CCS – Necessary Action to Reduce CO_2 Emissions from Energy Intensive Industries

(Case Study for the Iron and Steel Sector)

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IEA Greenhouse Gas R&D Programme

Scottish CO2 Capture & Storage Workshop

October 2013

IEA Greenhouse Gas R&D Programme

- A collaborative research programme founded in 1991
- Aim: Provide members with definitive information on the role that technology can play in reducing greenhouse gas emissions.
- Producing information that is:
  - ✓ Objective, trustworthy, independent
  - ✓ Policy relevant but NOT policy prescriptive
  - ✓ Reviewed by external Expert Reviewers
  - ✓ Subject to review of policy implications by Members
- IEA GHG is an IEA Implementing Agreement in which the Participants contribute to a common fund to finance the activities.
- Activities:
  - Studies and Reports (>120);
  - International Research Networks
  - Communications (GHGT conferences, IJGGC, etc);
  - facilitating and focusing R&D and demonstration activities e.g. Weyburn

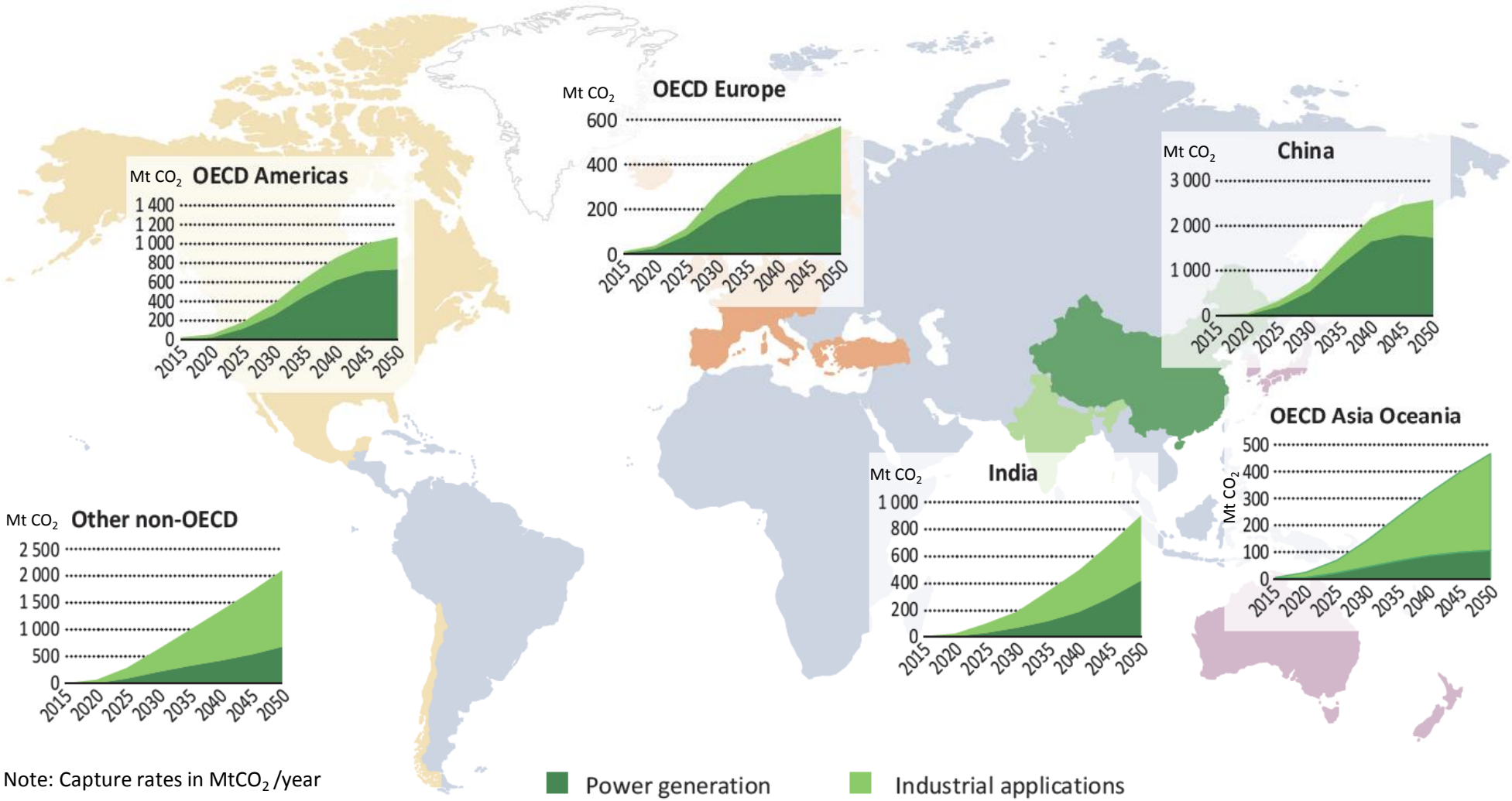
Members and Sponsors

Introduction

Why We Need CO_2 Capture & Storage in the Energy Intensive Industries?

Nearly half of the 123 Gt CO_2 by 2050 should be from industrial applications

ETP 2012



Note: Capture rates in $MtCO_2$ /year

This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Key point *Between 2015 and 2050, almost 123 $GtCO_2$ is captured and stored in the 2DS; in the near term, the largest amount of CO_2 is captured in OECD countries, but by 2050, non-OECD countries will have captured more CO_2 than OECD countries.*

