CO_2 Capture in the Steel Industry

Review of the Current State of Art

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IEA Greenhouse Gas R&D Programme

Cheltenham, UK

Industry CCS Workshop

Vienna, Austria

28th April 2014

IEAGHG Activities on CCS for the Iron & Steel Industry

- ***Reports***
  - 2013-04 – “Understanding the Economics of Deploying CO_2 Capture Technologies in an Integrated Steel Mill”
  - 2013-TR3 – “Overview of the Current State and Development CO_2 Capture Technologies in the Ironmaking Process”

- **Total Cost of the Study:** ~ £ 440,000
- **IEA GHG Contribution:** ~ £ 120,000

Swedish Energy Agency
SSAB
LKAB
swerea | MEFOS

- ***Stakeholders Engagement***
  - 1st Workshop (Nov. 2011)
    Dusseldorf, Germany
    in collaboration with VDeH, Swerea MEFOS
  - 2nd Workshop (Nov. 2013)
    Tokyo, Japan
    in collaboration with IETS, World Steel, Swerea MEFOS

Presentation Overview

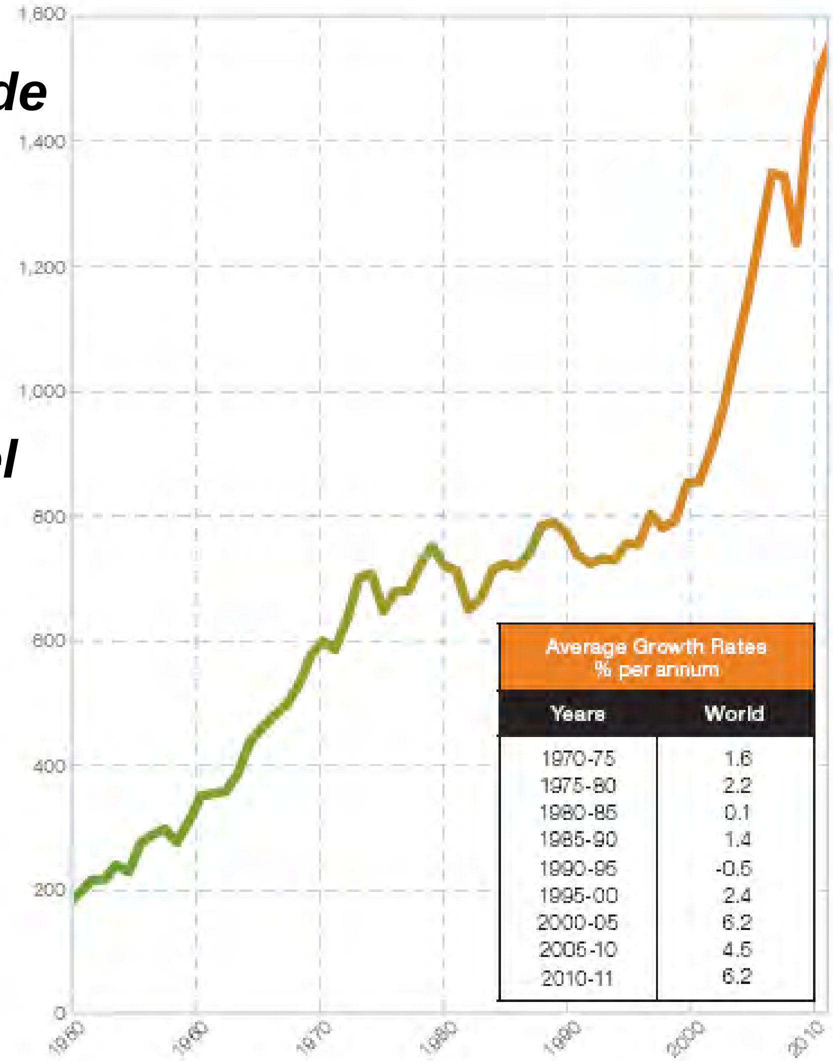
- ***Brief Introduction***
  - Global Steel Industry
  - Overview to the Steel Production
- ***Capture of CO_2 from Blast Furnace Gas***
  - ULCOS Programme – Oxygen Blown BF with TGR
  - COURSE50 Programme – Chemical Absorption & Physical Adsorption
  - POSCO / RIST Programme – Chemical Absorption
- ***Capture of CO_2 from Alternative Ironmaking Process***
  - Direct Reduction Ironmaking
    - MIDREX, ENERGIRON (HYL), ULCORED
  - Smelting Reduction Ironmaking
    - COREX, FINEX, HISARNA
- ***Summary / Concluding Remarks***

World Crude Steel Production
(Data and Figure from World Steel)

- ***Total Crude Steel Production has reached 1.545 Billion Tonnes of crude steel in 2012.***
  - As compared to 2002 (905.2 million tonnes), crude steel production has increased by ~70%.

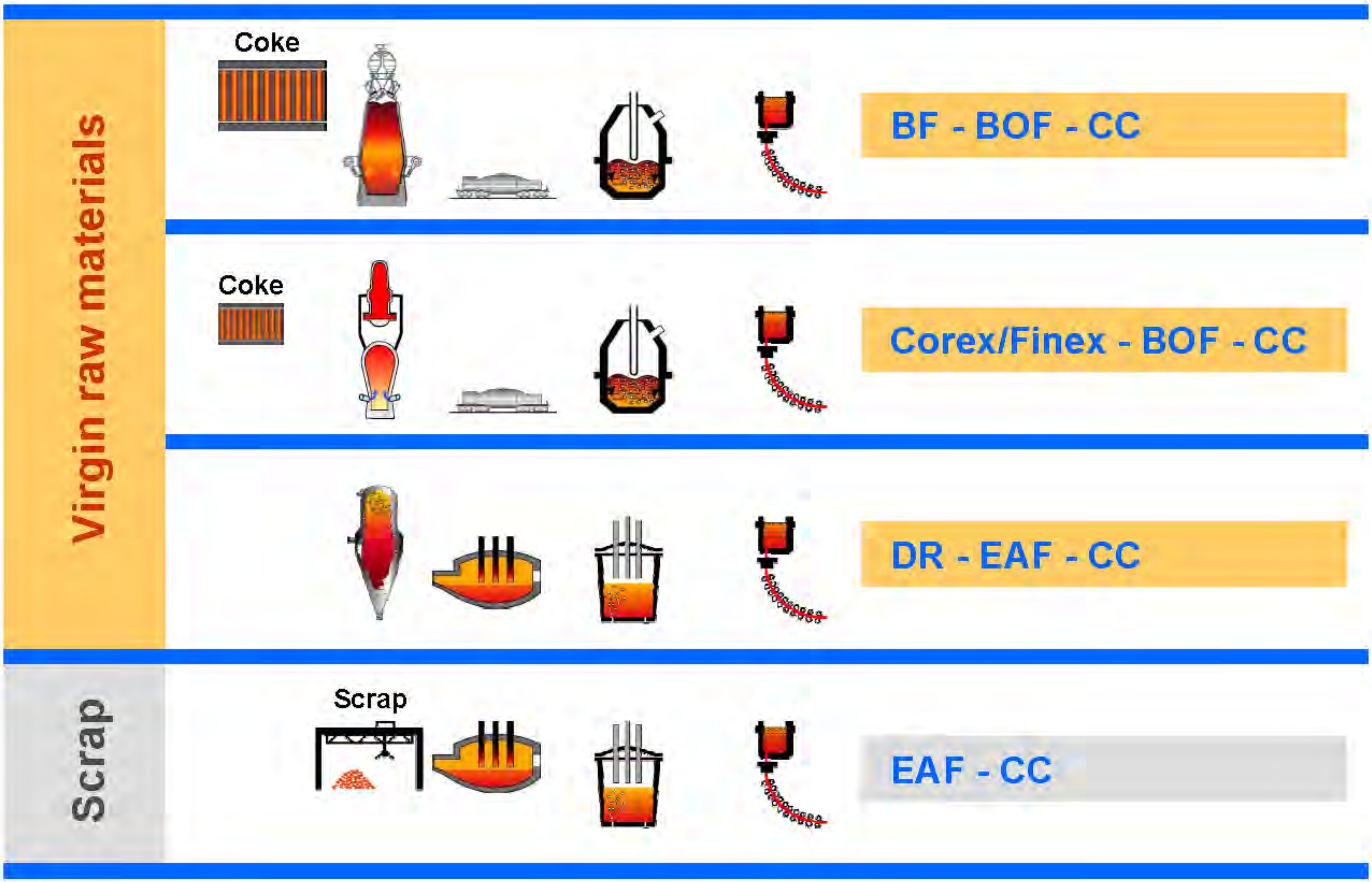
- ***Global CO_2 Emissions from the steel industry is roughly at ~2.3-2.5Gt/y***

- ***Major Steel Producing Regions***
  - China (716.5 million tonnes)
  - EU27 (168.6 million tonnes)
  - N. America (121.6 million tonnes)
  - CIS (111.0 million tonnes)
  - Japan (107.2 million tonnes)
  - India (77.6 million tonnes)



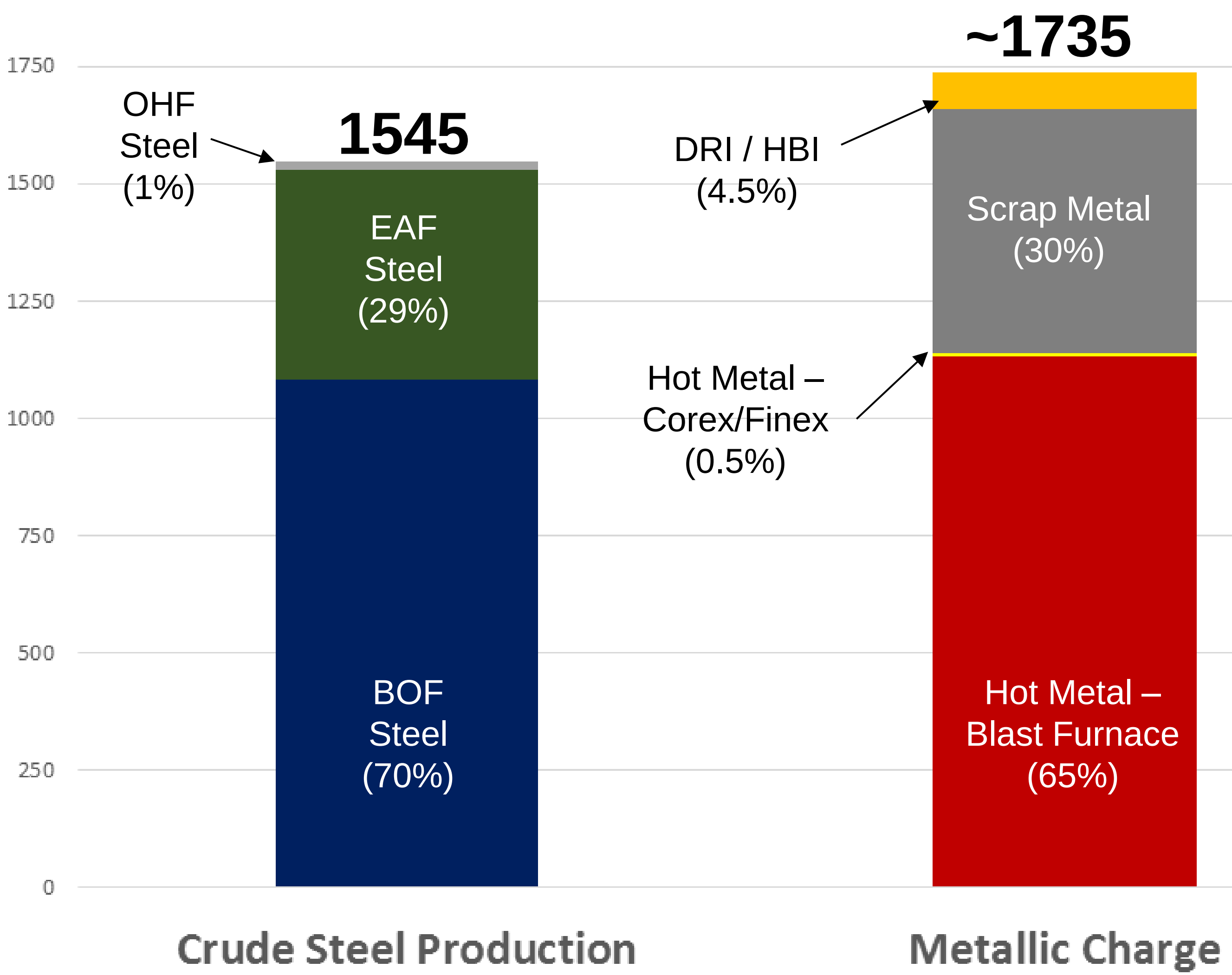
Overview of Steel Production

(Picture from VDEH)



World Crude Steel Production

Data estimated from WSA & VDEH statistics (2012)



