blast furnace top gas
- VPSA/PSA operation + CCS
- 3 different ULCOS-BF concepts developed
- Injection of decarbonated top gas
  - *Shaft (Version 1 & 4)*
  - *Tuyeres (Version 1,3 &4)*
  - *Temperature*
- Mathematical modelling to find process with highest carbon saving potential
- Process modelling according to data from a commercial European BF
- Laboratory testing



Version 1

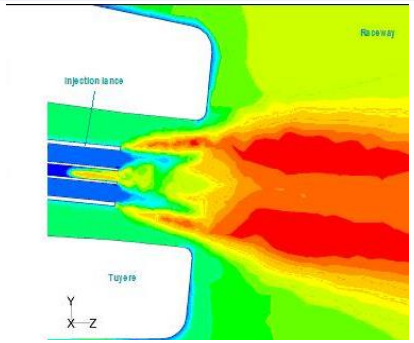
Version 3



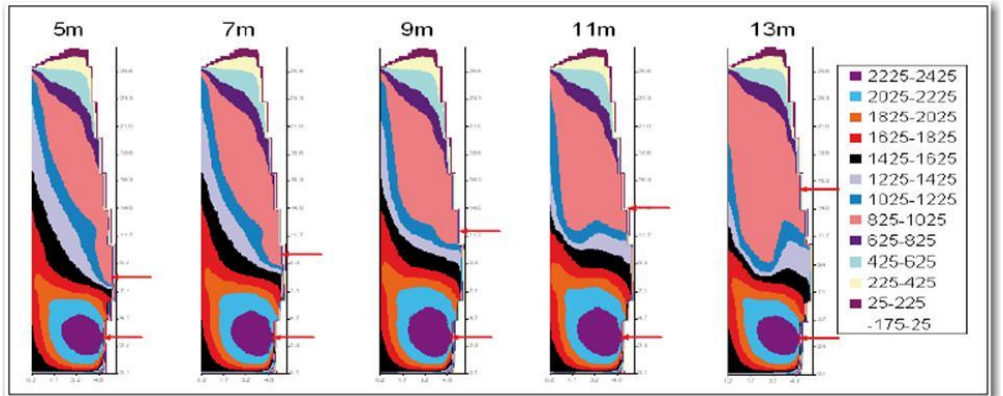
Version 4