International Energy Agency

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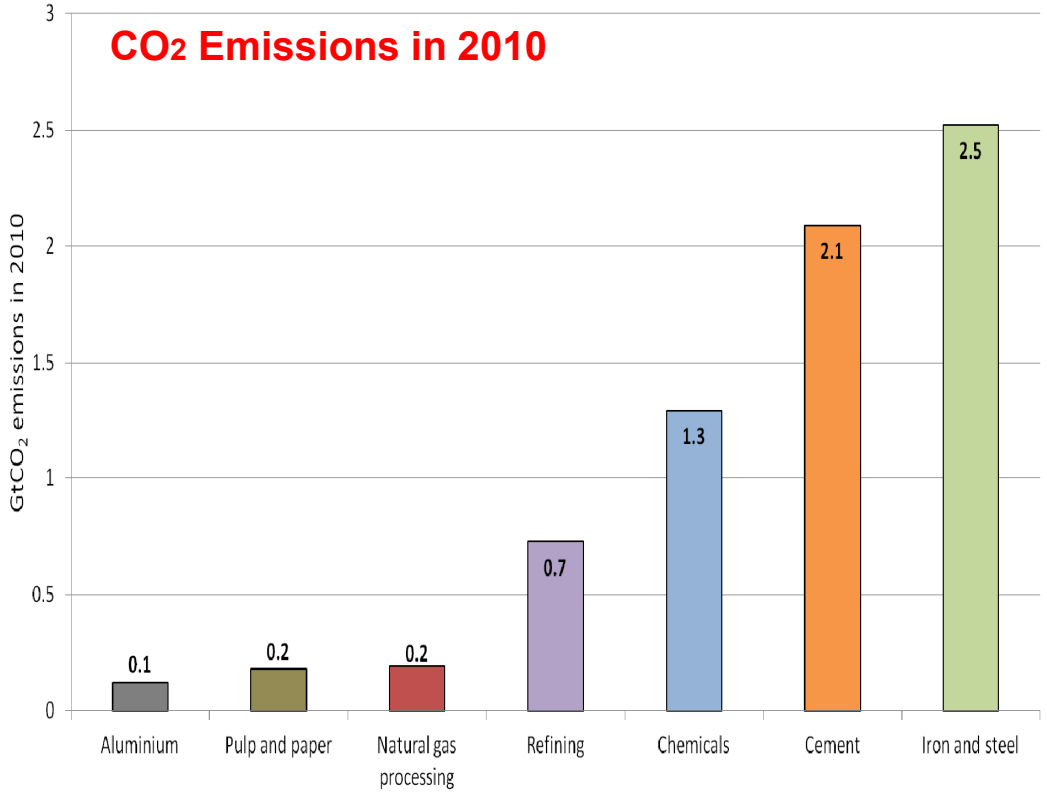
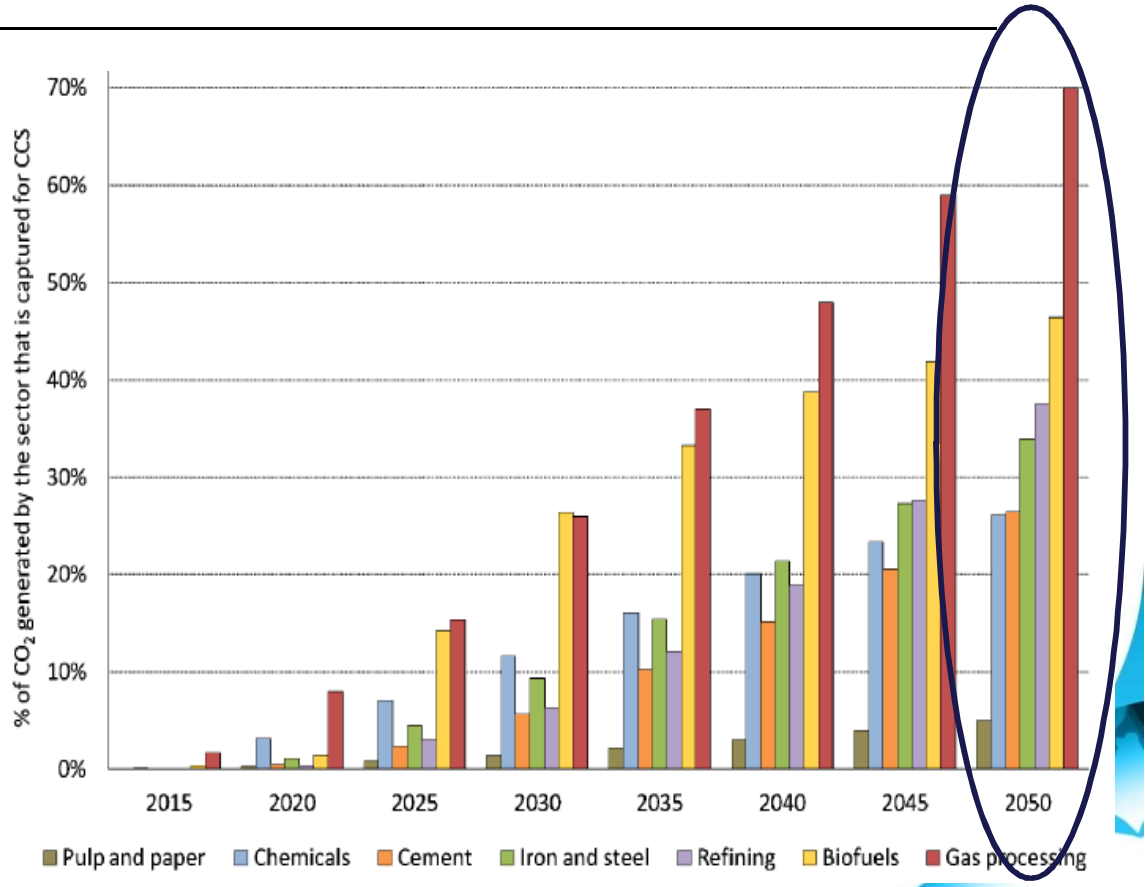
Global CO_2 Emissions from Industrial Sources

(Data from IEA ETP 2012)

Figure 3. Proportion of CO_2 generated globally that is captured and stored through CCS in the sectors analysed in the 2DS





By 2050 - 38%, 35% & 28% of global CO_2 emissions from the Oil refining, I&S and Cement industries should be captured.

Takeaway Message from IEA Analysis

- It could be concluded that CCS is an important part to the CO_2 emissions reduction strategy from various industrial sector.

- Technology is not the only barrier to the deployment of CCS in the industrial sector.

- Market competitiveness and global nature of some of these industries is an important issues that should be addressed.