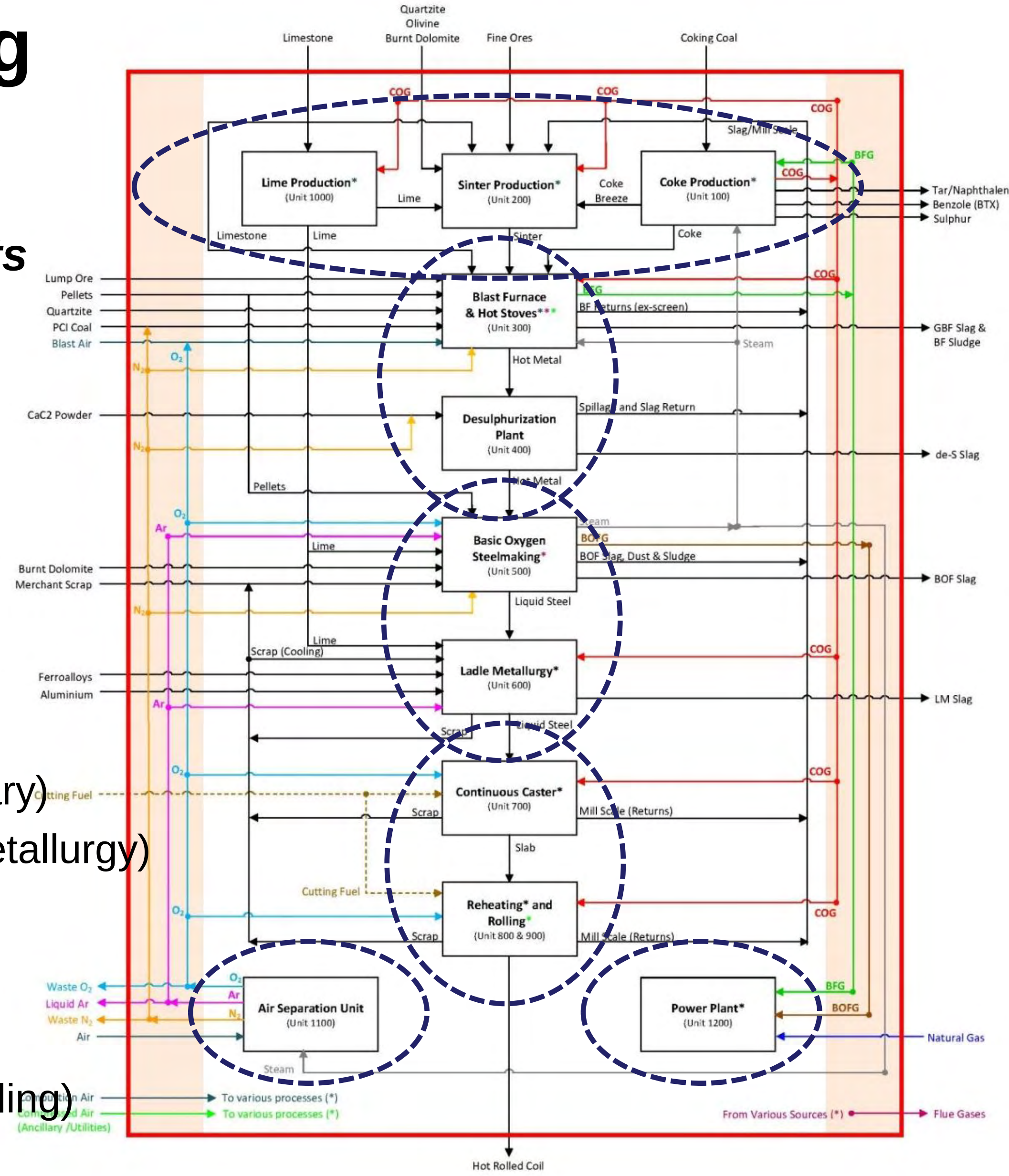
OVERVIEW OF STEEL PRODUCTION VIA BF/BOF ROUTE

NOTE:

- Presentation is derived from the results of IEAGHG Study (Report No. 2013-04)

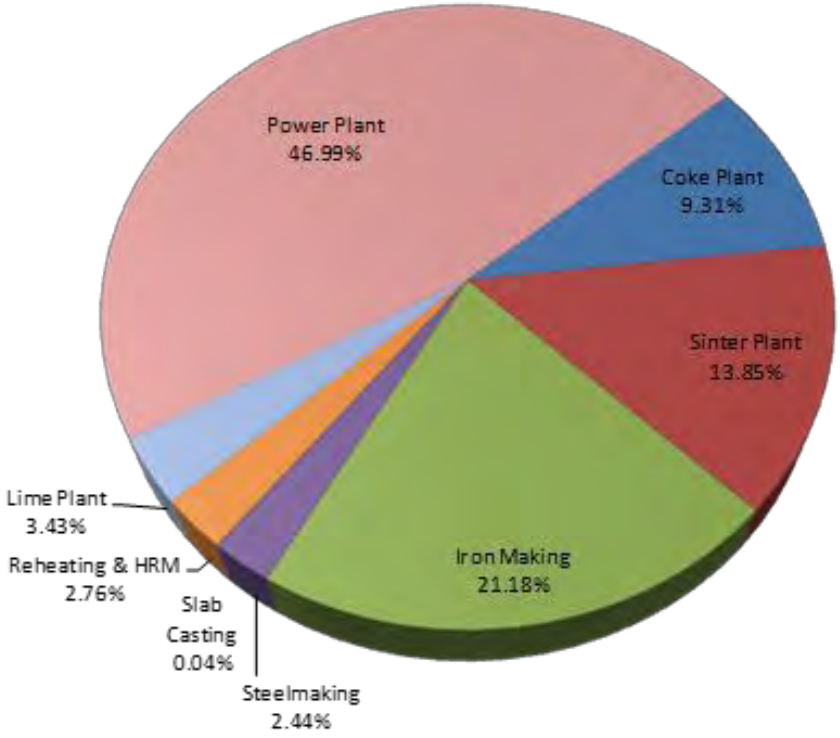
Integrated Steelmaking Process (BF/BOF)

- ***Raw Materials Preparation Plants***
  - Coke Production
  - Ore Agglomerating Plant (Sinter Production)
  - Lime Production
- ***Ironmaking***
  - Blast Furnace
  - Hot Metal Desulphurisation
- ***Steelmaking***
  - Basic Oxygen Steelmaking (Primary)
  - Secondary Steelmaking (Ladle Metallurgy)
- ***Casting***
  - Continuous Casting
- ***Finishing Mills***
  - Hot Rolling Mills (Reheating & Rolling)



Point Source Emissions

(Results of IEAGHG Study – An Example)



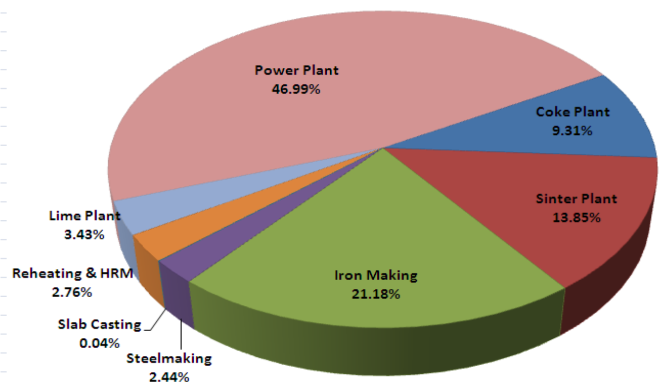
CO_2 Emissions are released at various stacks within the integrated steel mill.

UNIT	Source of CO_2 Emissions	Emissions (kg/t HRC)	Annual Emission (t/y)
100	Coke oven flue gas	191.37	765,495
100	Coke oven gas flare	3.30	13,196
200	Sinter plant flue gas (CO2 + CO)	289.46	1,157,825
300	Hot Stove flue gas	415.19	1,660,769
400/1300	PCI Coal drying, torpedo car and ladle heating (HM Desulphurisation) diffuse emissions	7.76	31,042
300	Blast Furnace Gas flare	19.73	78,931
500/600	Basic Oxygen Furnace gas flared and system losses, SM diffuse Emissions	51.02	204,089
700	Continuous Casting - diffuse emissions (from slab cutting)	0.80	3,188
800	Reheating Furnace flue gas	57.71	230,833
900	Hot Rolling Mills - diffuse emissions (from cutting and scarfing)	0.04	179
1000	Lime Plant flue gas	71.62	286,493
1200	Power Plant flue gas	982.13	3,928,513
1300	Ancillaries transport fuel emissions (trucks and rails)	4.00	16,000
	Total Emissions	2094.14	8,376,554

Carbon Balance of Ironmaking Process

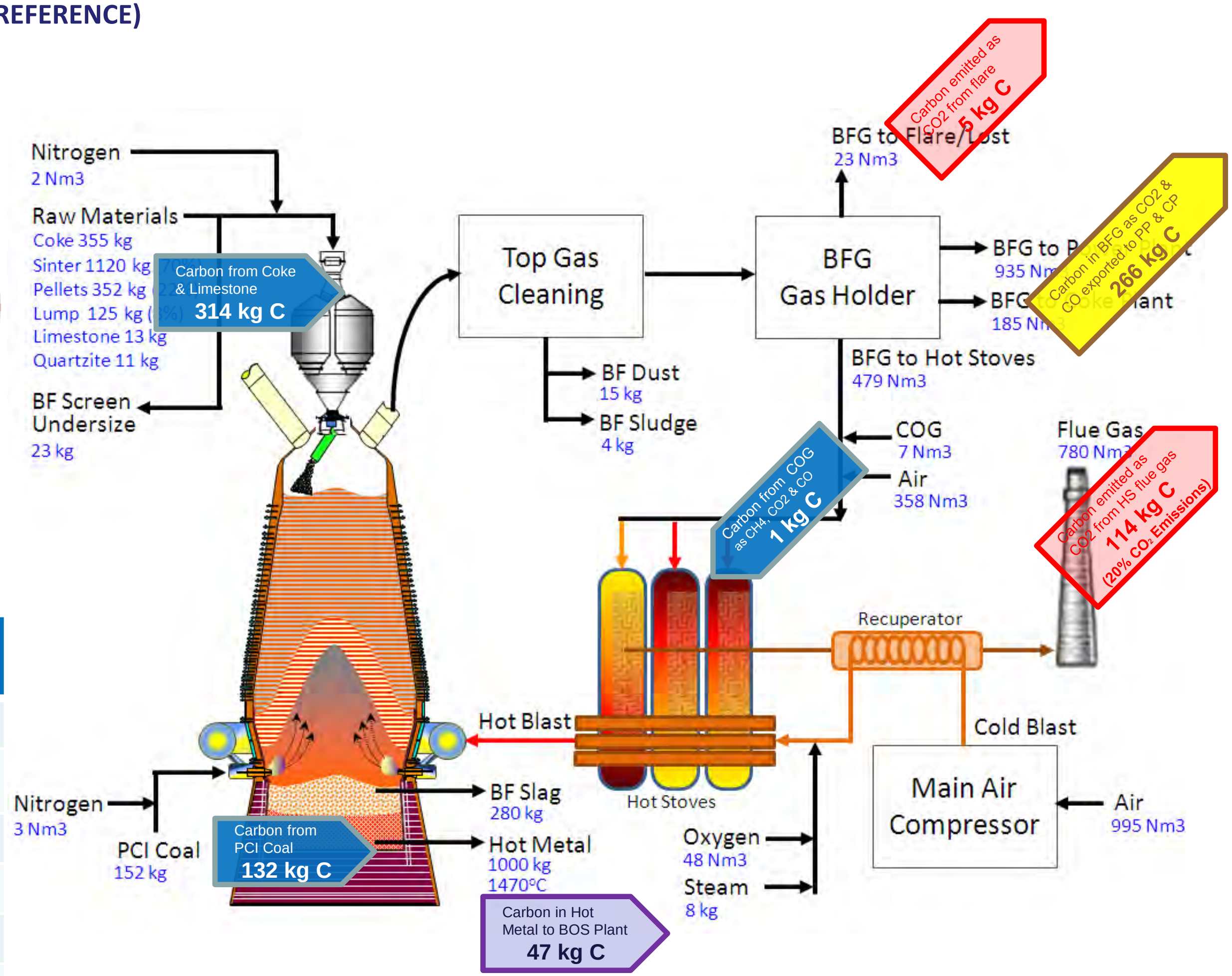
(Results of IEAGHG Study)

Direct CO_2 Emissions of an Integrated Steel Mill (REFERENCE)
Producing 4 MTPY Hot Rolled Coil
2090 kg CO_2/t HRC (2107 kg CO_2/thm)



Carbon Balance of Ironmaking Process

Carbon Input (kg C/thm)		Carbon Output (kg C/thm)	
Coke	312.4	Hot Metal	47.0
Limestone	1.5	BF Screen Undersize	6.3
PCI Coal	132.2	Dust & Sludge	8.0
COG	1.3	BFG Export	266.4
		BFG Flared	5.4
		Hot Stove's Flue Gas	114.1
Total	**447.5**	**Total**	**447.2**



80-90% of the carbon that caused to the CO_2 emissions of the steel production.

Composition of Off-Gases

(Results of IEAGHG Study – An Example)

Wet Basis (%vol.)	Coke Oven Gas (COG)	Blast Furnace Gas (BFG)	Basic Oxygen Furnace Gas (BOFG)
CH_4	23.2	- NA -	- NA -
H_2	60.1	3.6	2.6
CO	3.9	22.1	56.9
CO_2	1.0	22.3	14.4
N_2	5.8	48.3	13.8
O_2	0.2	- NA -	- NA -
H_2O	3.2	3.2	12.2
Other HC	2.7	- NA -	- NA -
LHV (MJ/Nm^3) – wet basis	17.5	3.2	7.5
Users of the Off-Gases	Hot Stoves, Coke Ovens, Lime Kilns, Reheating Furnaces and others	Hot Stoves, Power Plant	Power Plant

Carbon in BFG as CO2 & CO exported to PP & CP
266 kg C / thm

Carbon in Hot Metal to BOS Plant
47 kg C / thm

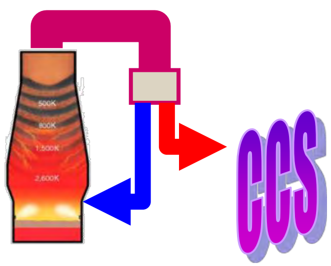
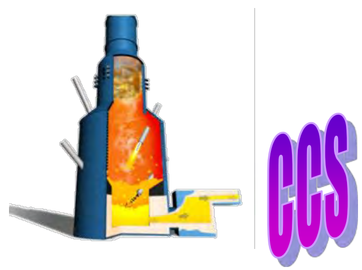
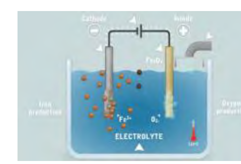
CAPTURE OF CO_2 FROM BLAST FURNACE GAS (BFG)

Treated BFG (Components)	Units	Composition
CO_2	%(v/v) – dry	17 - 25
CO	%(v/v) – dry	20 - 28
H_2	%(v/v) – dry	1 – 5
N_2 / Ar	%(v/v) – dry	45 -55 (balance)
H_2S	mg/Nm^3	10 - 20
Particulate Matter	mg/Nm^3	1 – 10
Heavy Metals		
Mn	mg/Nm^3	0.10 - 0.29
Pb	mg/Nm^3	0.01 – 0.05
Zn	mg/Nm^3	0.03 - 0.17

NOTE:

- **Blast Furnace is a reduction process.**
- **CO_2 capture from BFG cannot be classified as post-combustion or oxy-combustion.**