Tests prior to the 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

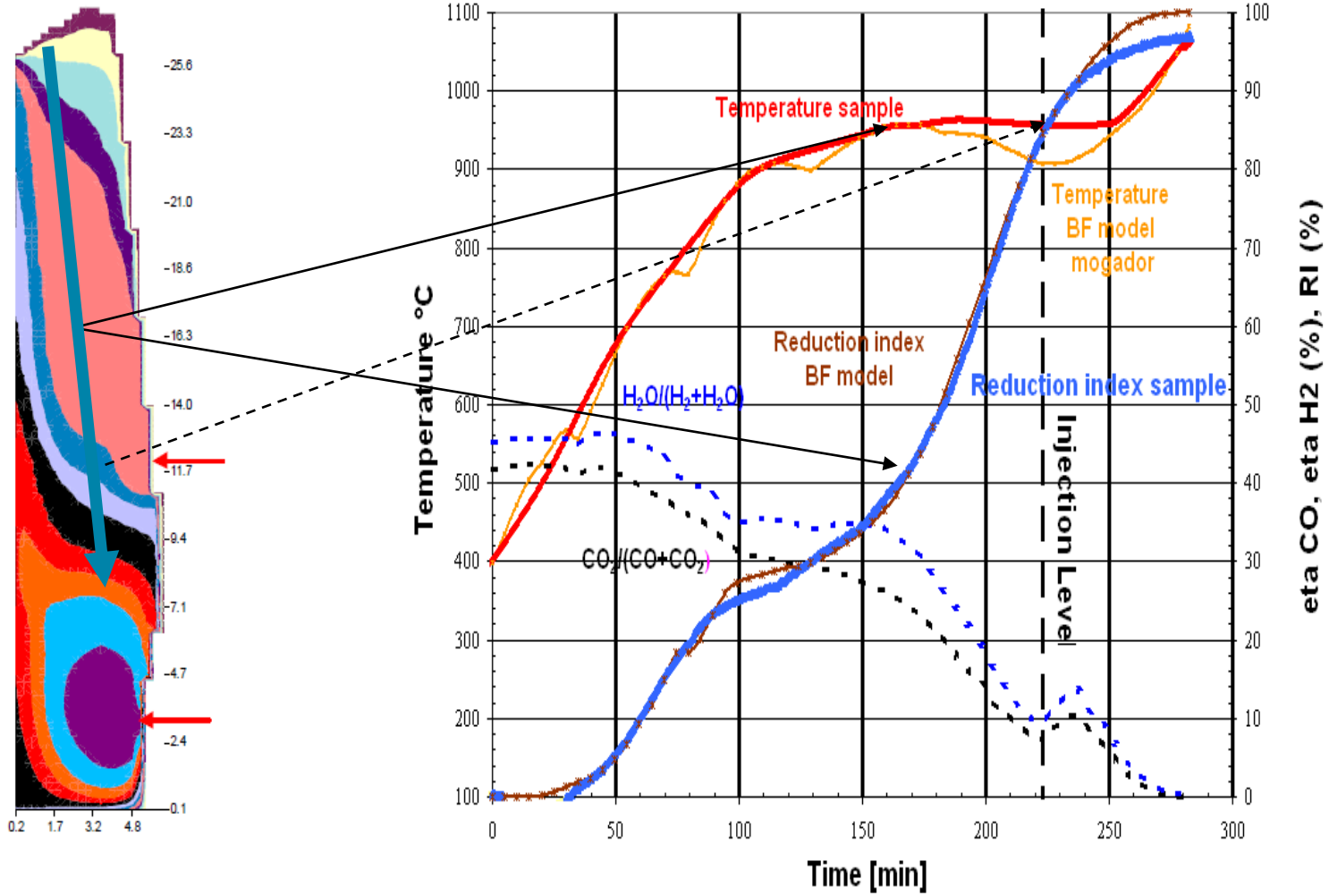


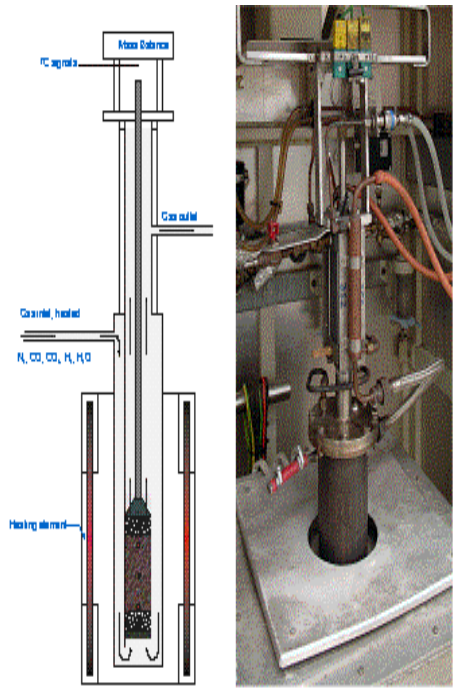
Version 3



Developments

Behaviour of existing raw materials

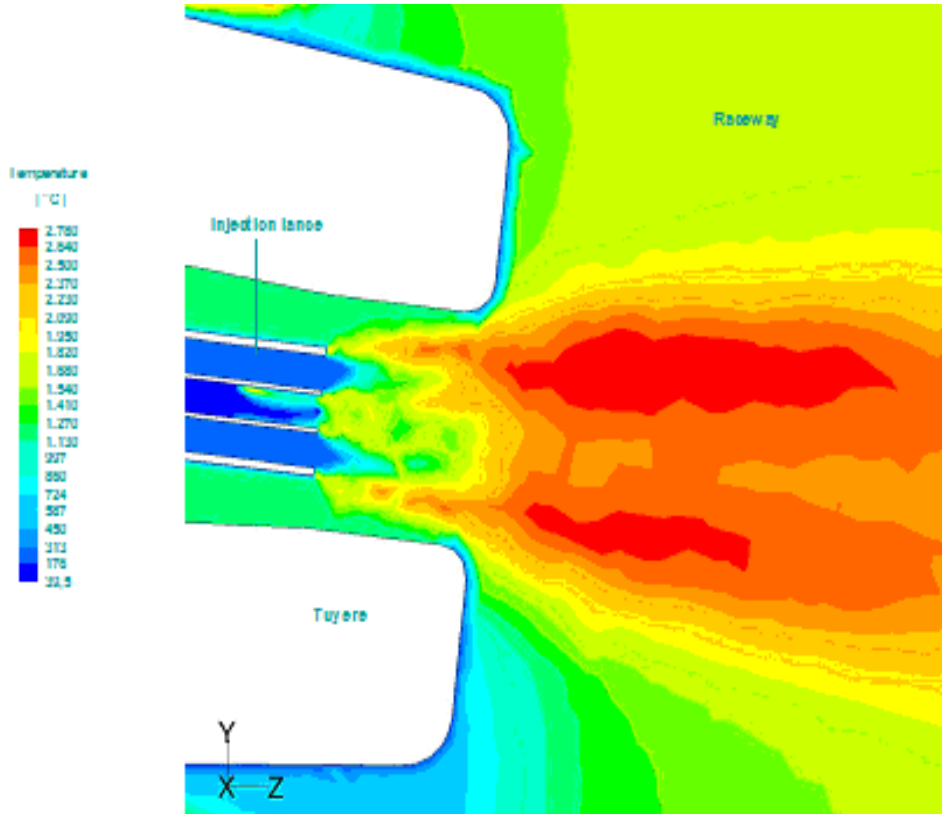




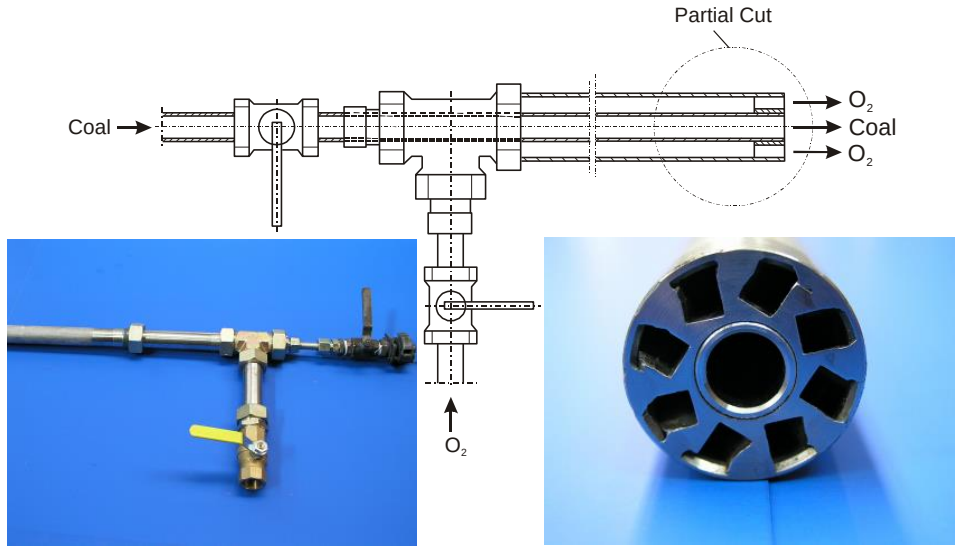
Developments

Raceway conditions and tuyere design

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



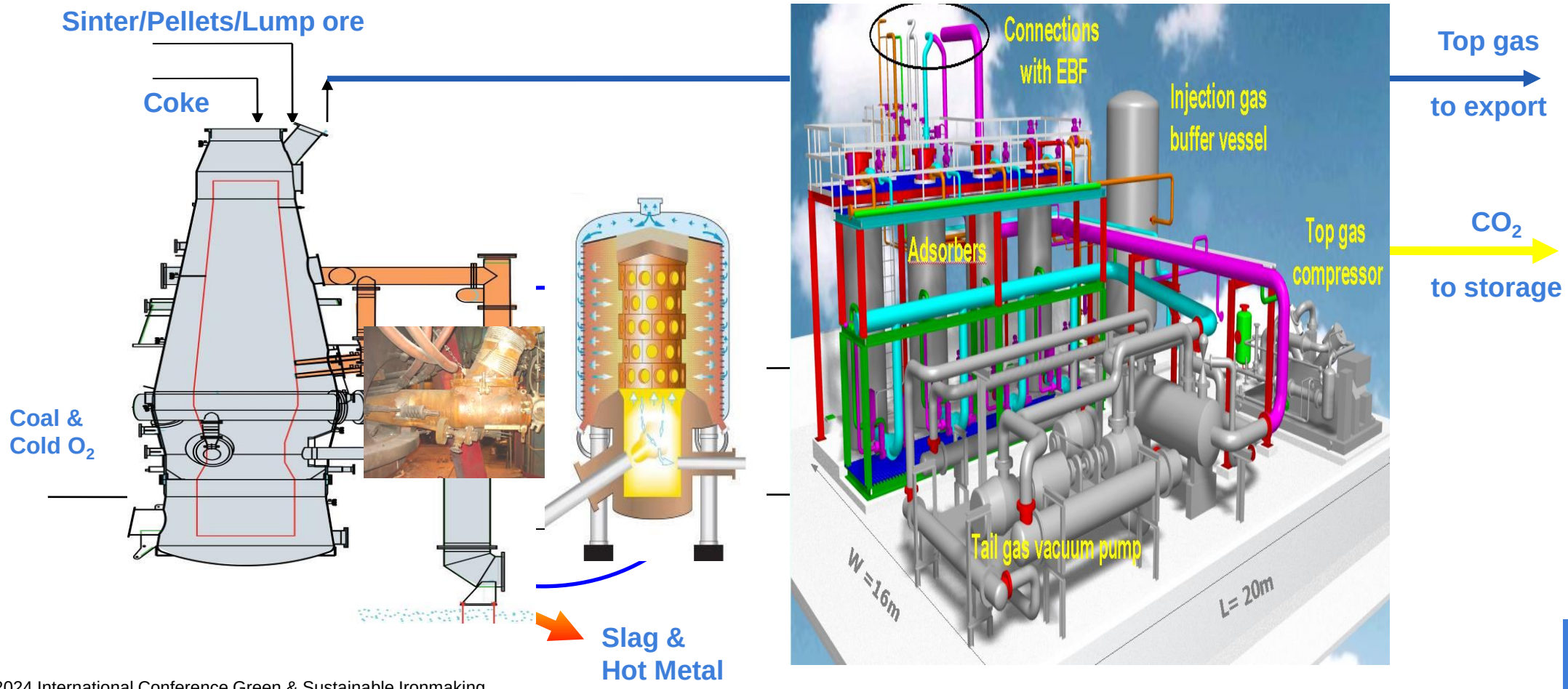
Lance design for coal and oxygen injection