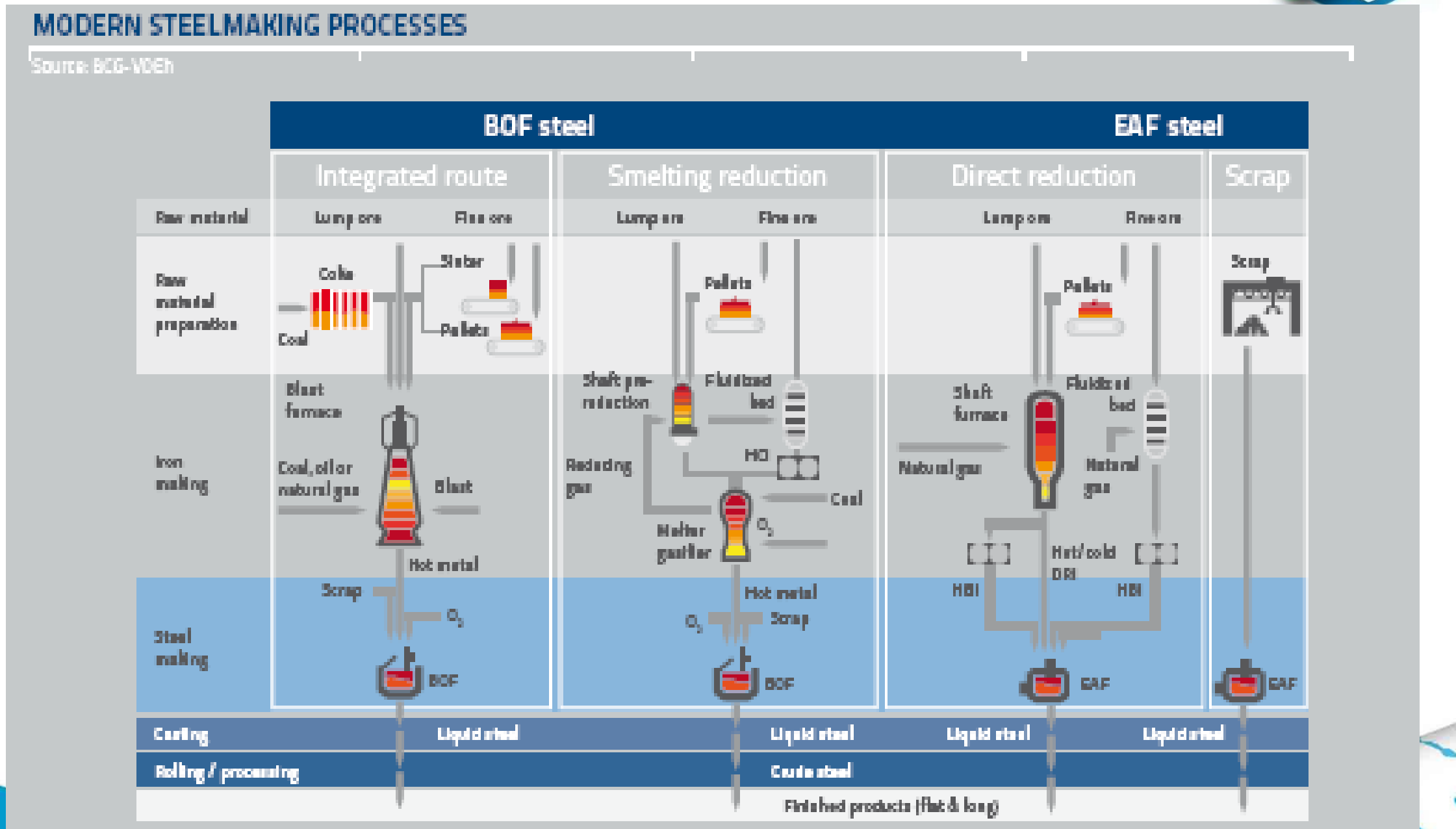
Presentation Outline

- ***Iron and Steel Industry***
  - Overview to the production of steel
  - Case Study - Cost implication of CO_2 Capture Deployment in an Integrated Steel Mill
  - Challenges to the industry
- ***Summary and Concluding Remarks***

Energy Intensive Industry

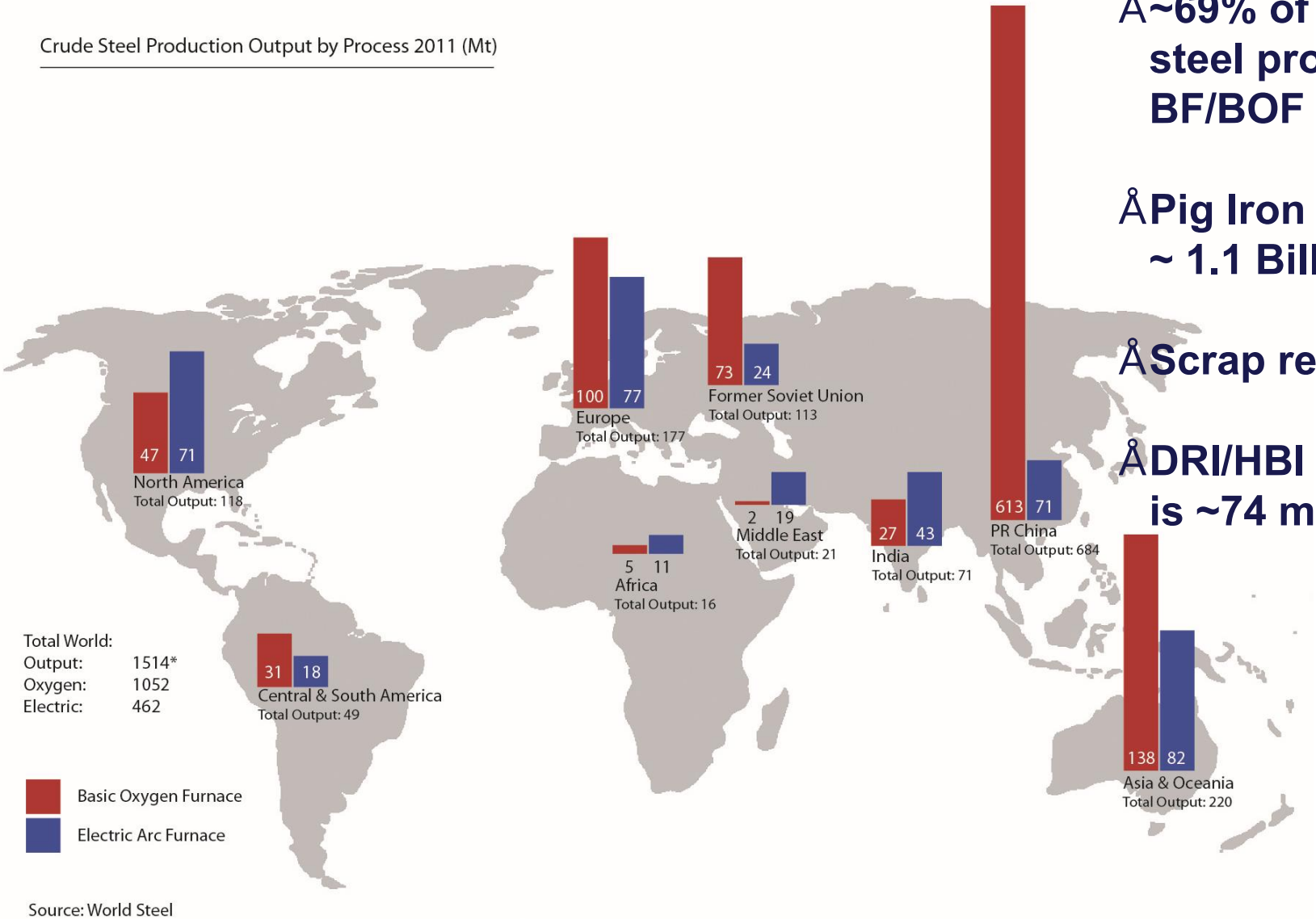
Part 1: Iron and Steel Industry

Steel Production Routes



World Crude Steel Production (Share of BOF vs. EAF Route)

- ~69% of the crude steel produced via BF/BOF Route
- Pig Iron Production ~ 1.1 Billion tonnes
- Scrap recycled
- DRI/HBI Production is ~74 million tonnes