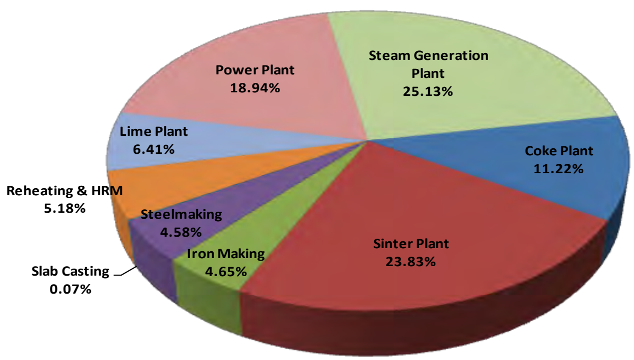
The 4 ulcos process routes

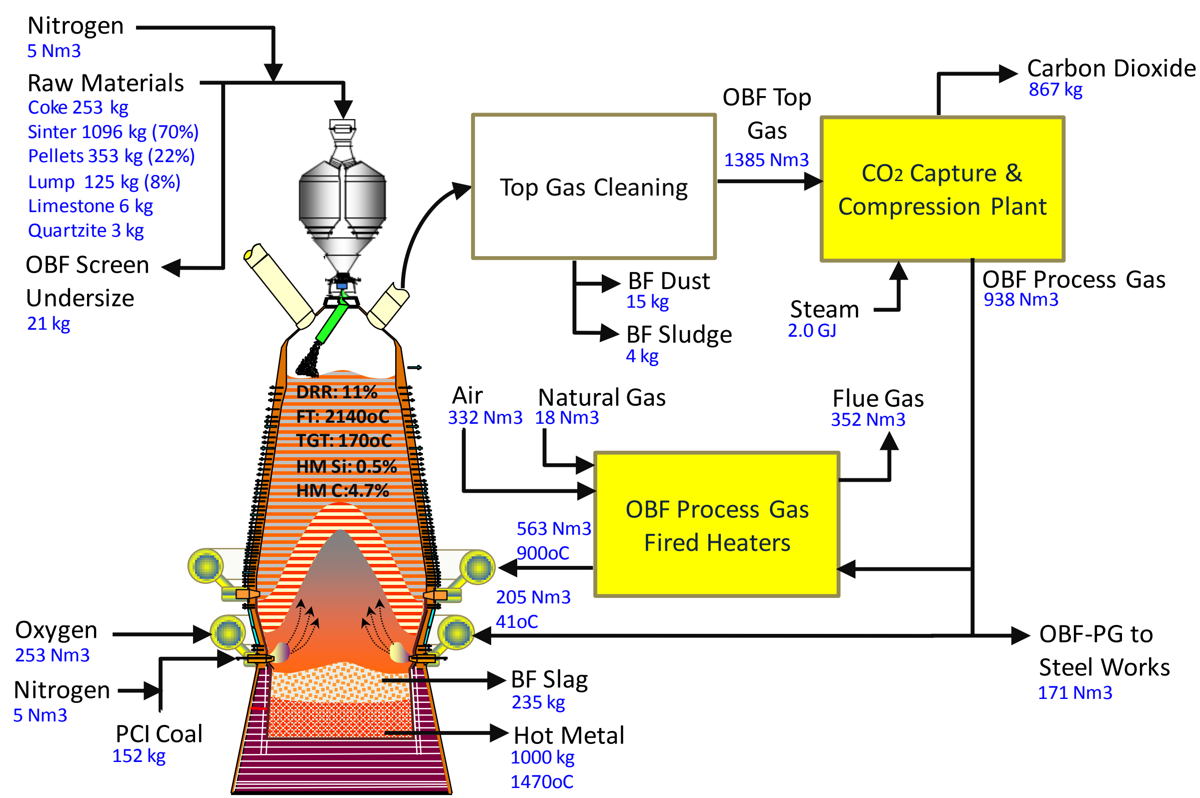
Coal & sustainable biomass		Natural gas	Electricity
Revamped BF	Greenfield	Revamped DR	Greenfield
ULCOS-BF 	HIsarna 	ULCORED 	ULCOWIN ULCOLYSIS 
Pilot tests (1.5 t/h) Demonstration under way	Pilot plant (8 t/h) start-up 2010	Pilot plant (1 t/h) to be erected in 2013?	Laboratory

Carbon Balance of Ironmaking Process

Results from IEAGHG Study – Case 3: OBF with MDEA/Pz CO_2 Capture

Direct CO_2 Emissions of an Integrated Steel Mill (with OBF & MDEA CO_2 Capture)
Producing 4 MTPY Hot Rolled Coil
1115 kg CO_2/t HRC (1124 kg CO_2/thm)



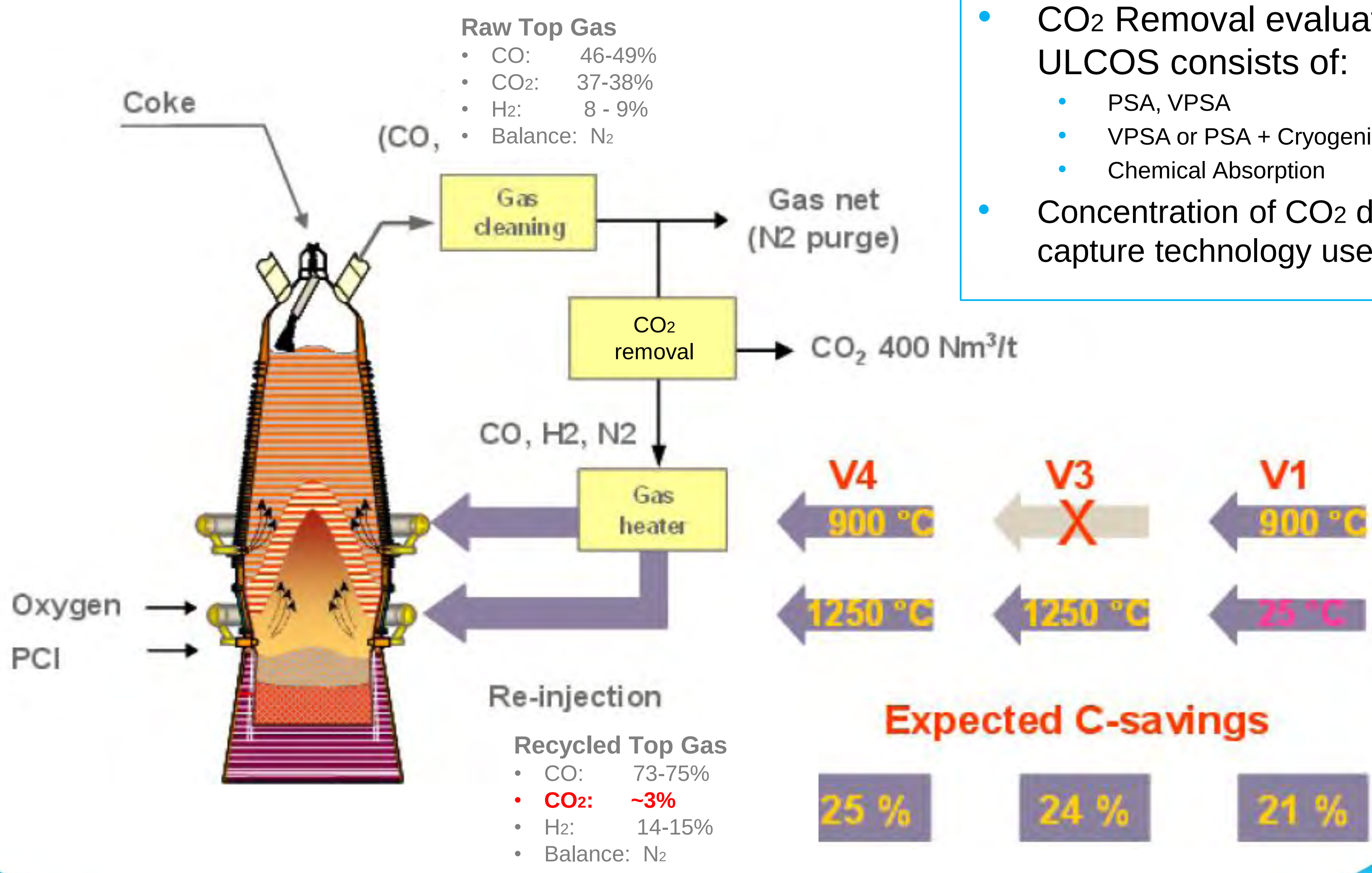


Carbon Balance of Ironmaking Process

Carbon Input (kg C/thm)		Carbon Output (kg C/thm)	
Coke	227.7	Hot Metal	47.0
Limestone	0.7	BF Screen Undersize	4.6
PCI Coal	132.2	Dust & Sludge	8.0
Natural Gas	12.0	OBF PG Export	64.5
		PG Heater Flue Gas	12.0
		CO2 Captured	236.3
Total	**372.7**	**Total**	**372.4**

Blast Furnace (TGR BF)

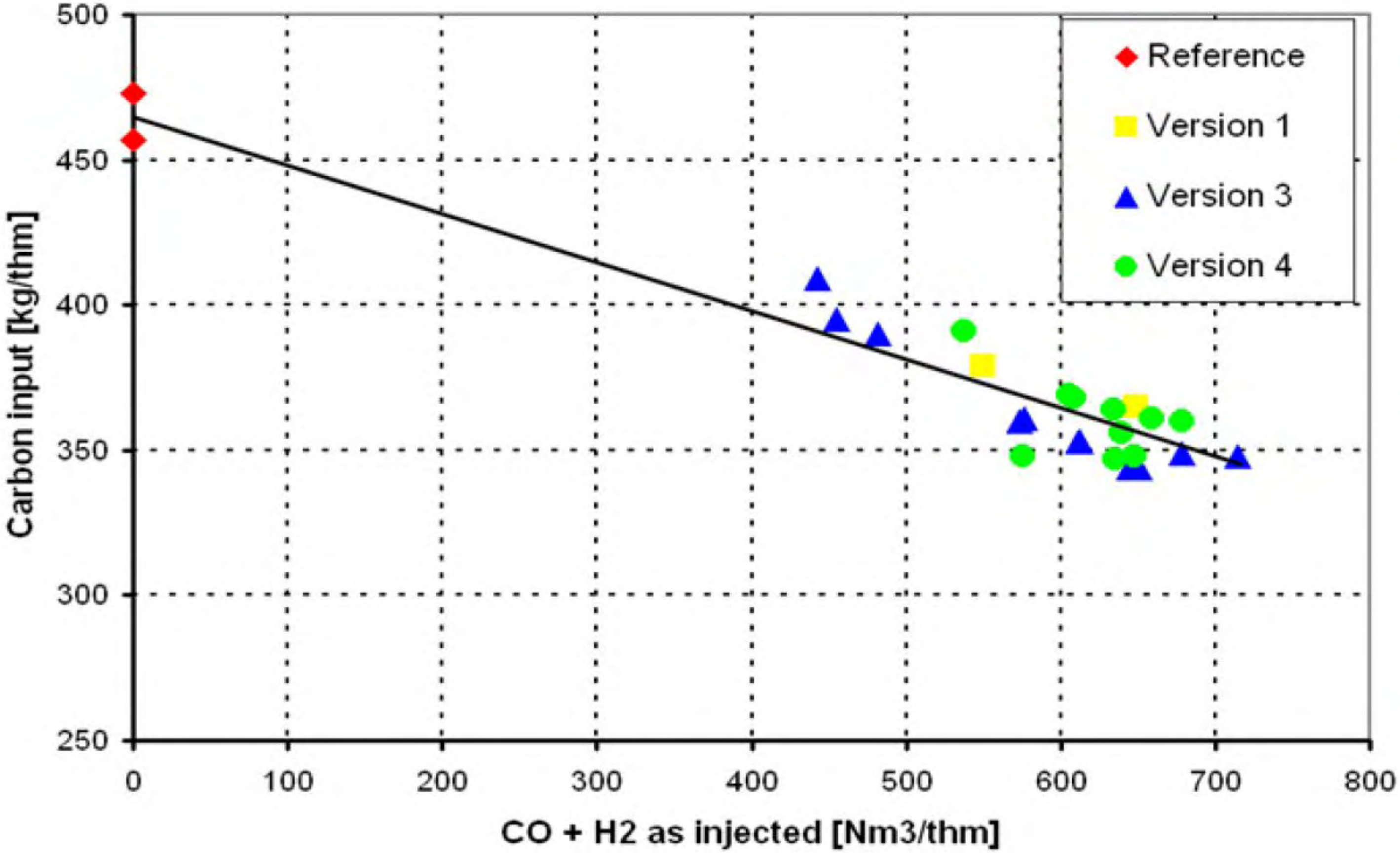
- CO_2 Removal evaluated by ULCOS consists of:
  - PSA, VPSA
  - VPSA or PSA + Cryogenic Separation
  - Chemical Absorption
- Concentration of CO_2 depends on capture technology used