Test results at the Teesside single tuyere rig

Preparations prior to the TGR Blast Furnace trials

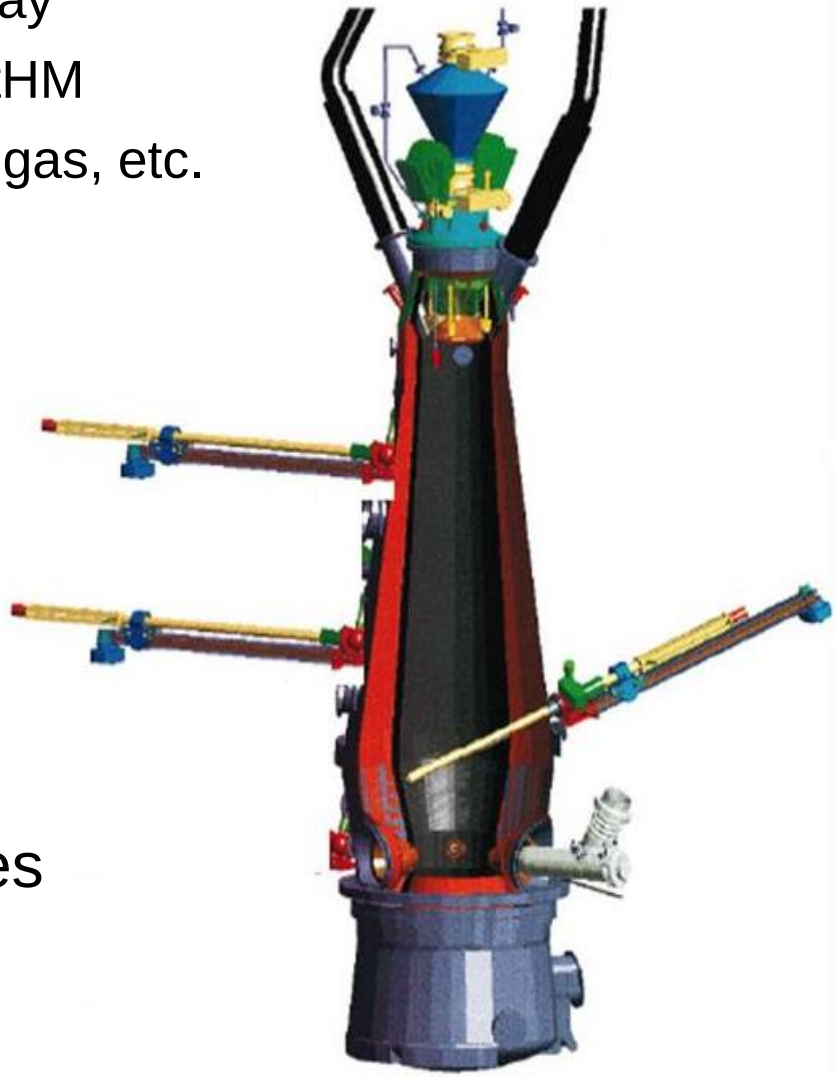
- Extensive **HAZOP** studies
- Erection of an **PSA/VPSA** plant on site by Air Liquide
- **Modification** of existing EBF equipment
- Installation of **new equipment** at **EBF**
- ***Simulated*** TGRBF operation using cold nitrogen
- ***Training*** of personnel

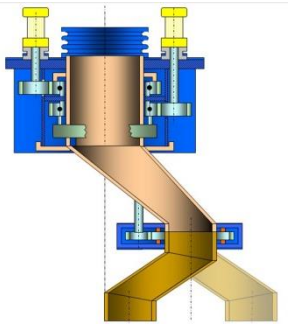


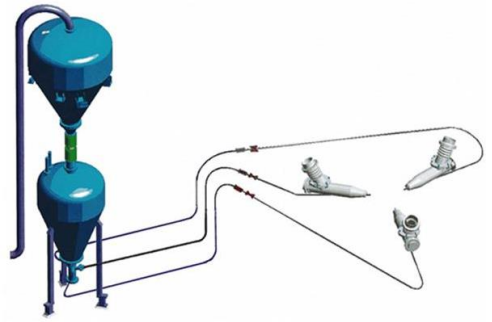
Top Gas Recycle Blast Furnace Campaigns at EBF in Luleå

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 temperature:	1200°C
Oxygen in blast:	21-40%
Tuyeres:	3
Hearth diameter:	1,2 m
Working volume:	9 m^3