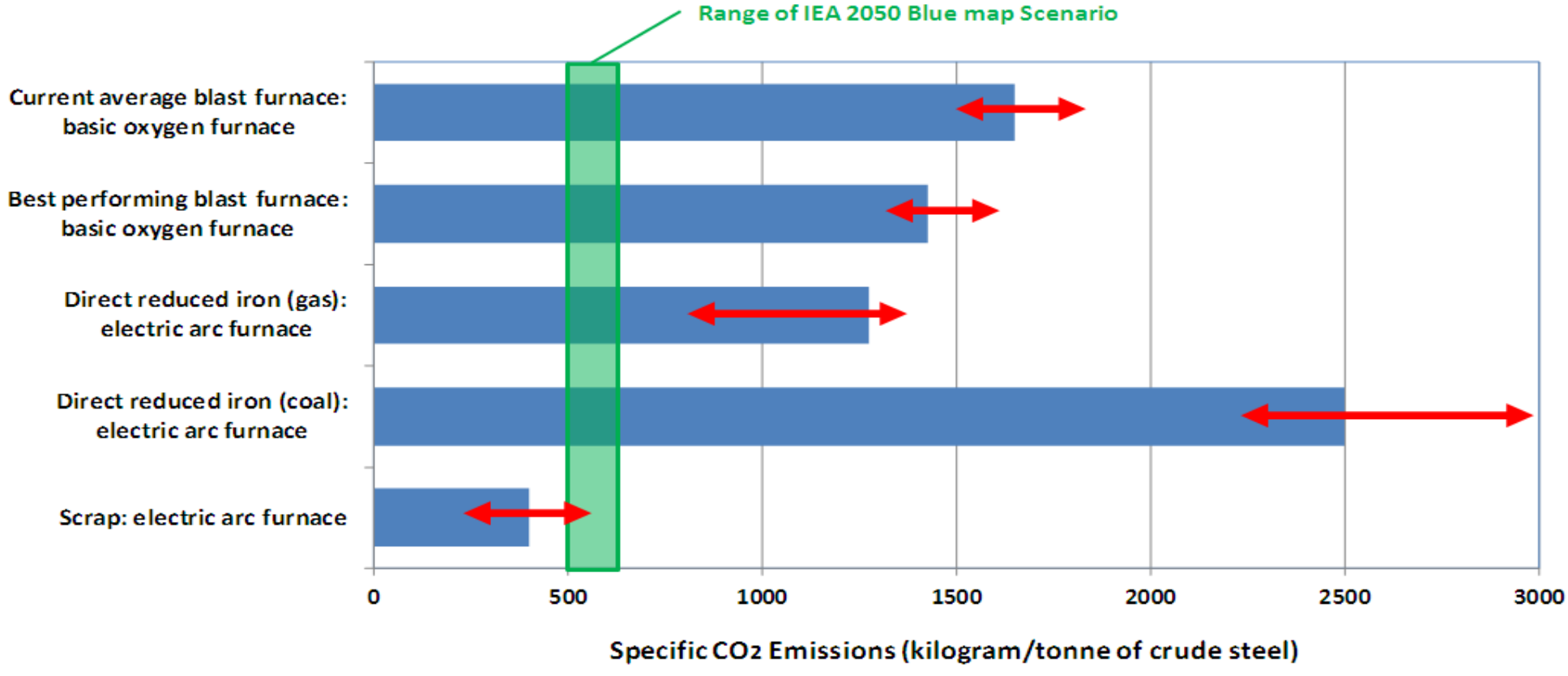


Source: World Steel

* A small percentage of steel is also produced using open hearth & other methods (particularly in FSU)

Direct CO_2 Emissions

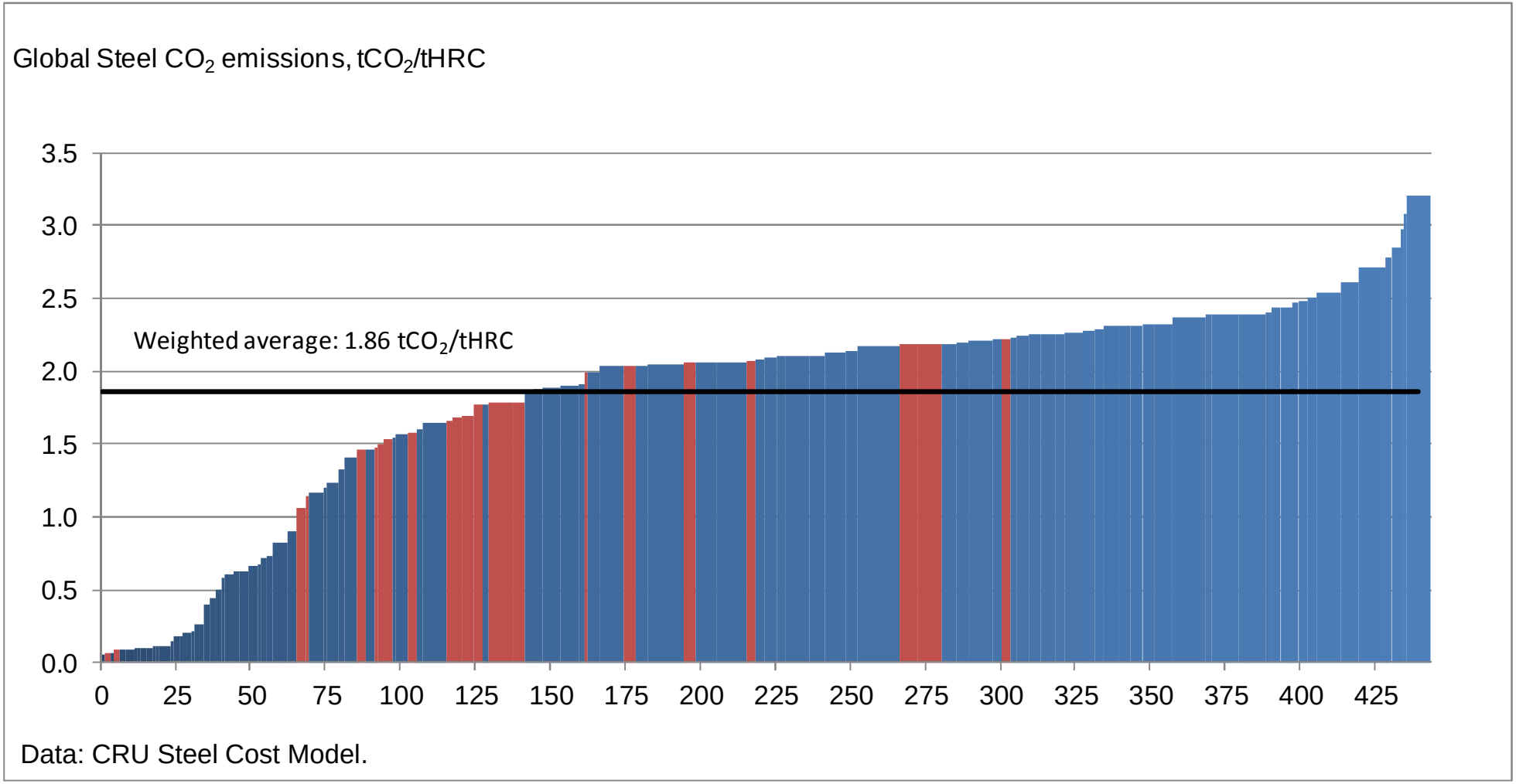
(An Overview)