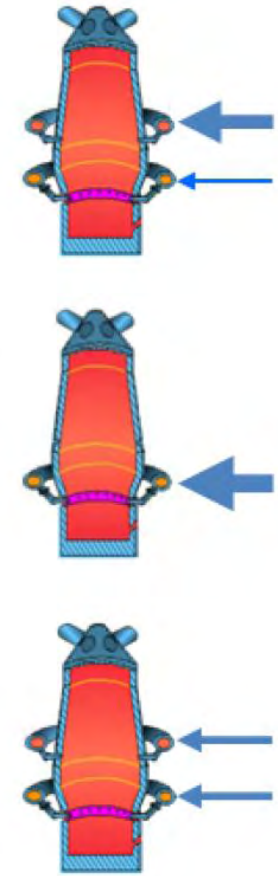


ULCOS BF

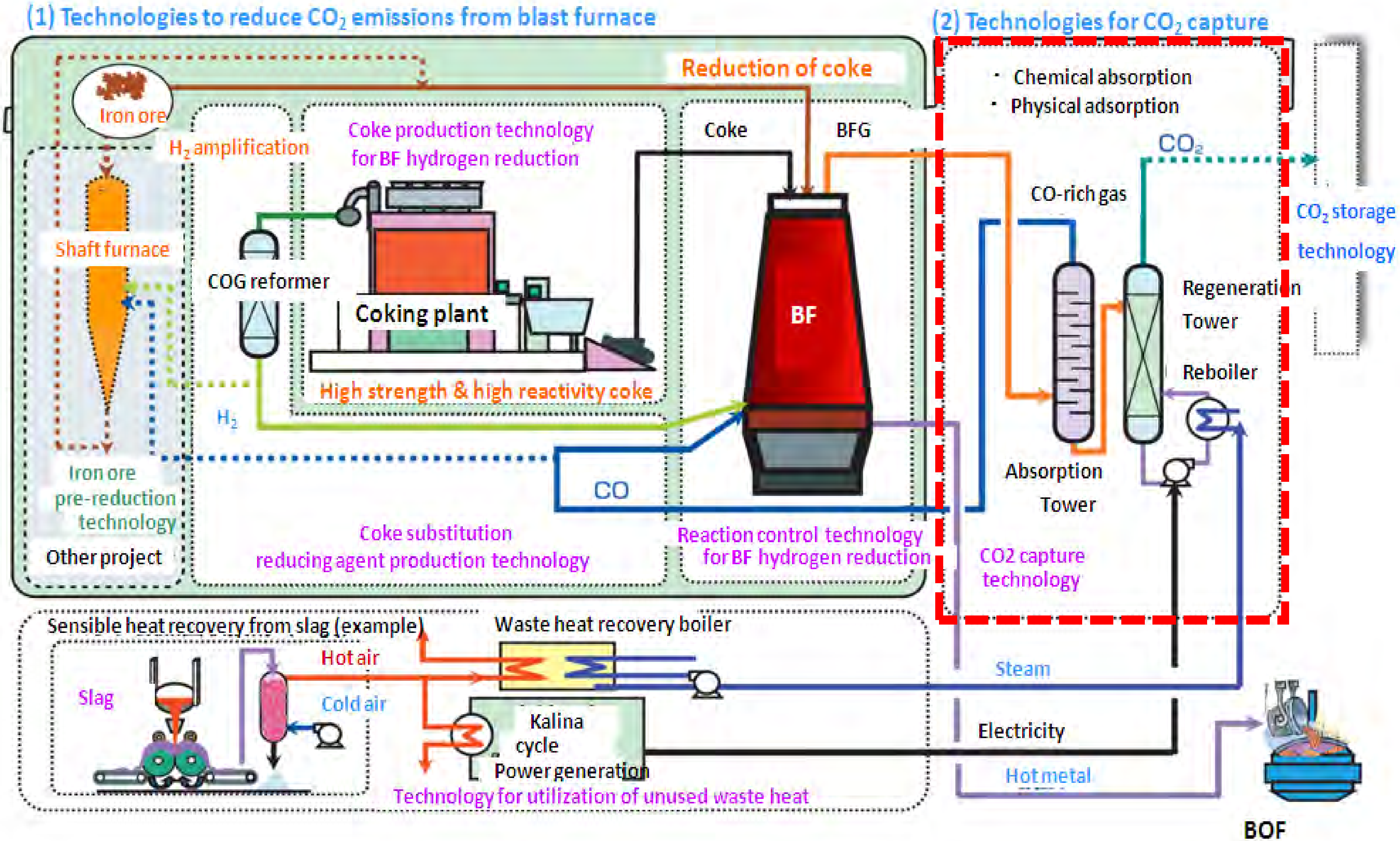
(Experimental Results from Lulea’s EBF Work)

Data courtesy of Tata Steel





COURSE50 Programme



COURSE 50

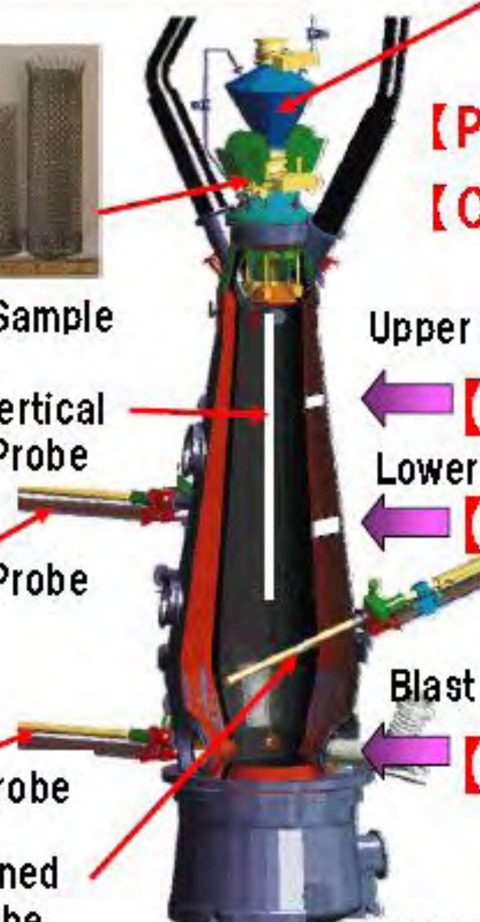
LKAB's EBF Trial

Schedule: 16th April ～11th May, 2012

Ferrous Material: Sinter 70%-Pellet 30%
Coke、PC: from SSAB

Basket Sample

Raceway



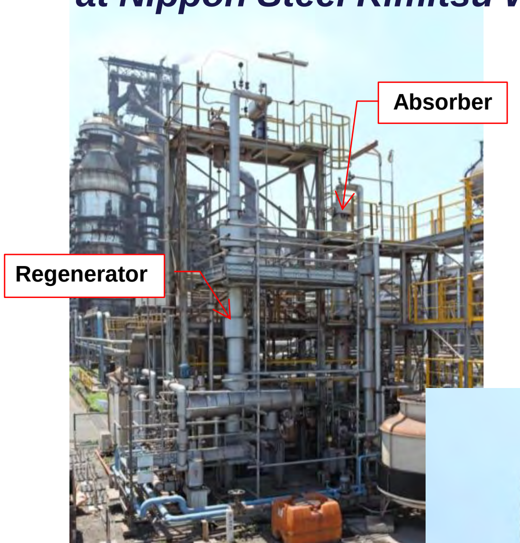
Figures are quoed from Swerea/MEFOS and LKAB brochure

COURSE50 Programme

CO_2 Capture Pilot Plants

CAT-1 & CAT-10

at Nippon Steel Kimitsu Works



CAT-1
1 t/d CO_2 for solvent testing

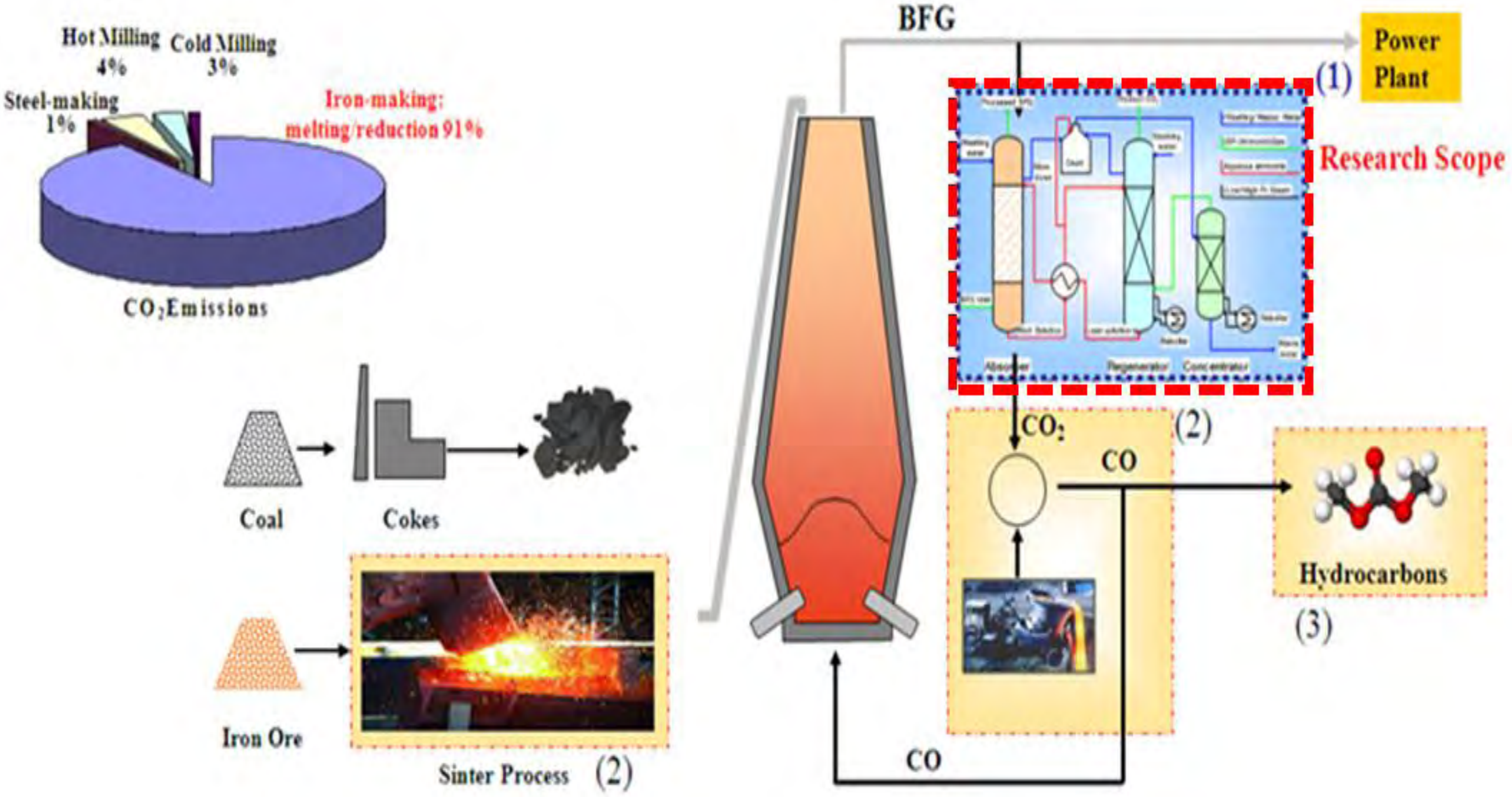
CAT-30
30 t/d CO_2 for process improvement evaluation

ASCOA

at JFE Steel Fukuyama Works

Pictures & Info from Osame et al (2011) – Nippon / JFE Steel

POSCO – RIST Programme



CO_2 Capture Using Aqueous Ammonia (II): Milestones

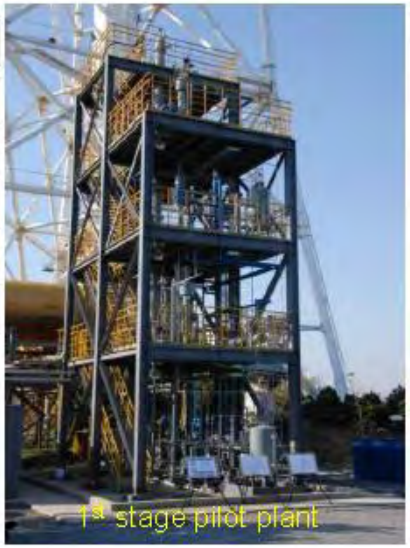
□ R&D history

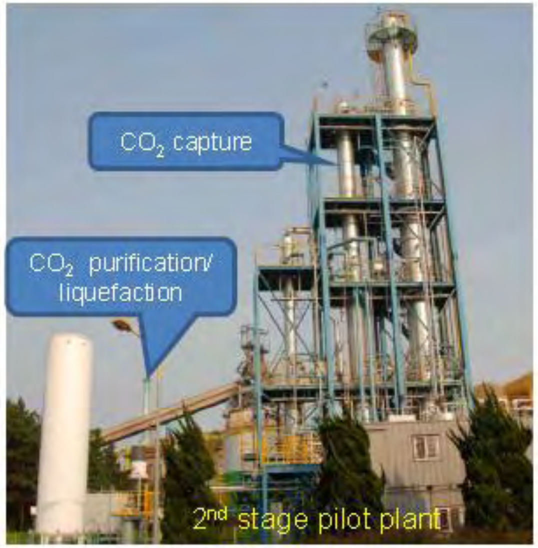
- Lab-scale research (2006~2007)
- 1st stage pilot plant research (2008-2010): 50 Nm^3-BFG/hr (Dec. 2008)
- 2nd stage pilot plant research (2010-2014): 1,000 Nm^3-BFG/hr

- One-site pilot tests are on-going (May 2011-), Purification/Liquefaction facilities integrated (Apr. 2012-)

□ 2nd Pilot Plant Spec.