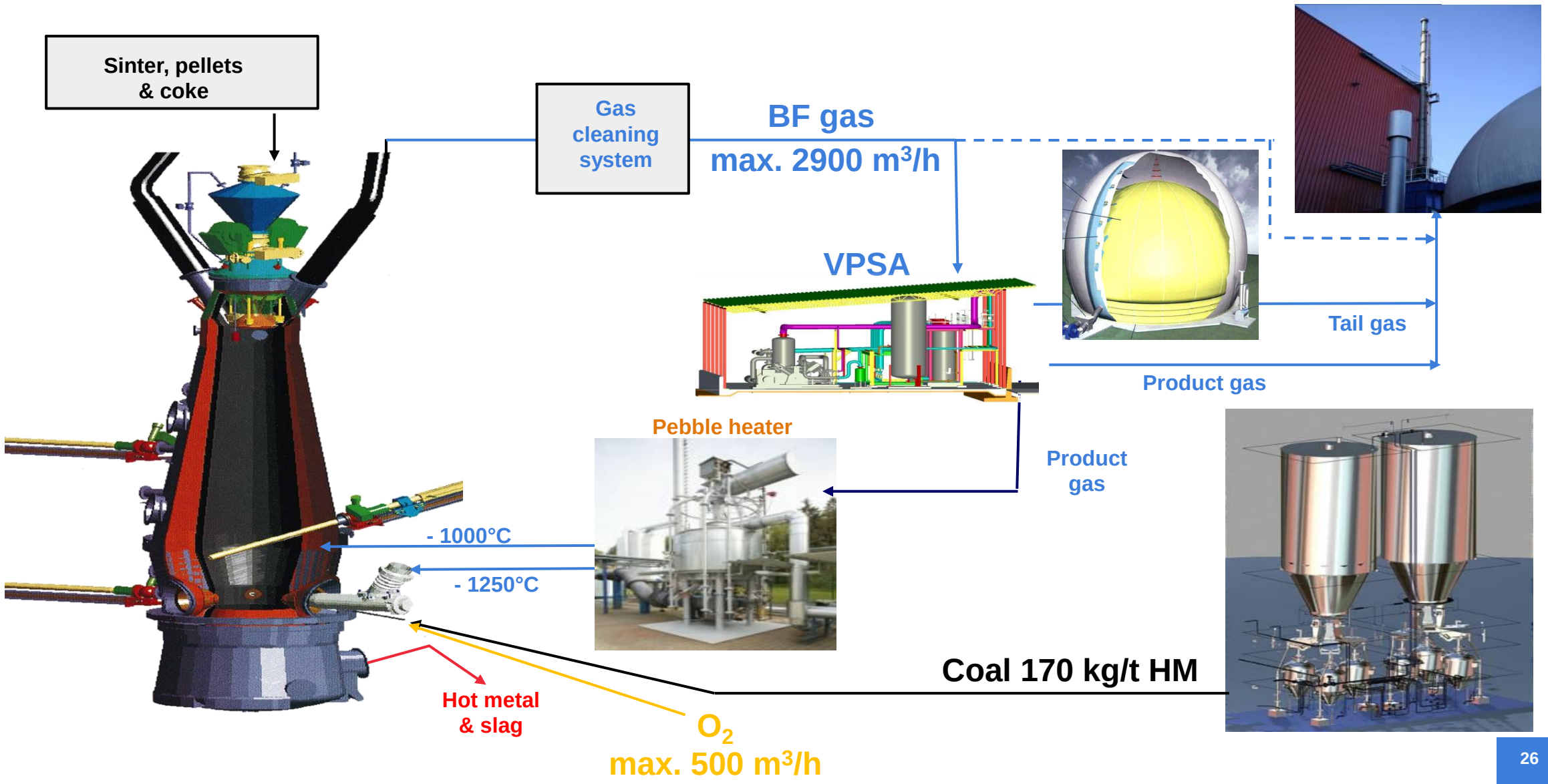




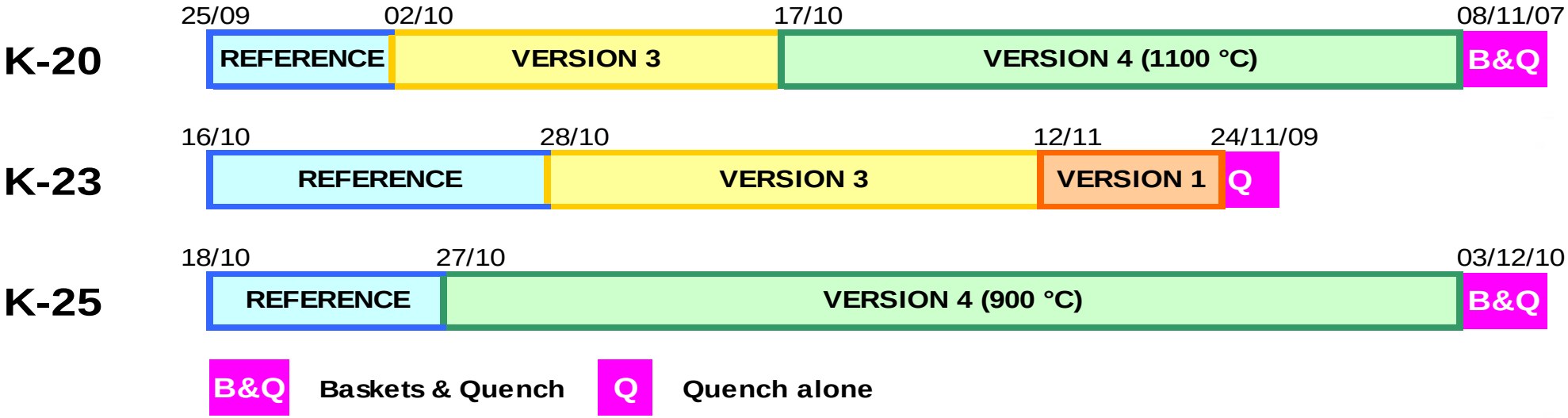
Flexible sampling possibilities

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

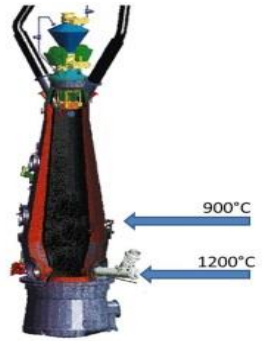
The Top Gas Reclyce Blast Furnace concept at EBF in Luleå

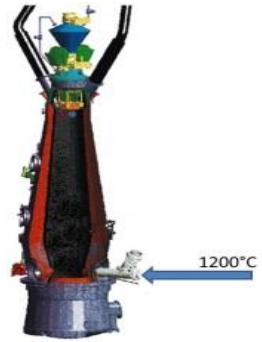


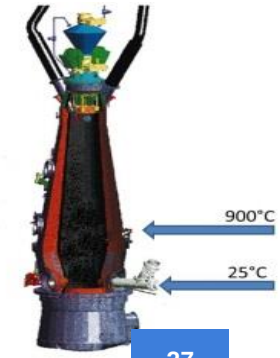
Operating trials



- 3 TBR BF trials operated at the EBF in 2007, 2009 and 2010
- Varied BF operation tested:
  - *Amount of recirculated gas;*
  - *Coal injection (130 and 170 kg/tHM);*
  - *Distribution (70% SSAB-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 samples



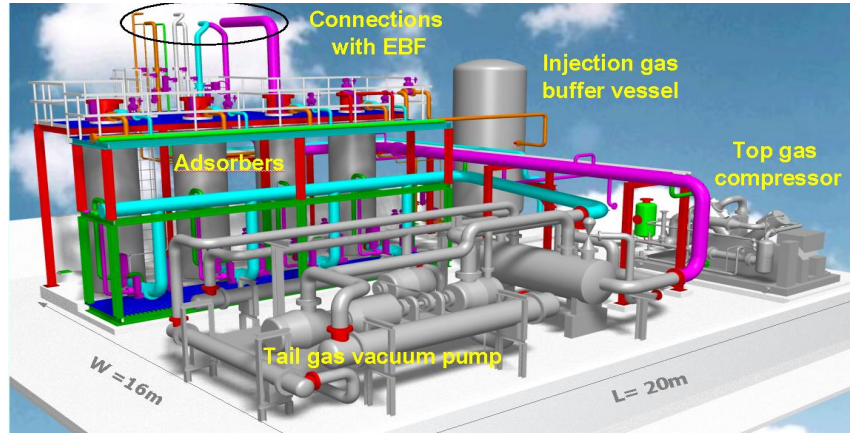




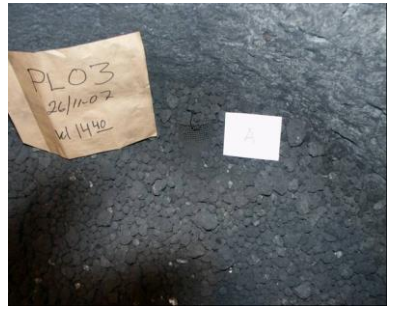
ULCOS BF
EBF
Results

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



Evaluation of process and equipment
Excavation of the Experimental BF

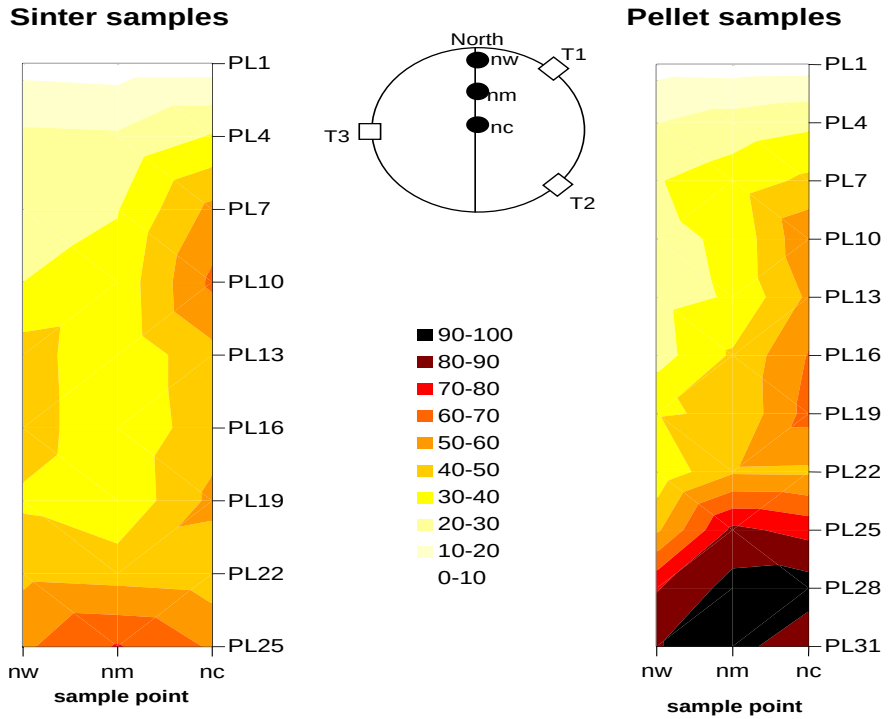


Reduction profile:

- center working furnace;

Similar behavior as in conventional BF:

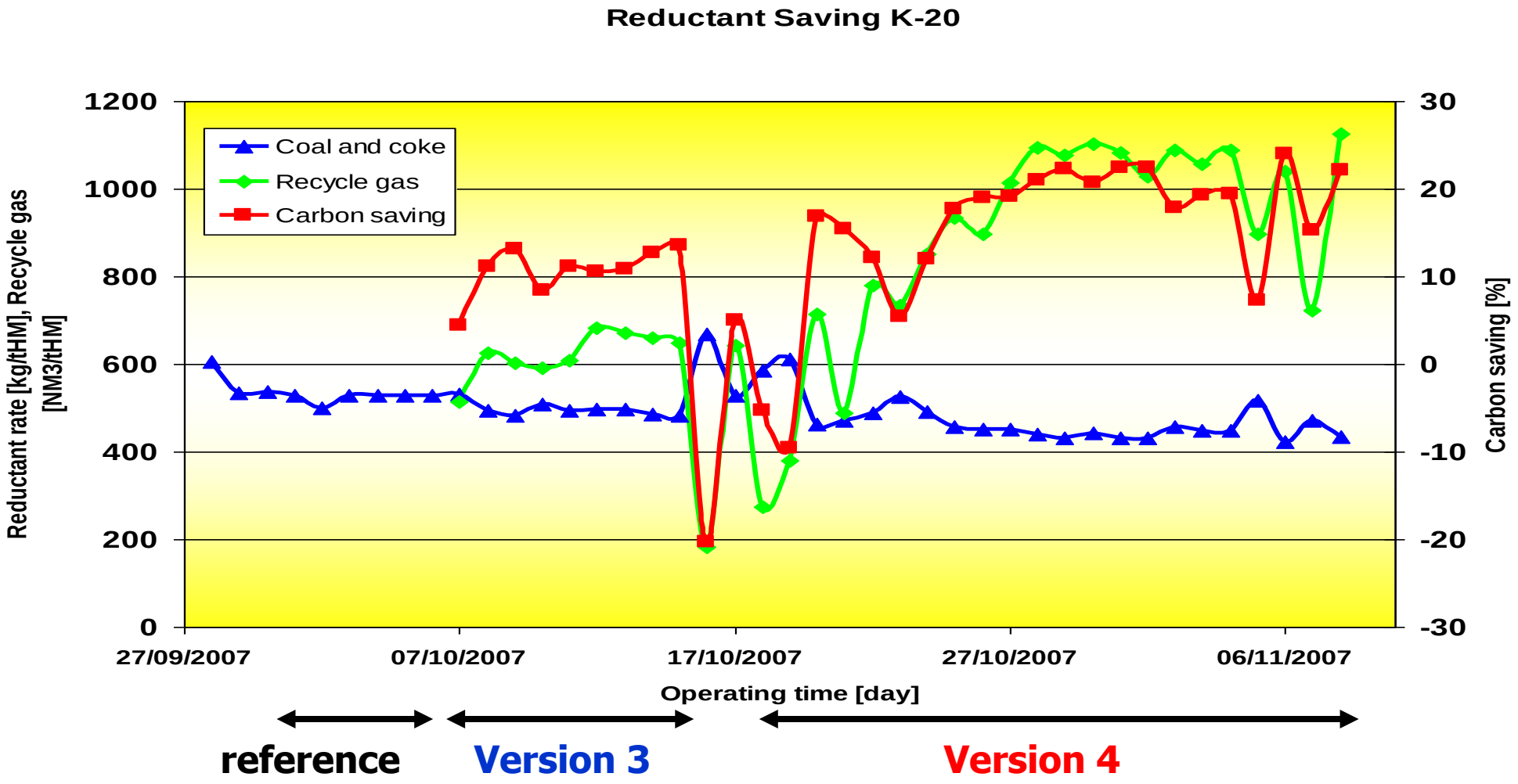
- Strength index shows linear trend with reduction degree;
- Sinter disintegration.