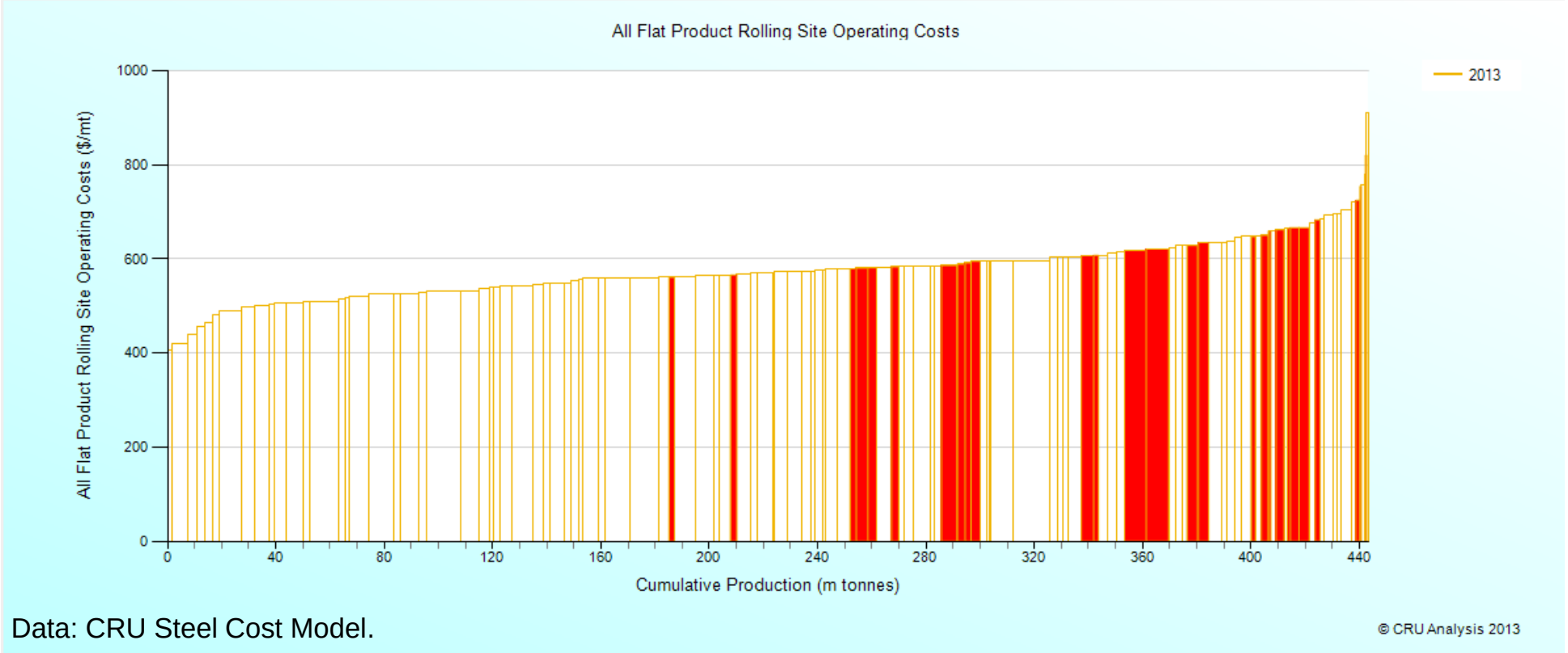
Note: Reported values are for crude steel only (i.e. up to casting) and excludes any emissions from rolling or finishing mills. Variation in the values include the range of CO_2 content of the electricity used (i.e. These are data from IEA using various country average). Scrap used by the BF-BOF is around 10%. For DR technology, the variations also include impact of the quality of the DRI (typical average of 92% metallisation are reported for gas-based DRI and 85% for coal based DRI have been reported). CO_2 utilisation from gas-based DRI (for example – HYL/Energiron) are not included.

Source: Adapted from "IEA Tracking Industrial Energy Efficiency and CO_2 Emissions" (2007) and "Preparing for the Technology Transition in Steel Production (focus on Carbon Capture & Storage) - John Newman (2011)

Global steel CO_2 curve...showing European sites



European steel cost competitiveness...



Data: CRU Steel Cost Model.

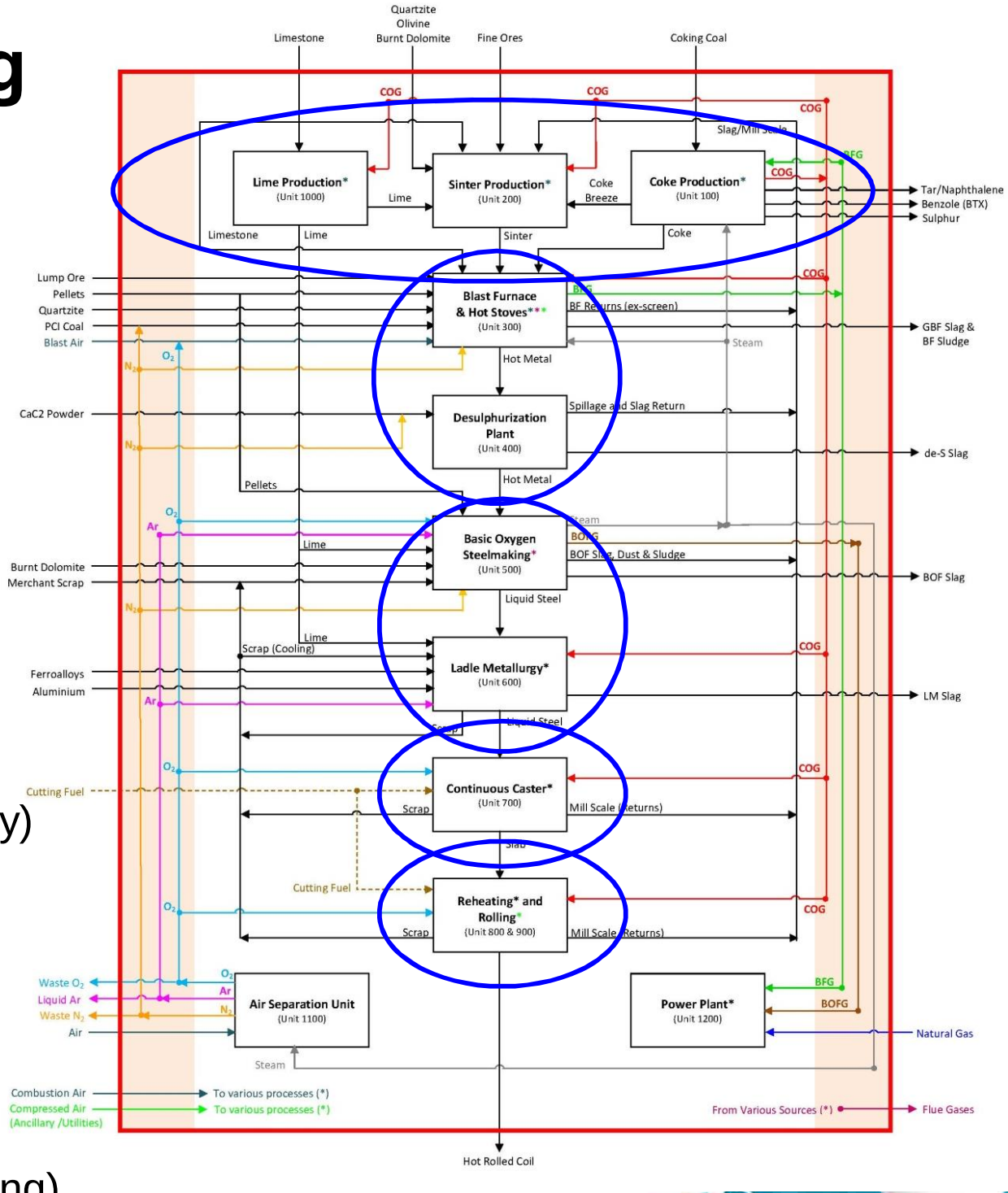
Techno-Economics of CO_2 Capture Deployment in an Integrated Steel Mill