Item	Spec.
Feed Gas	BFG (Blast Furnace Gas, CO_2 ~ 22%)
Feed Gas Flow rate	1,000Nm^3/h
Absorbent Sol.	<10% NH_3
Product CO_2	10 t-CO_2/d, 0.5MW power plant
Purity of product CO_2	>95% (Gas)
	>99.8% (Liquid)





□ Test Results

- CO_2 recovery > 90%, L-CO_2 purity > 99.5%

□ Further Plan

- Long-term continuous operation
- Additional pump around and higher NH_3 concentration in absorbent solution
- Basic engineering design for commercial scale

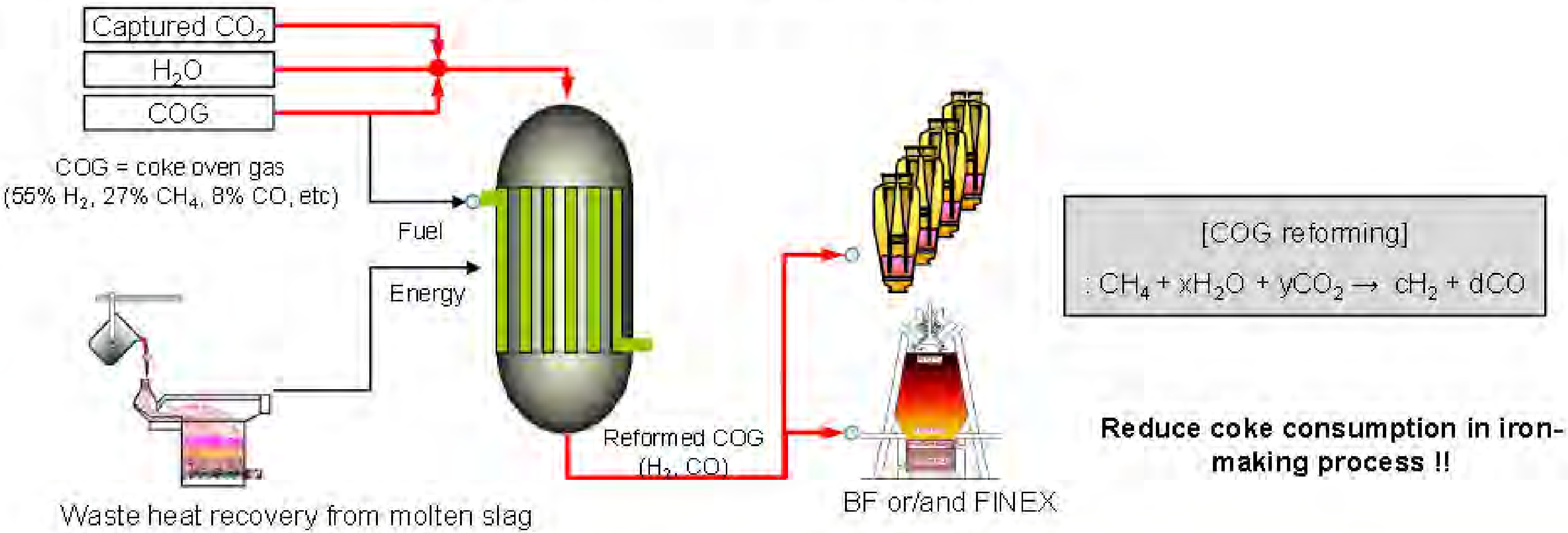
Dry ice

CO_2 Conversion using COG Reforming (I) : Concept/Feature

☐ **Background**

-Need for the conversion of capture CO_2 and the utilization in steel industry

☐ **Steel-industry-specific CO_2 conversion and utilization**



[Conceptual scheme for production and utilization of the reducing gas in the steel process]

○ Mass production of the H_2 and/or CO rich gases by using COG reforming with steam and CO_2

- Require highly coking-resistant catalyst for the COG reforming
- Require optimization of reaction condition, heat integration, and scale-up by using reactor modeling

CAPTURE OF CO_2 FROM ALTERNATIVE IRONMAKING PROCESS

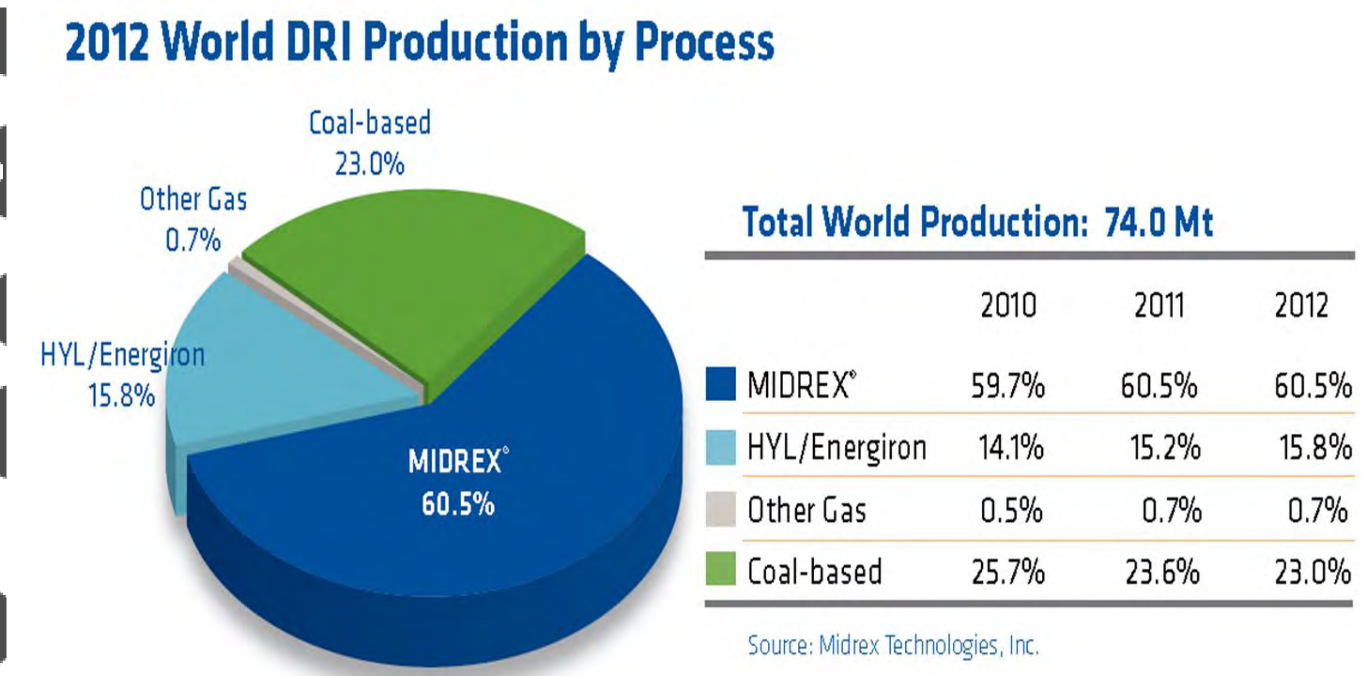
- Direct Reduction Ironmaking Process
- Smelting Reduction Ironmaking Process

Direct Reduction Ironmaking

70 Process Developments

From “Aachener Drehofen” to “Zam Zam” Process

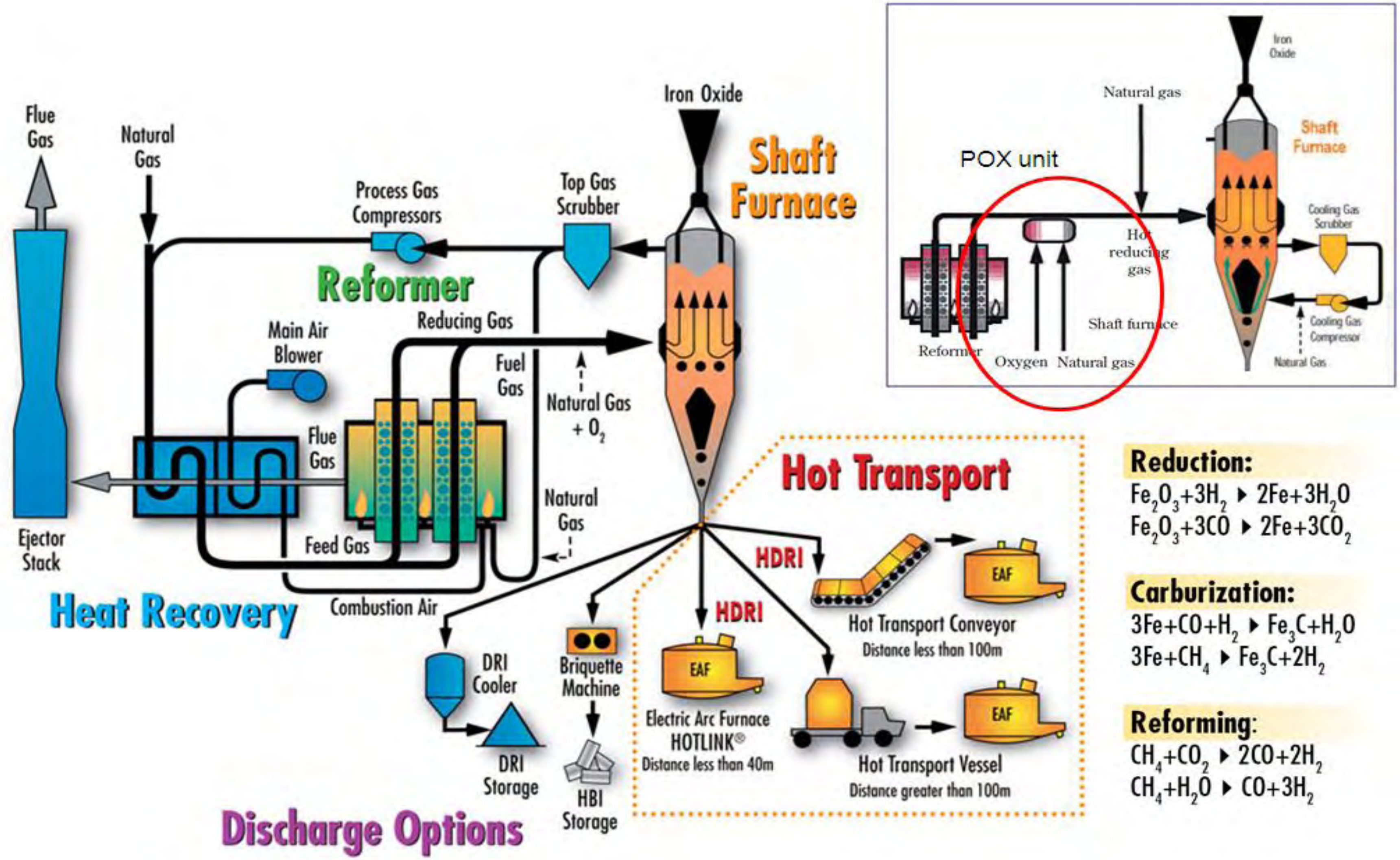
Only <u>Midrex & Energiron (HYL)</u> reached successful commercialisation



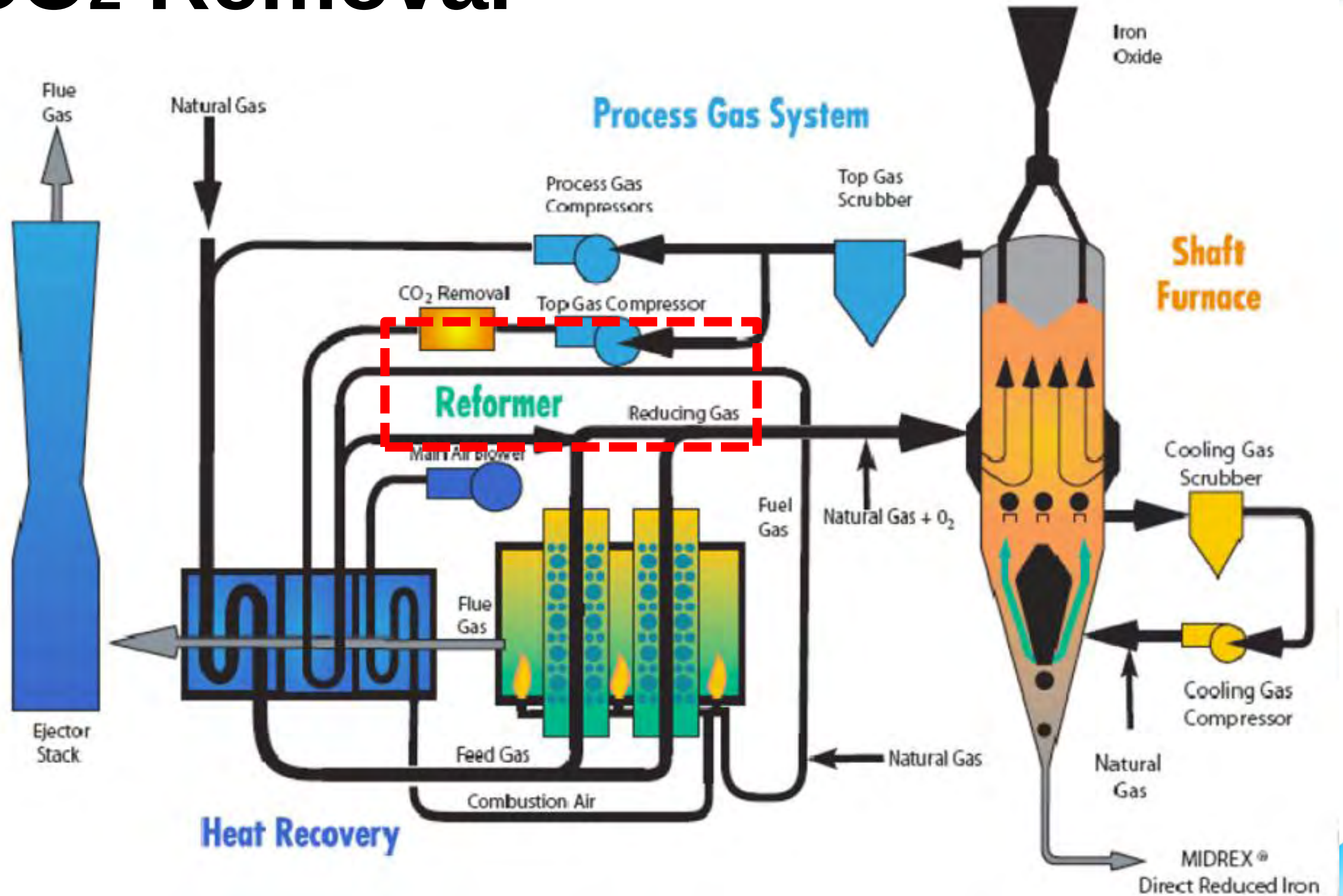
	2010	2011	2012
MIDREX®	59.7%	60.5%	60.5%
HYL/Energiron	14.1%	15.2%	15.8%
Other Gas	0.5%	0.7%	0.7%
Coal-based	25.7%	23.6%	23.0%

Picture Courtesy of VDEH

MIDREX Plant w/o CO_2 Removal (Picture Courtesy of MIDREX)