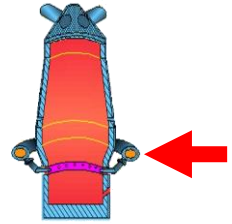


Reduction degree of sinter and pellet samples north-axis

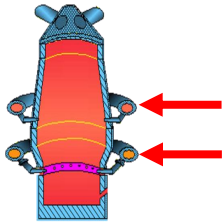
Evaluation of process and equipment

K-20 results: reductant rate, recycled gas injection and carbon saving





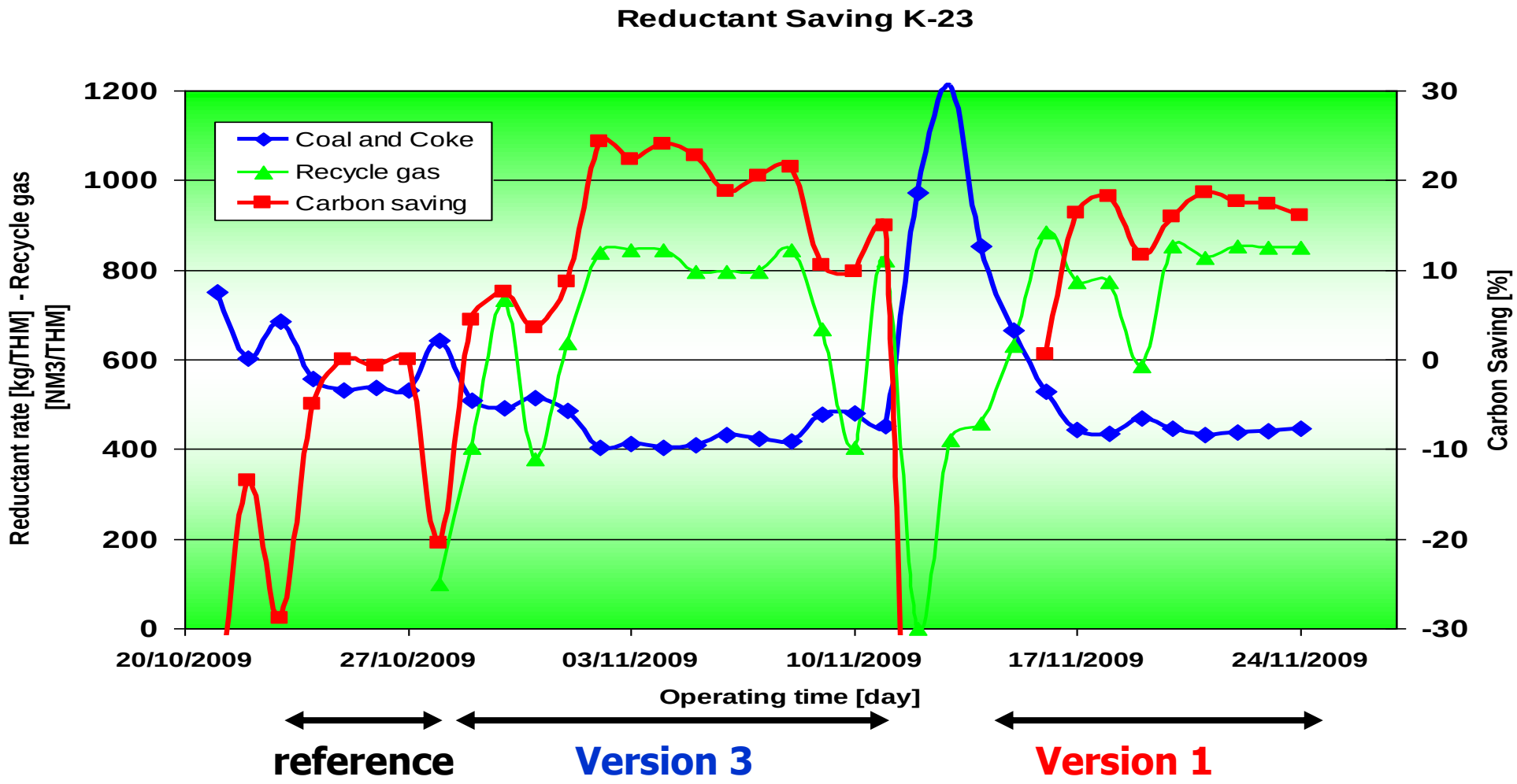
Version 3

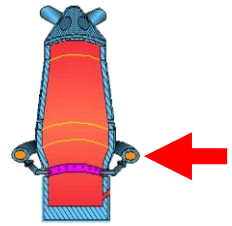


Version 4

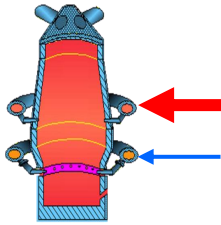
Evaluation of process and equipment

K-23 results: reductant rate, recycled gas injection and carbon saving





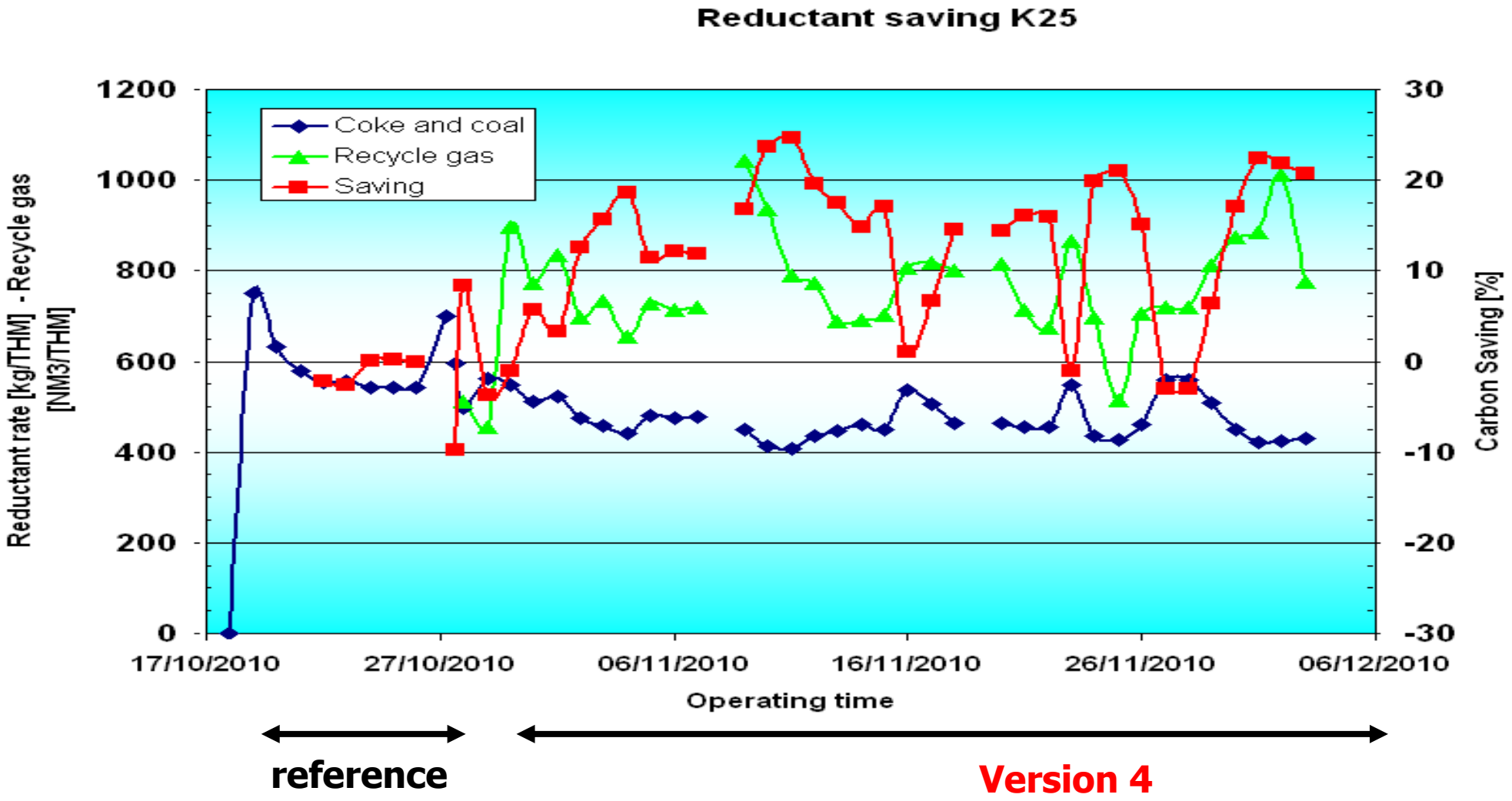