- Project Partners
  - Swedish Energy Agency
  - IEA Greenhouse Gas R&D Programme
  - SSAB
  - LKAB
  - Members of Swerea MEFOS
- Project Team:
  - Swerea MEFOS
  - Tata Steel Consulting
  - SINTEF Materials and Chemistry

- Total Value of Project: ~3.6 million SKr
  - IEAGHG Contribution: ~1.0 million SKr

Integrated Steelmaking Process

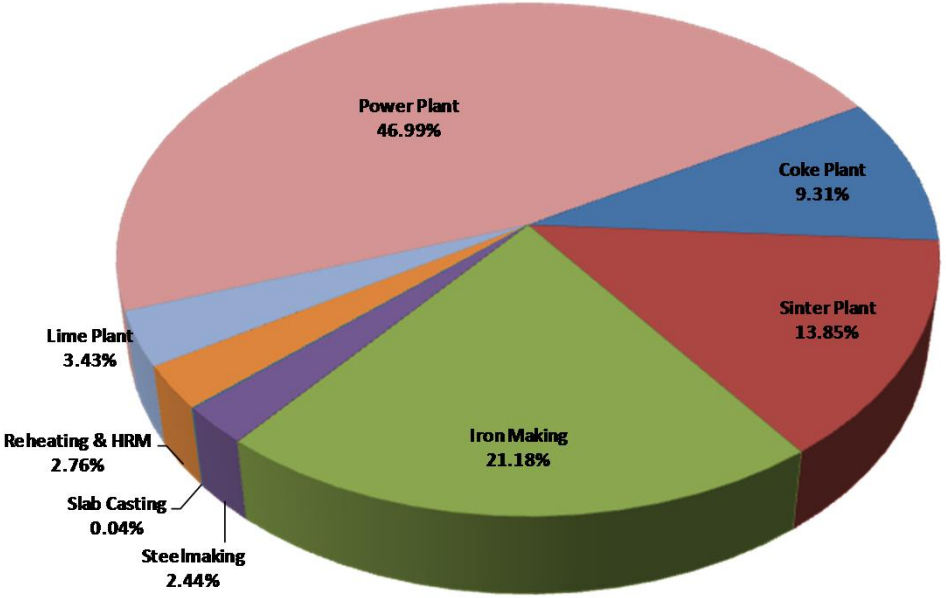
- Raw Materials Preparation Plants
  - Coke Production
  - Ore Agglomerating Plant (Sinter Production)
  - Lime Production
- Ironmaking
  - Blast Furnace
  - Hot Metal Desulphurisation
- Steelmaking
  - Basic Oxygen Steelmaking (Primary)
  - Secondary Steelmaking (Ladle Metallurgy)
- Casting
  - Continuous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



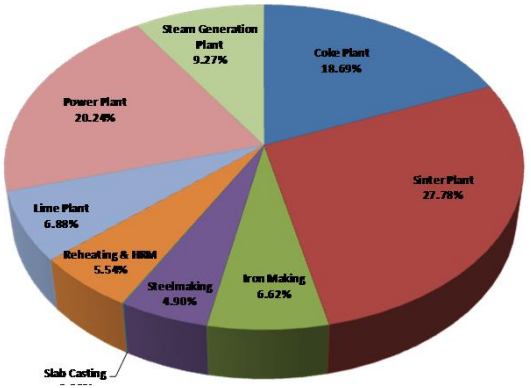
Definition of the Case Studies

- Case 1: REFERENCE Case ï Integrated Steel Mill producing 4MTPY situated at Coastal Region of Europe.
- Case 2A: Steel Mill with Post-Combustion CO_2 Capture ï capturing CO_2 from flue gases of the hot stoves and steam generation plant (achieving 50% avoidance)
- Case 3: Steel Mill with Oxy-BF, Top Gas Recycle and MDEA CO_2 Capture (achieving 47% avoidance)

Summary of Results
(CO_2 Emissions)

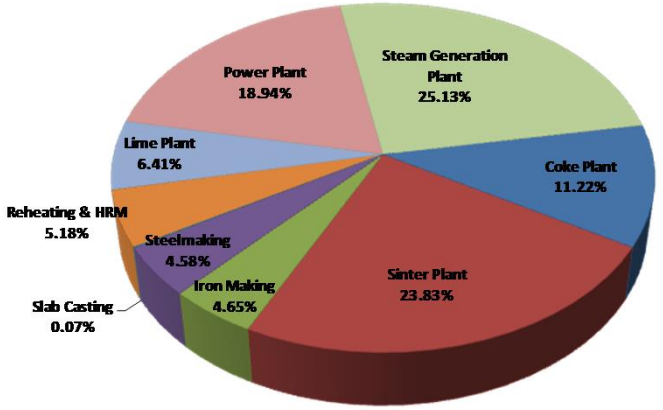


REFERENCE Integrated Steel Mill
(2090 kg per tonne of Hot Rolled Coil)



Steel Mill with Post Combustion CO_2 Capture (CASE 2A)
(1042 kg per tonne of Hot Rolled Coil)

- CO_2 Captured: 1243 kg/t HRC
- CO_2 Avoided: 50.2%



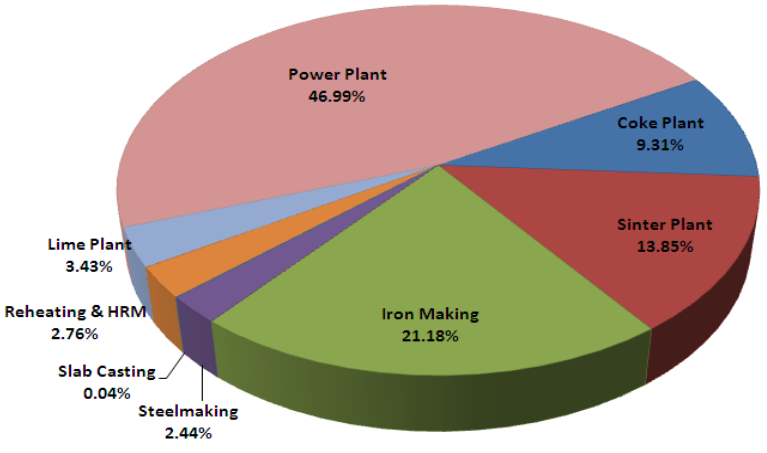
Steel Mill with OBF, MDEA CO_2 Capture, & TGR (CASE 3)
(1115 kg per tonne of Hot Rolled Coil)