MIDREX Plant with CO_2 Removal



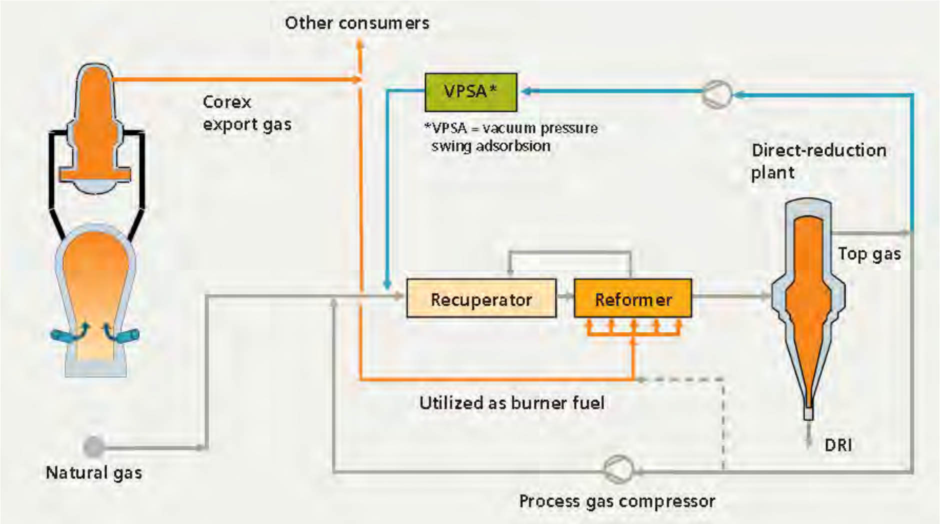
MIDREX PLANT with CO_2 Removal

Reference Plant

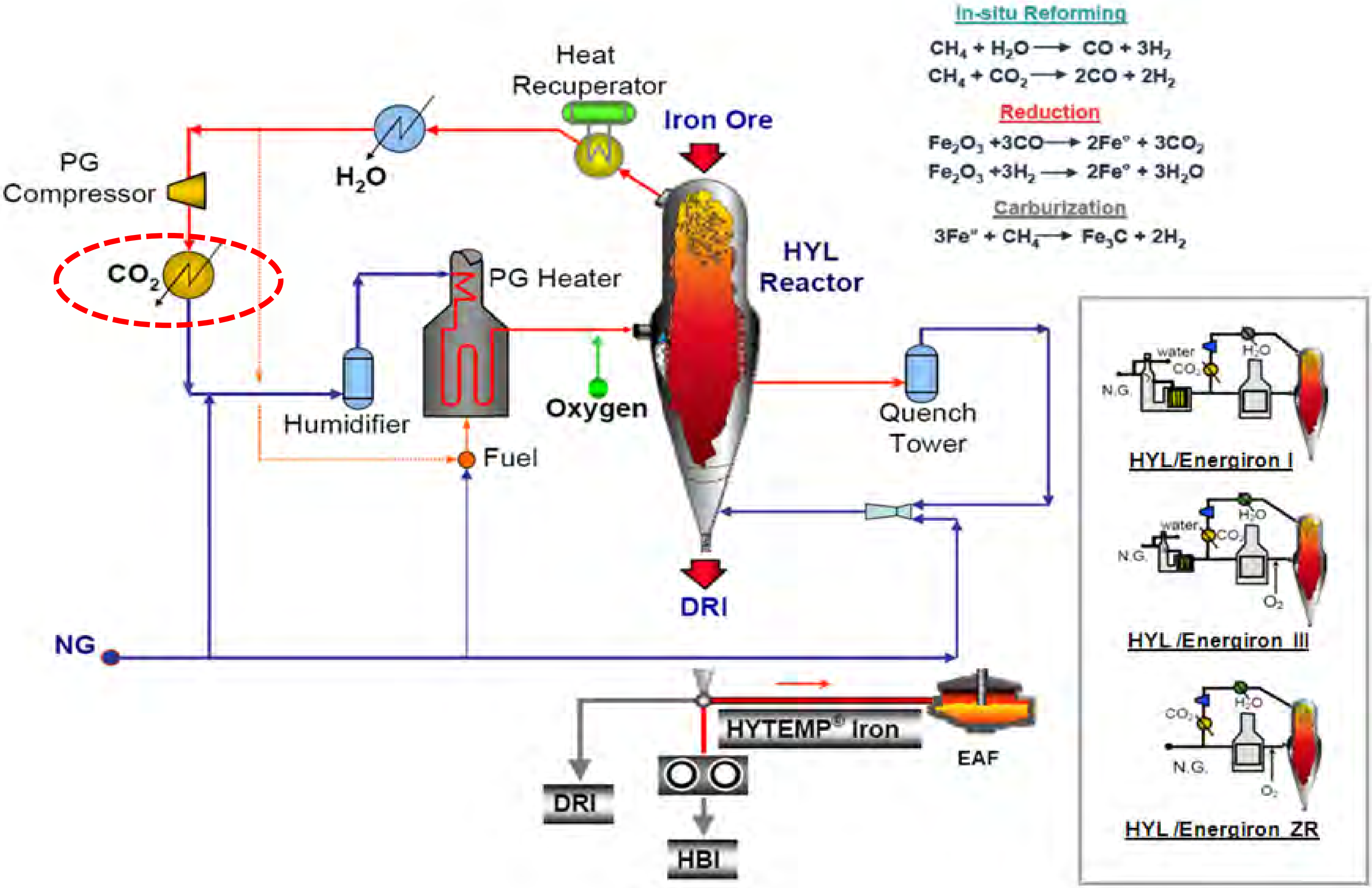
(Picture Courtesy of Siemens VAI & Essar Steel)

- <u>NO standalone</u> Midrex Plant that removes CO_2 from the DRI shaft reactor's off-gas.

- However, ESSAR Steel employed partial removal of CO_2 using VPSA at their Hazira Steelworks (India).
  - Steelworks is hybrid plant where COREX gas is used as fuel to the reformer of the MIDREX plant.
  - 2 Midrex modules (#5 & #6) equipped with CO_2 removal system
    - VPSA off gas is mixed with NG as feedstock to the reformer. This reduces NG consumption.
    - VPSA tail gas with ~60% CO_2, ~20% CO, ~5%H_2 is used as heating fuel within the steelworks



ENERGIRON – HYL Technology

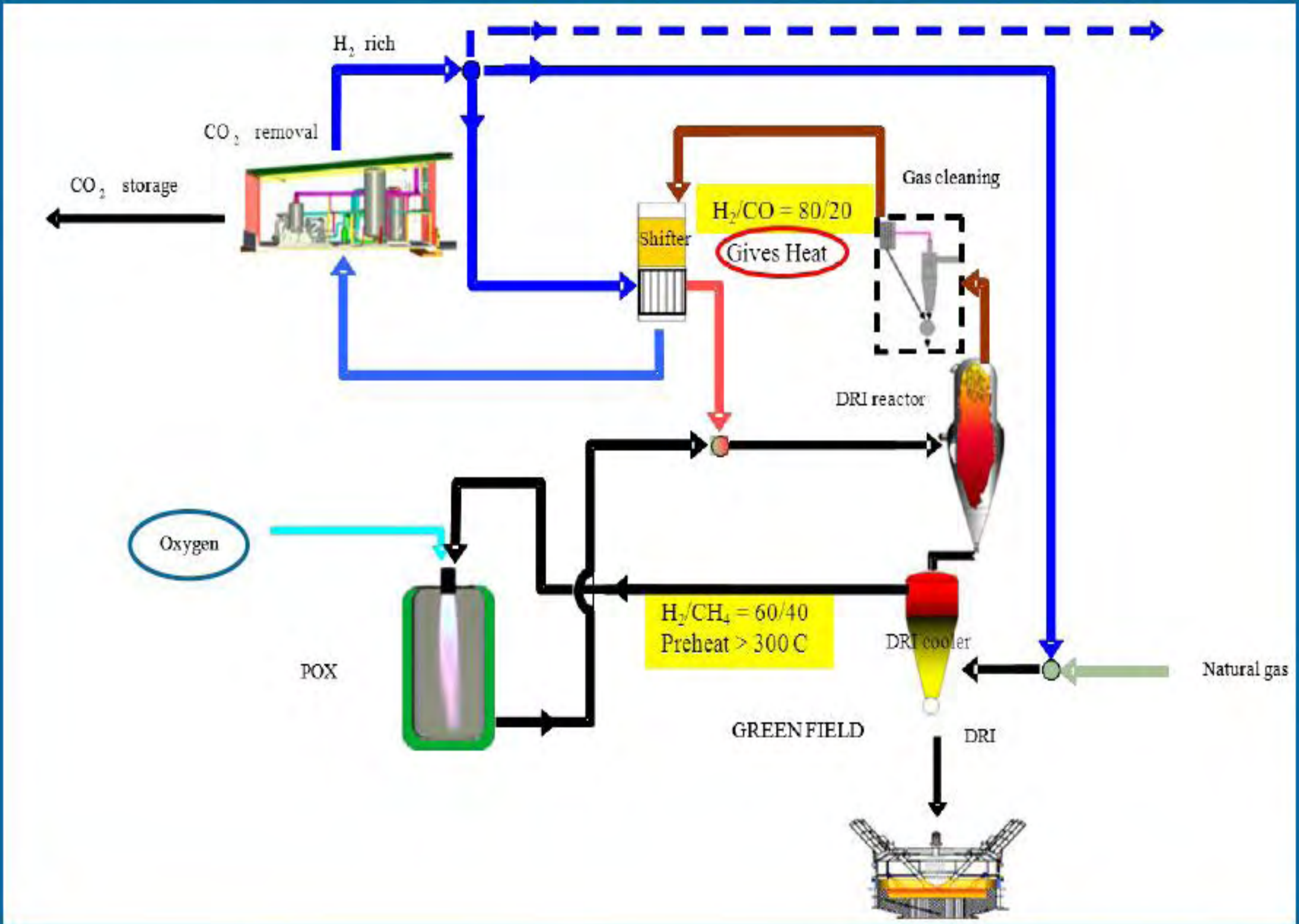


ENERGIRON WITH CO_2 CAPTURE REFERENCE PLANTS

- CO_2 removal system used by Energiron / HYL is a competition between Chemical Absorption (i.e. MDEA) vs Physical Adsorption (VPSA / PSA)

- List of Reference Plants with CO_2 Capture
  - Mexico
    - AM Lazaro Cardenas (2 modules) – food grade CO_2 – 2007/2009
    - Ternium 4M, 2P (2 modules) – food grade CO_2
  - India
    - Welspun Maxsteel (1 modules – food grade CO_2 - 2009
  - Abu Dhabi
    - Emirate Steel (2 modules) – EOR grade CO_2 – under construction

ULCORED



H2 rich
CO2 removal
CO2 storage
Gas cleaning
H2/CO = 80/20
Shifter
Gives Heat
DRI reactor
Oxygen
H2/CH4 = 60/40
Preheat > 300 C
DRI cooler
Natural gas
POX
GREEN FIELD
DRI

Smelting Reduction Ironmaking

45 Process Developments

From “AISI Direct Steelmaking” to “VOEST” Process
Only <u>COREX & FINEX</u> reaching commercialisation