Version 3

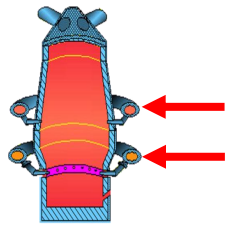


Version 1

Evaluation of process and equipment

K-25 results: reductant rate, recycled gas injection and carbon saving



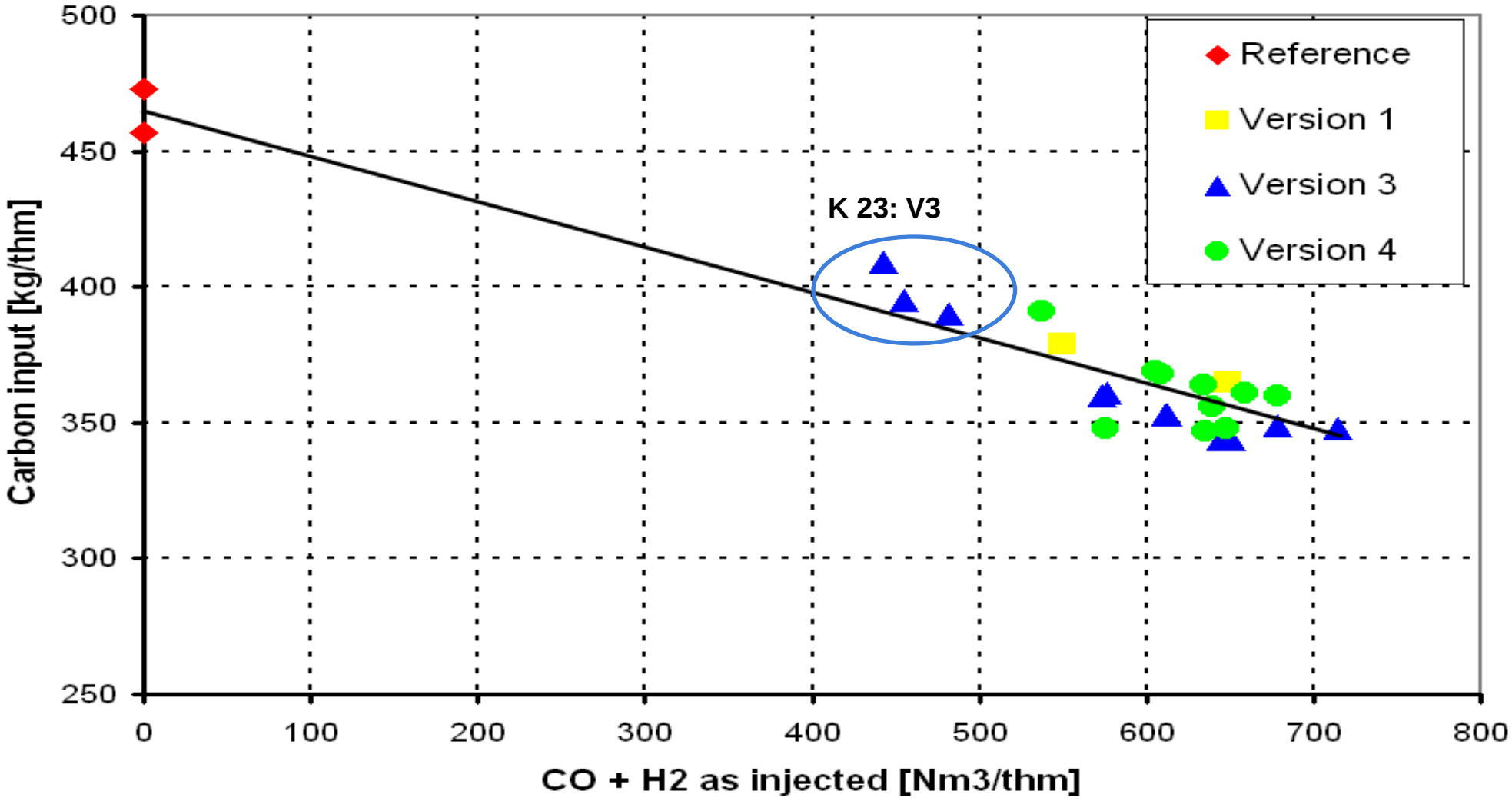


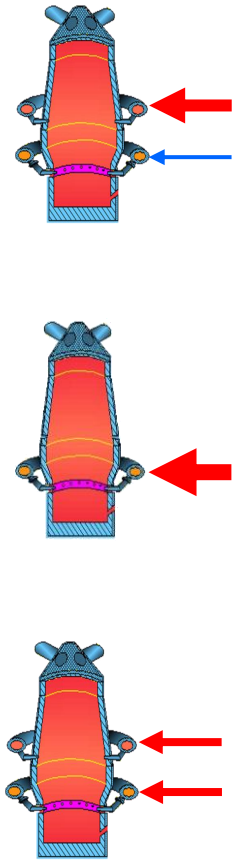
Version 4

CO_2 Emission Reduction

BF Results:

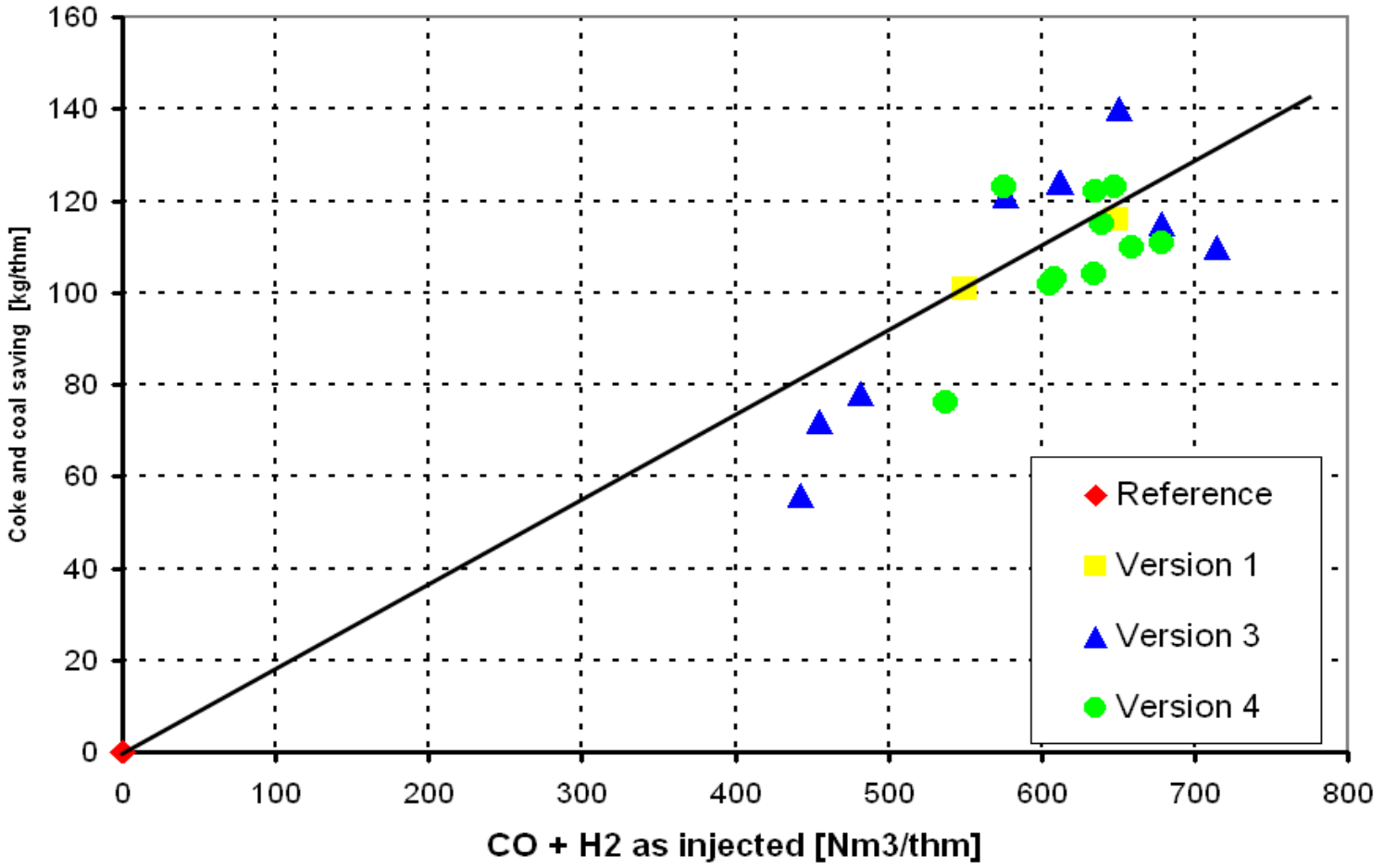
Carbon input and gas injection





BF Results:
Carbon savings

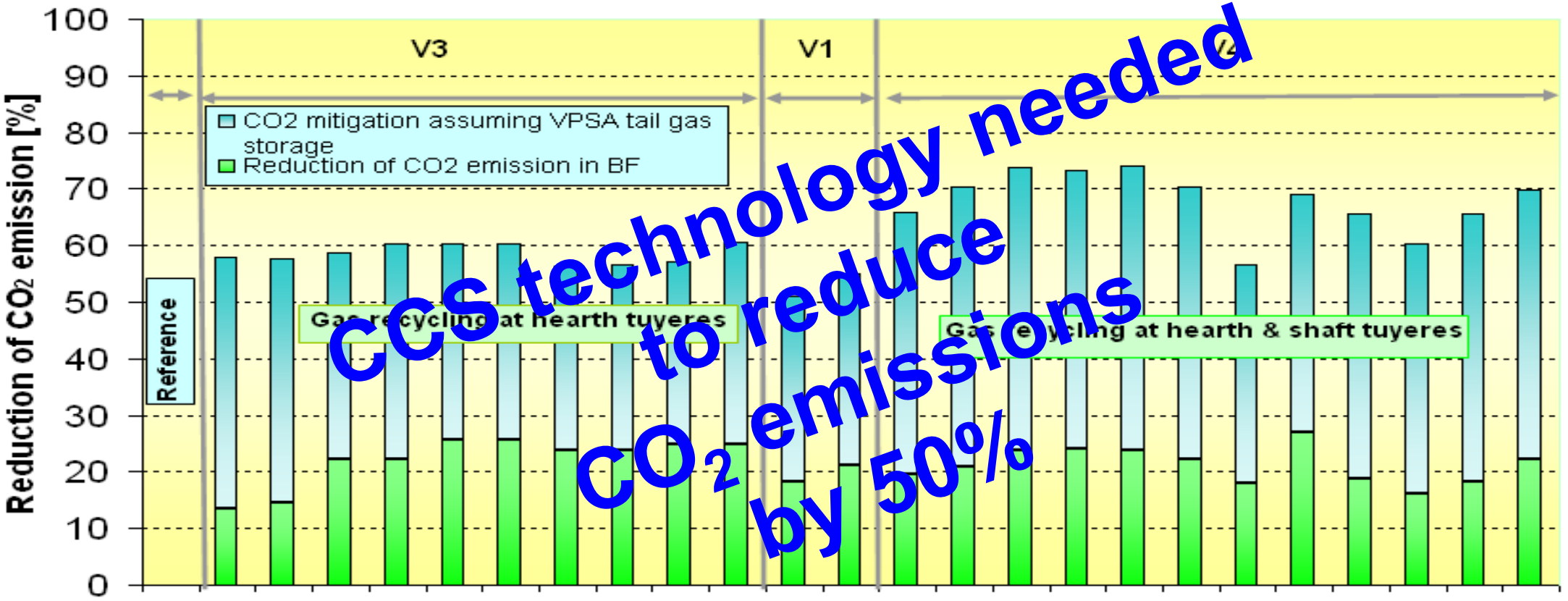
	Version 1	Version 3	Version 4
Carbon saving (%)	20	23	24
Recycling ratio (%)	85	87	90