- CO_2 Captured: 860 kg/t HRC
- CO_2 Avoided: 46.7%

Carbon Balance of Ironmaking Process

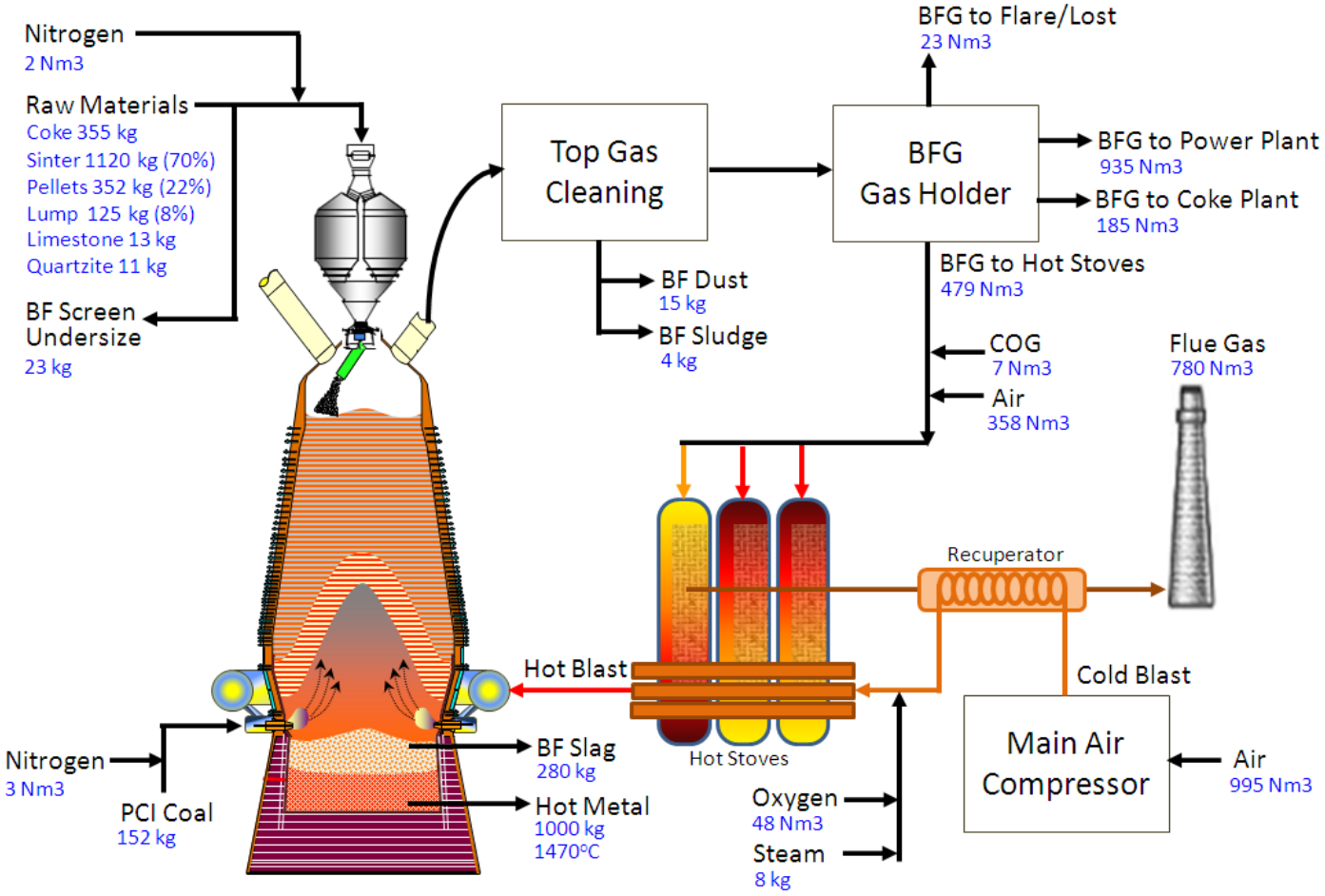
Direct CO_2 Emissions of an Integrated Steel Mill (REFERENCE) Producing 4 MTPY Hot Rolled Coil

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**



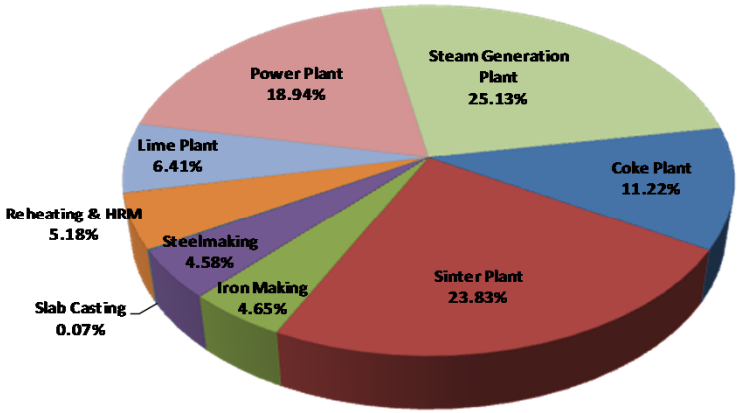
For this case study, it was demonstrated that the ironmaking process is responsible for 78% of the total carbon input of the steel mill. <u>BUT</u> only 21% of the carbon emitted as CO_2 emissions is attributed to this process. The rest of the carbon emitted as CO_2 are accounted to other processes (mostly end users of the by-product fuel gases) within the steel mill.

Carbon Balance of Ironmaking Process

(Equipped with OBF and MDEA/Pz CO_2 Capture)