ORF

Romelt

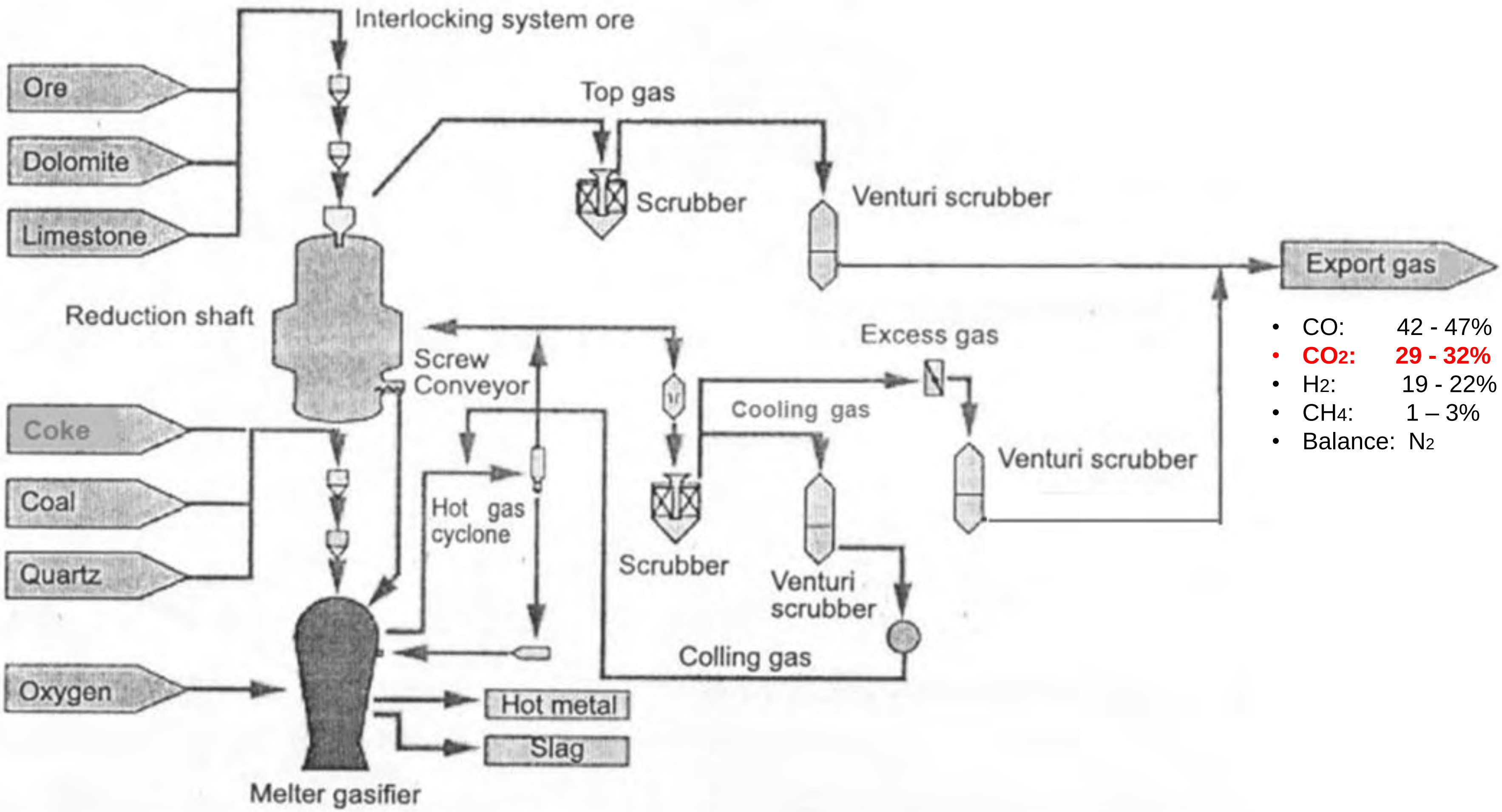
Tecnored

Rotored

VOEST

Picture Courtesy of VDEH

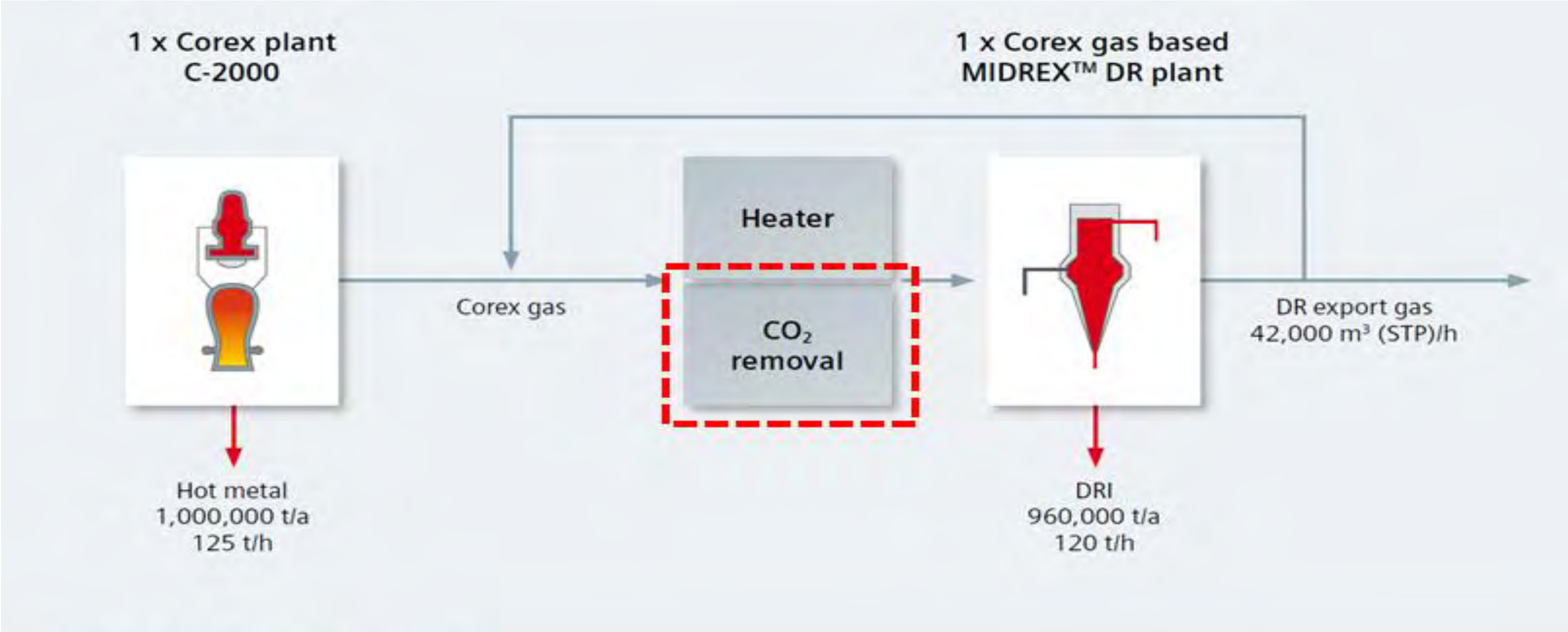
COREX Process



- CO: 42 - 47%
- **CO_2: 29 - 32%**
- H_2: 19 - 22%
- CH_4: 1 – 3%
- Balance: N_2

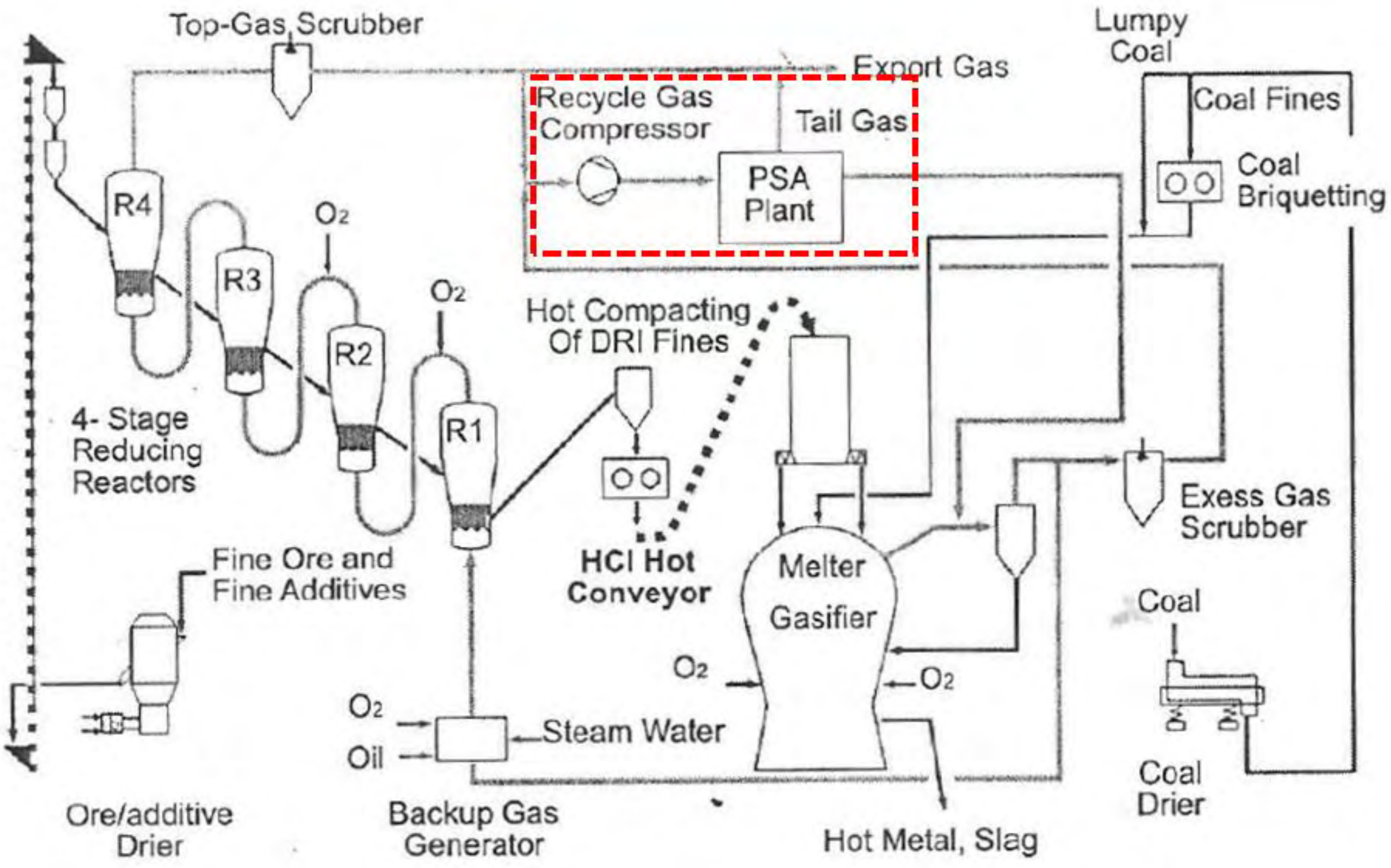
COREX with CO_2 Removal
Commercially Operated Plant based on VPSA or PSA

- No standalone COREX plant that removes CO_2 from their export gas.
- However, 2 Plants with COREX gas used as feedstock to Midrex do remove the CO_2.
  - Saldanha Steelworks, S. Africa (1 module commissioned in 2000)
  - JSW Vijayanagar Steelworks, India (2 modules , commissioned in 2013)

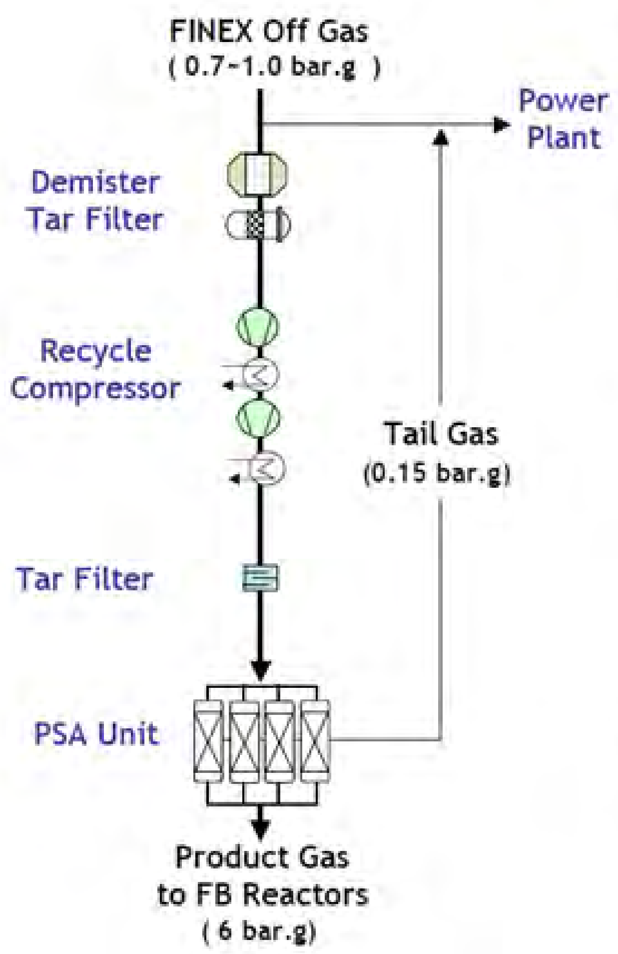


Production of DRI (Basis: Corex C-2000)

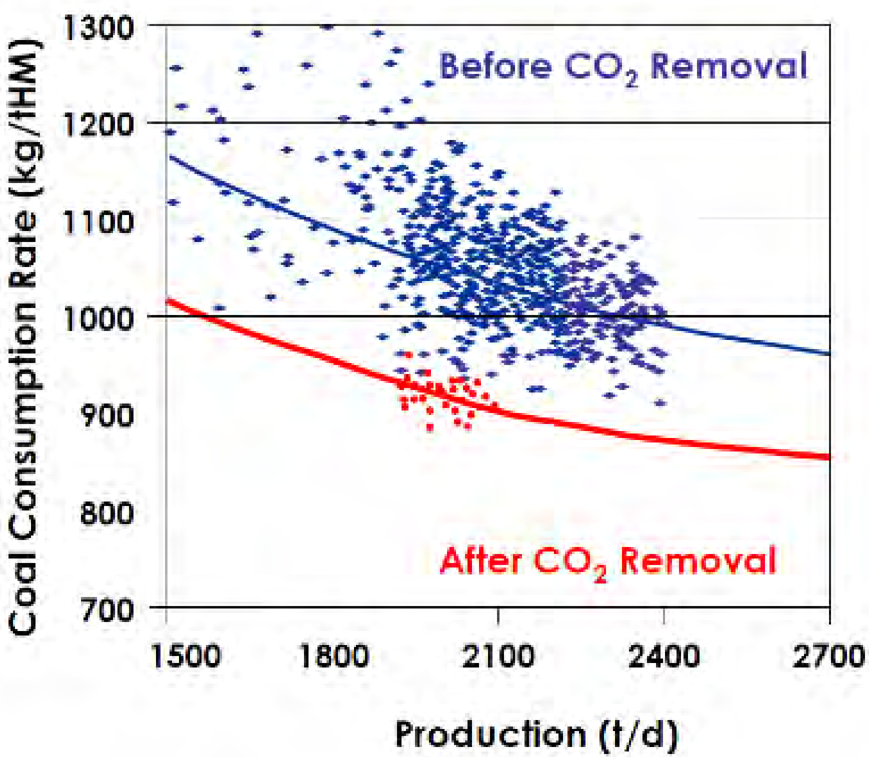
FINEX Process



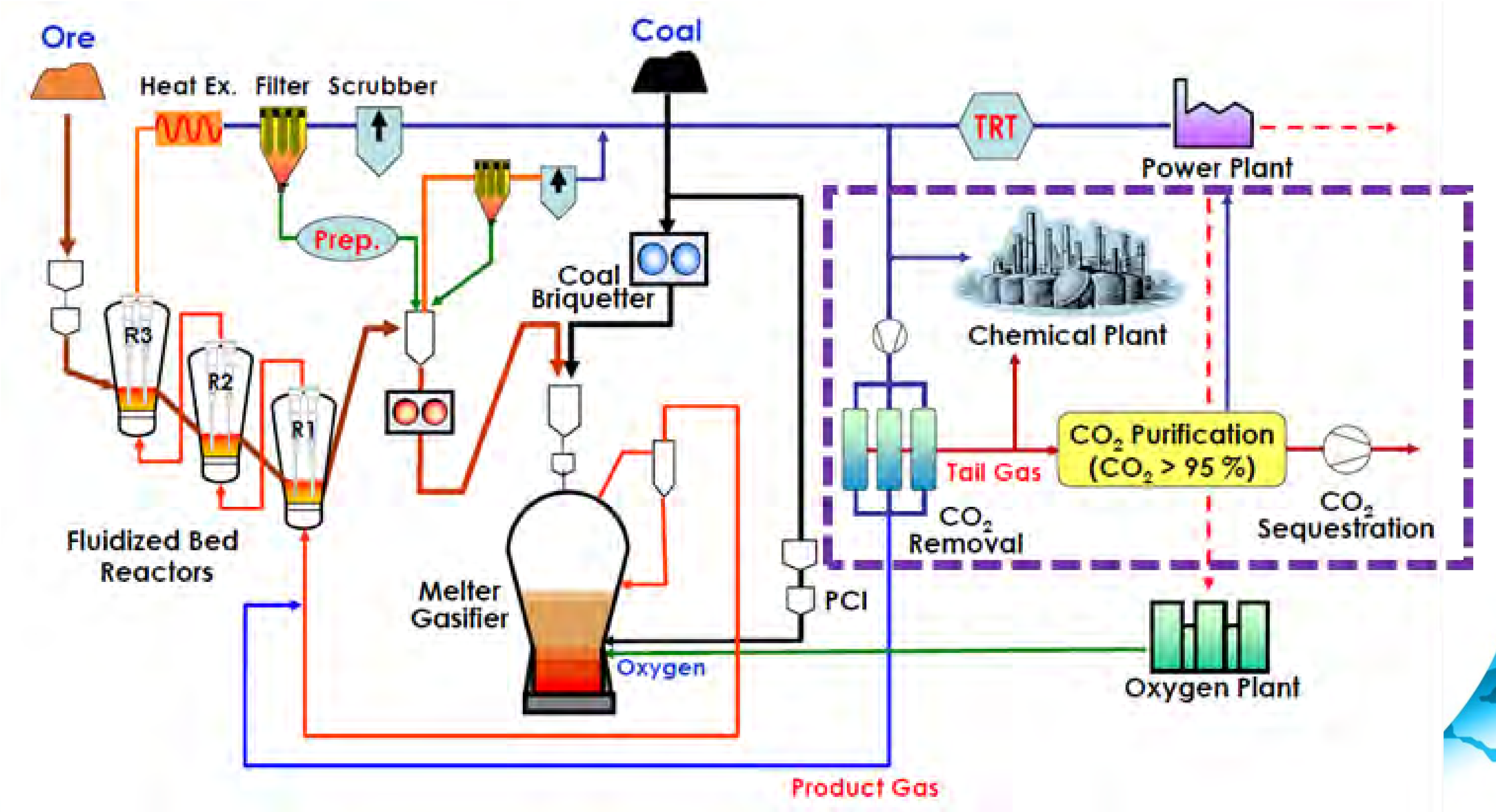
FINEX Process



Gas	Composition (%)			
	CO	CO_2	H_2	N_2
Off-Gas	36	33	15	11
Product Gas	53	3	25	18
Tail Gas	17	66	4	3