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
- In terms of coal and coke usage:
  up to 24% reduction
- Results in agreement with model calculations

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%

Scale to industrial

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
- Top gas 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

2025 Easy SmeIt

2023 BaoWu

2008 – 2014 study TGRBF industrial demonstration AM Florange

2004 – 2010 ULCOS TGRBF developments – EBF Lulea

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

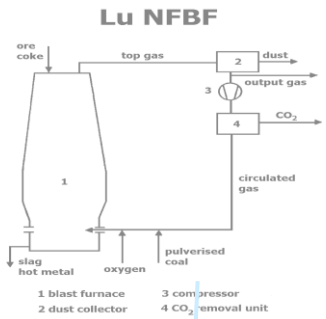
Mid of 80's Development of a NFBF by NKK (Japan)

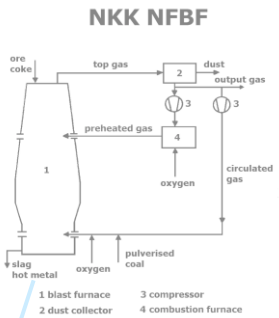
1984 NFBF-concept of Lu (Canada)

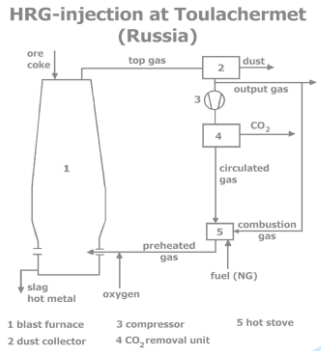
Late 70's Patent of Fink about a NFBF (Germany)

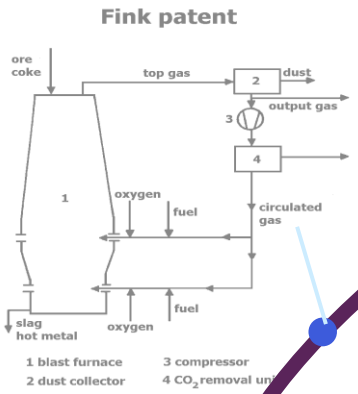
Mid 60's CRM at Cockerill-Seraing (Belgium)

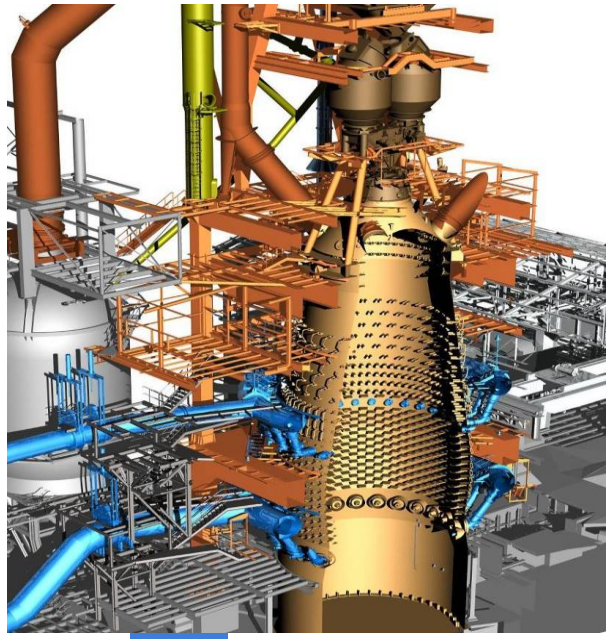
1920 Lance Hot reducing gas injection







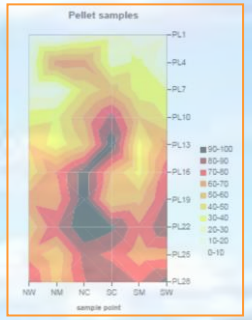


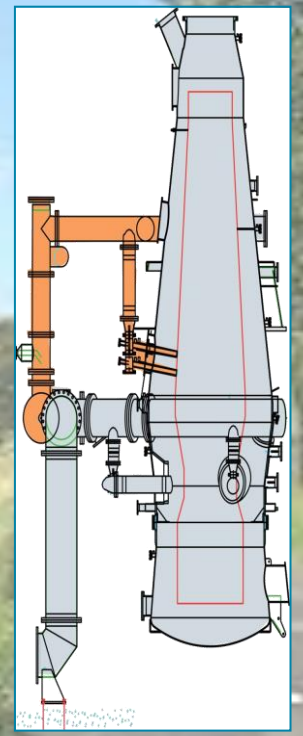


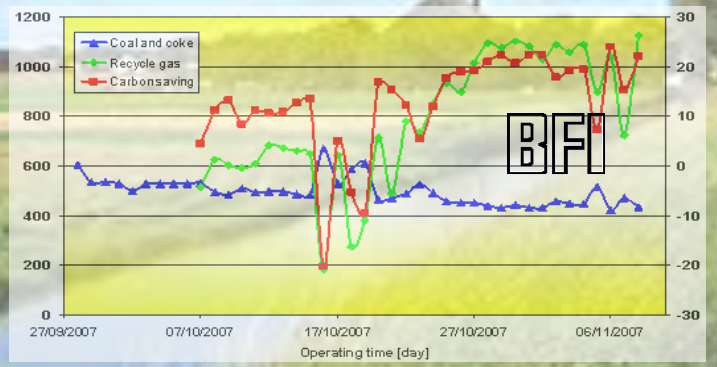
Conclusion

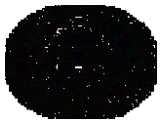
Conclusions ULCOS TGR BF Developments

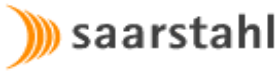
- **It has been possible to apply the Top Gas Recycling Blast Furnace process concept at the EBF;**
- **No <u>safety issue</u> has been recorded with the new process;**
- **The EBF and VPSA operations were smooth with good results;**
  - *High recycling ratios;*
  - *Closed loop operation;*
  - *Gas 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;**
- **Future:**
  Demonstrator plant on industrial scale for version 4 on a full Production Blast Furnace











Thanks to:

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The Ulcos TGR-BF team

For more info on Ulcos:
WWW.ulcos.org


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Thank you for your attention.
Together we make the difference