Future of FINEX with CCS



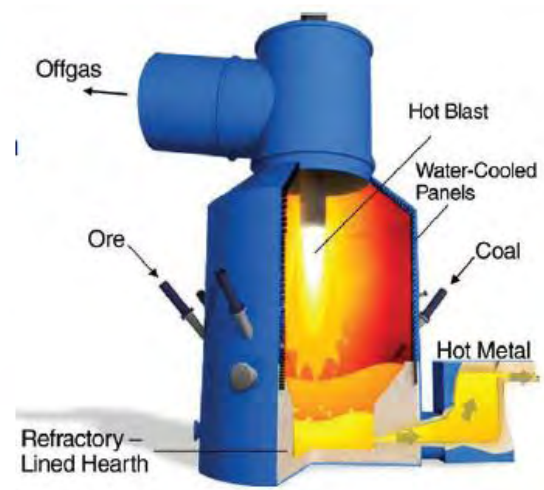
HISARNA (ULCOS Programme)

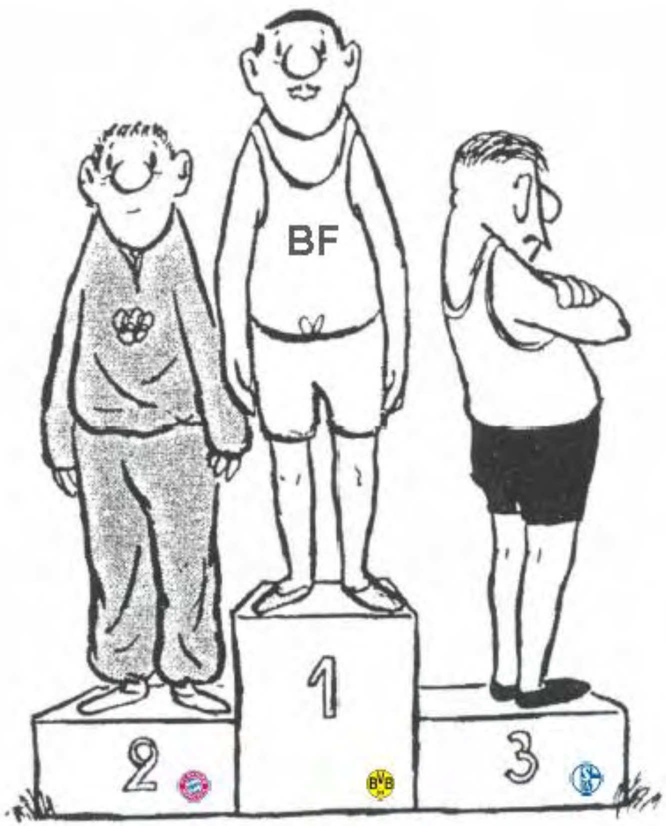
3. The HIsarna pilot plant

TATA STEEL Hot Metal / Slag pot

IEAGHG/IETS Iron and steel Industry
CCUS and Process Integration Workshop, Tokyo, Japan, 4 – 7 November 2013. Confidential

Experimental plant (1994-1998)





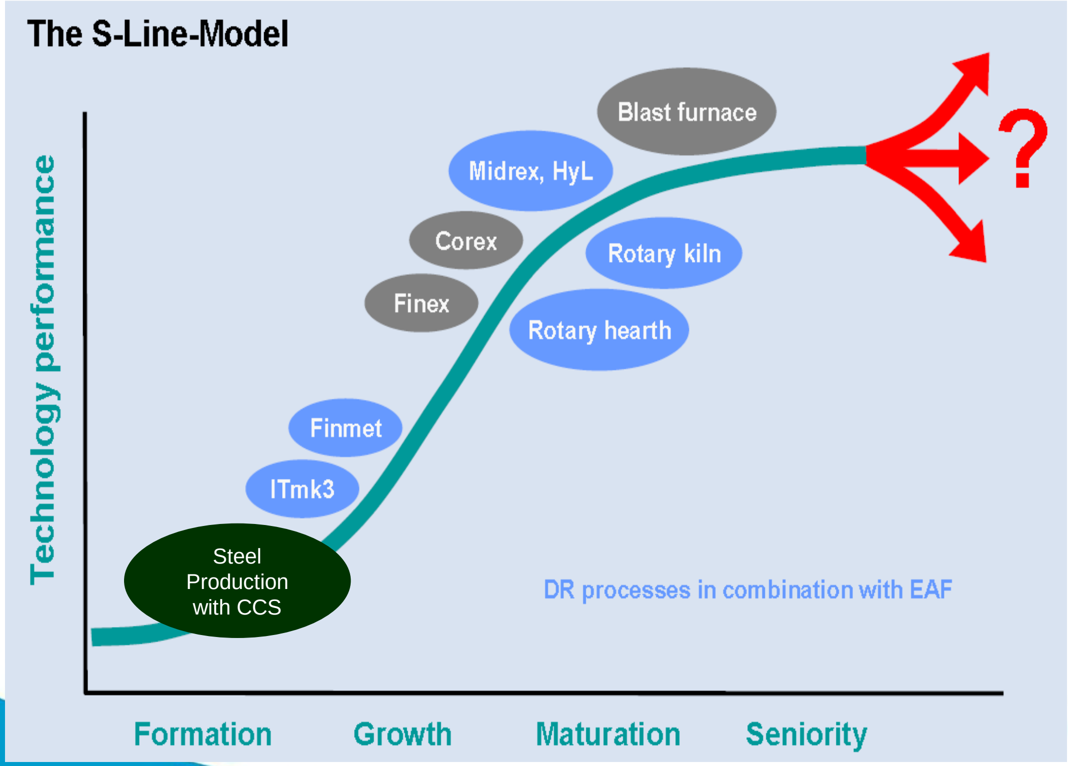
But who will be the winner ???

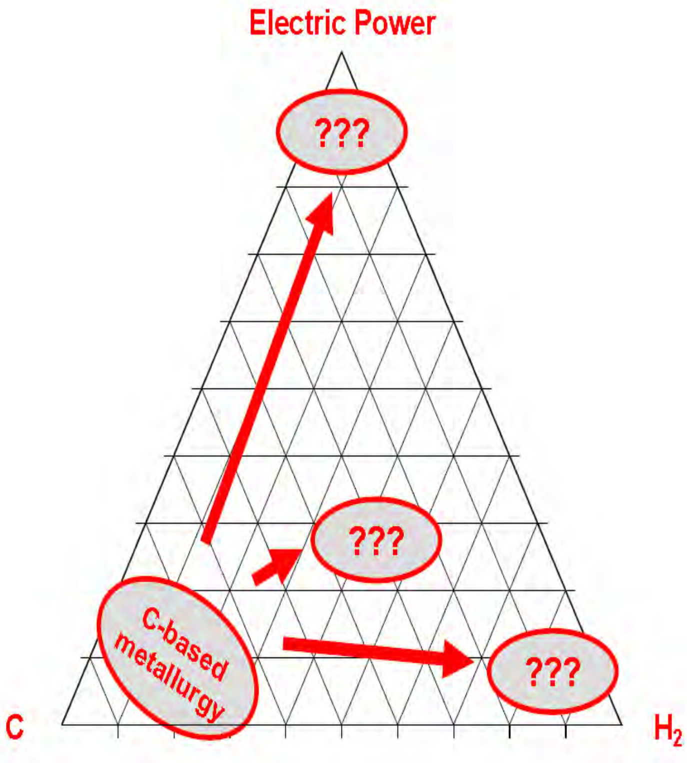
Stahl-Zentrum

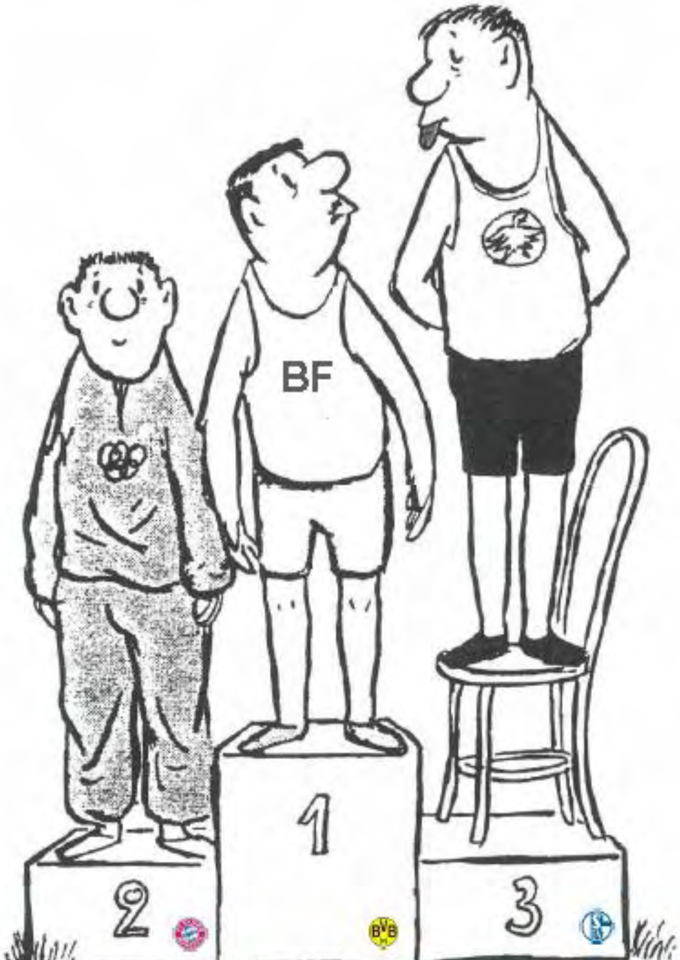
Concluding Remarks

(Figures adapted from VDEH)

- ***So many ways to produce steel…***
- ***What is the right way to reduce CO_2 emissions depends on so many factors…***
  - Raw materials (coke, iron ore, scrap,…)
  - Energy availability
  - Cost (Economics)
- ***It has been recognised that CCS will play an important role in reducing GHG emissions. To successfully deploy CCS, issues regarding MARKET COMPETITIVENESS should be addressed***

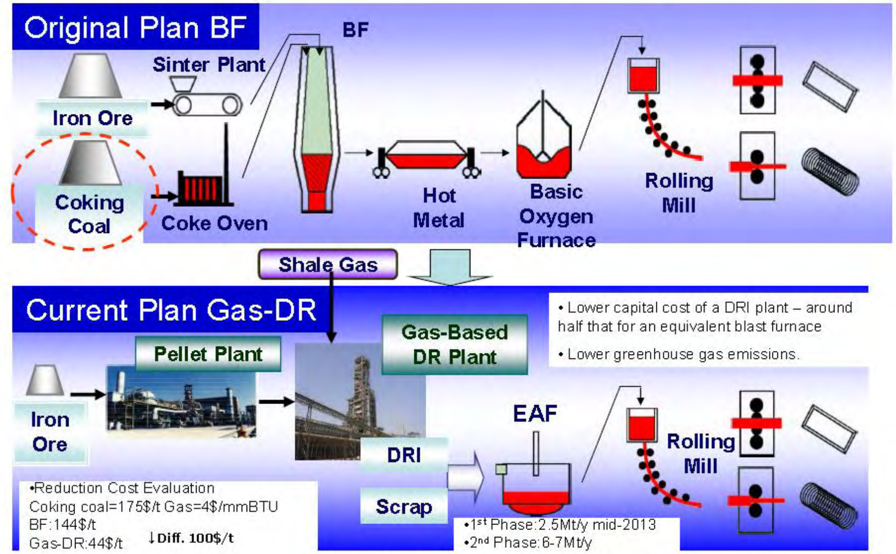






Nucor Louisiana Project in the U.S.A. (2.5Mt/y)

KOBELCO



- With the cheap shale gas, construction of the large-sized gas DR plant was started in the U.S. instead of construction of the BF

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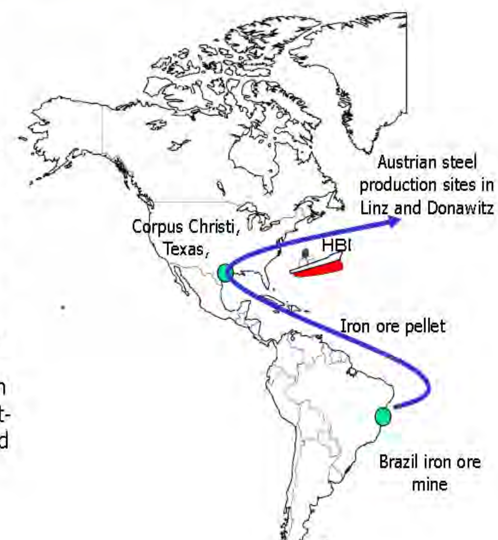
Voestalpine constructing MIDREX direct reduction plant in Texas, USA

- The decision on the construction of the Voestalpine direct reduction plant in North America has been made.
- The plant will be constructed on just outside the city of Corpus Christi, Texas, USA.
- The planned facilities are designed for an annual capacity of around 2 million tons of HBI and DRI.
- The investment volume is around EUR 550 million.
- The plant is due to begin operations in early 2016.
- This will provide the Austrian steel production sites in Linz and Donawitz with access to cost-efficient and environmentally-friendly HBI and DRI pre-materials, ensuring their competitiveness over the long-term.



Thank You

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