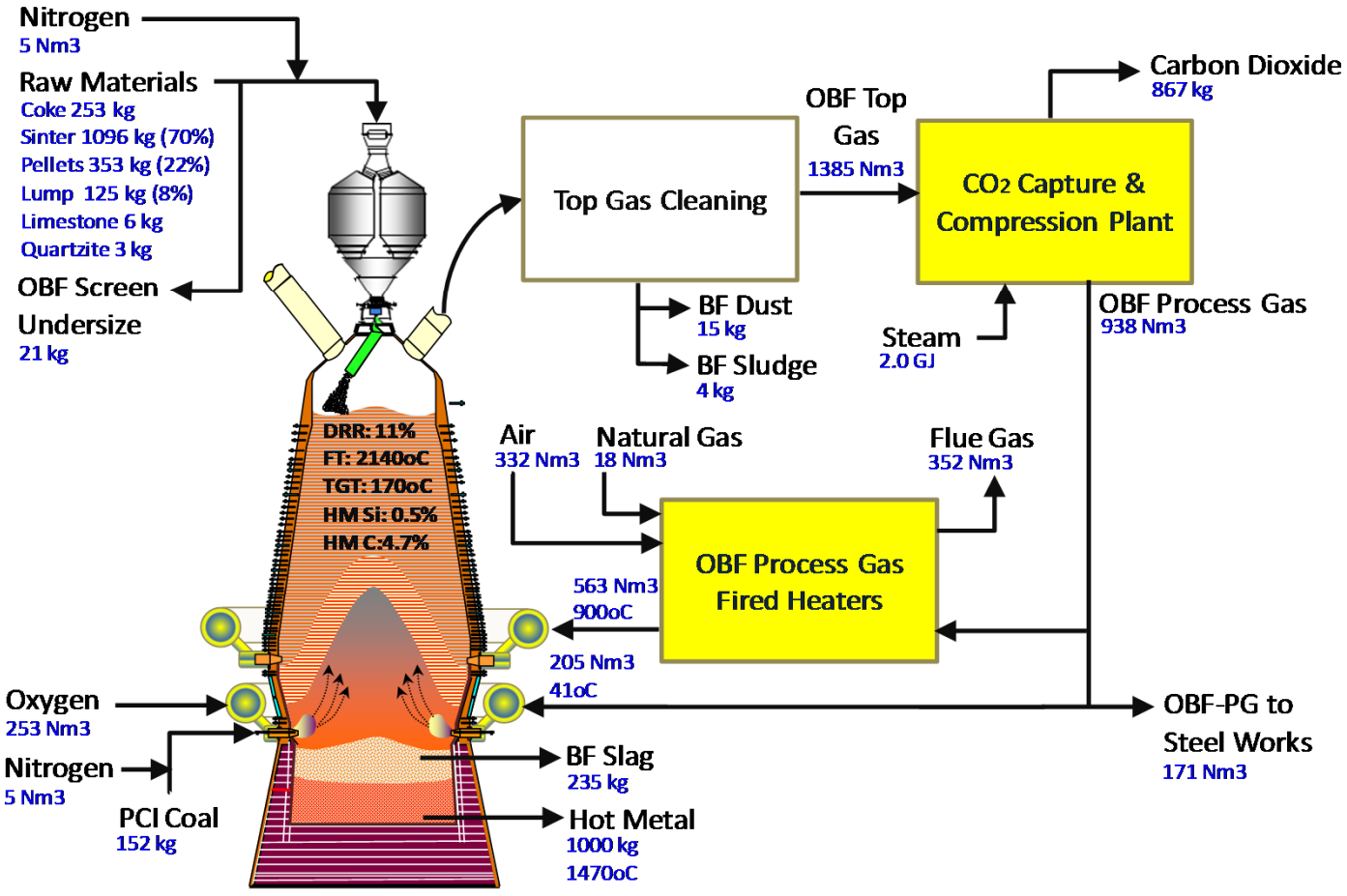
Direct CO_2 Emissions of an Integrated Steel Mill (with OBF & MDEA CO_2 Capture) Producing 4 MTPY Hot Rolled Coil

1115 kg CO_2/t HRC (1124 kg CO_2/thm)



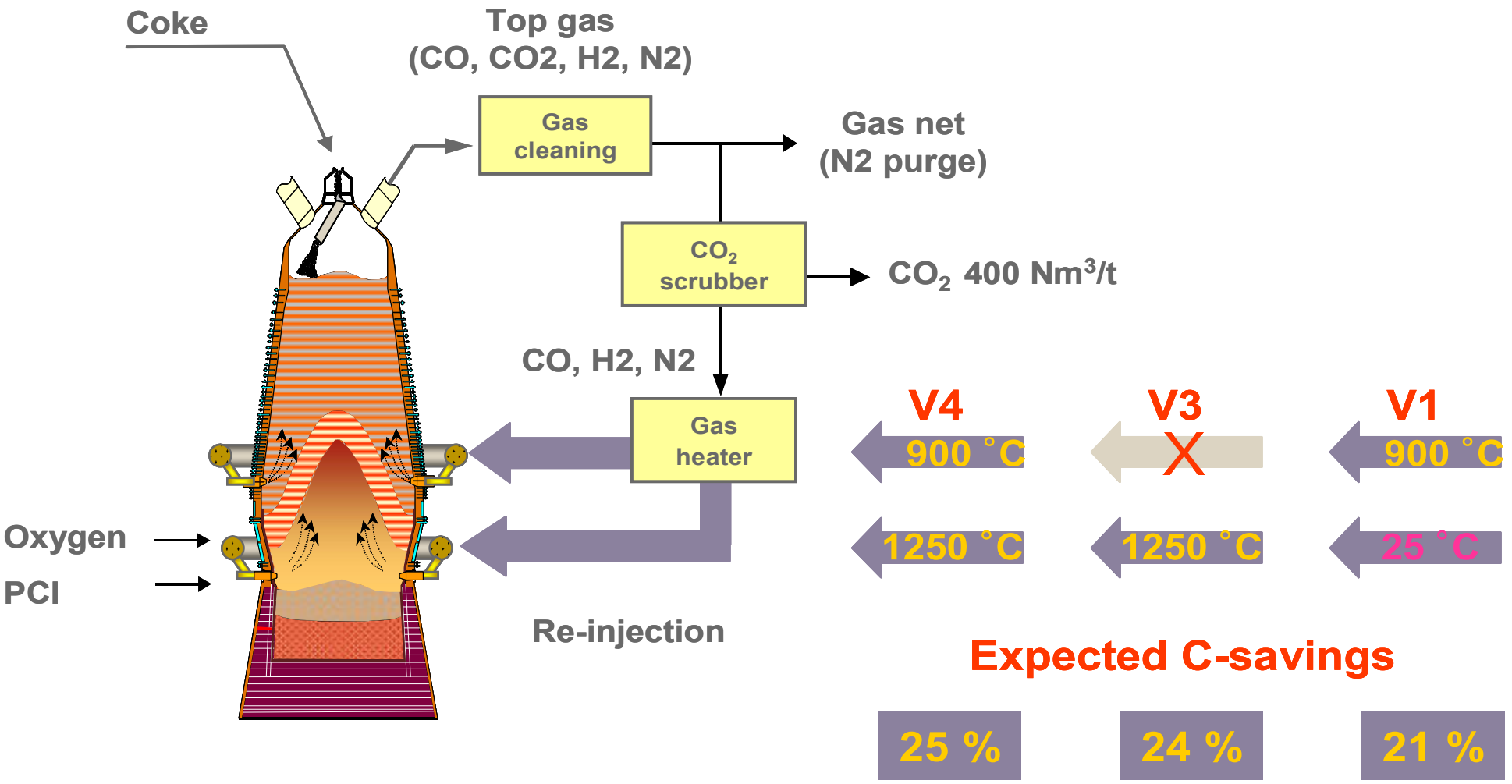
Carbon Balance of Ironmaking Process

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**



For this case study, the Oxy-Blast Furnace has the potential to reduce carbon input to the iron making process by 17% as compared to the REFERENCE case (@447.5 kg C/thm). This is due to the reduced consumption of the coke. ULCOS has reported a higher carbon input reduction potential of up to ~28%. Further reduction of CO_2 emissions could only be achieved by CCS.

The Ulcos Blast Furnace Concepts



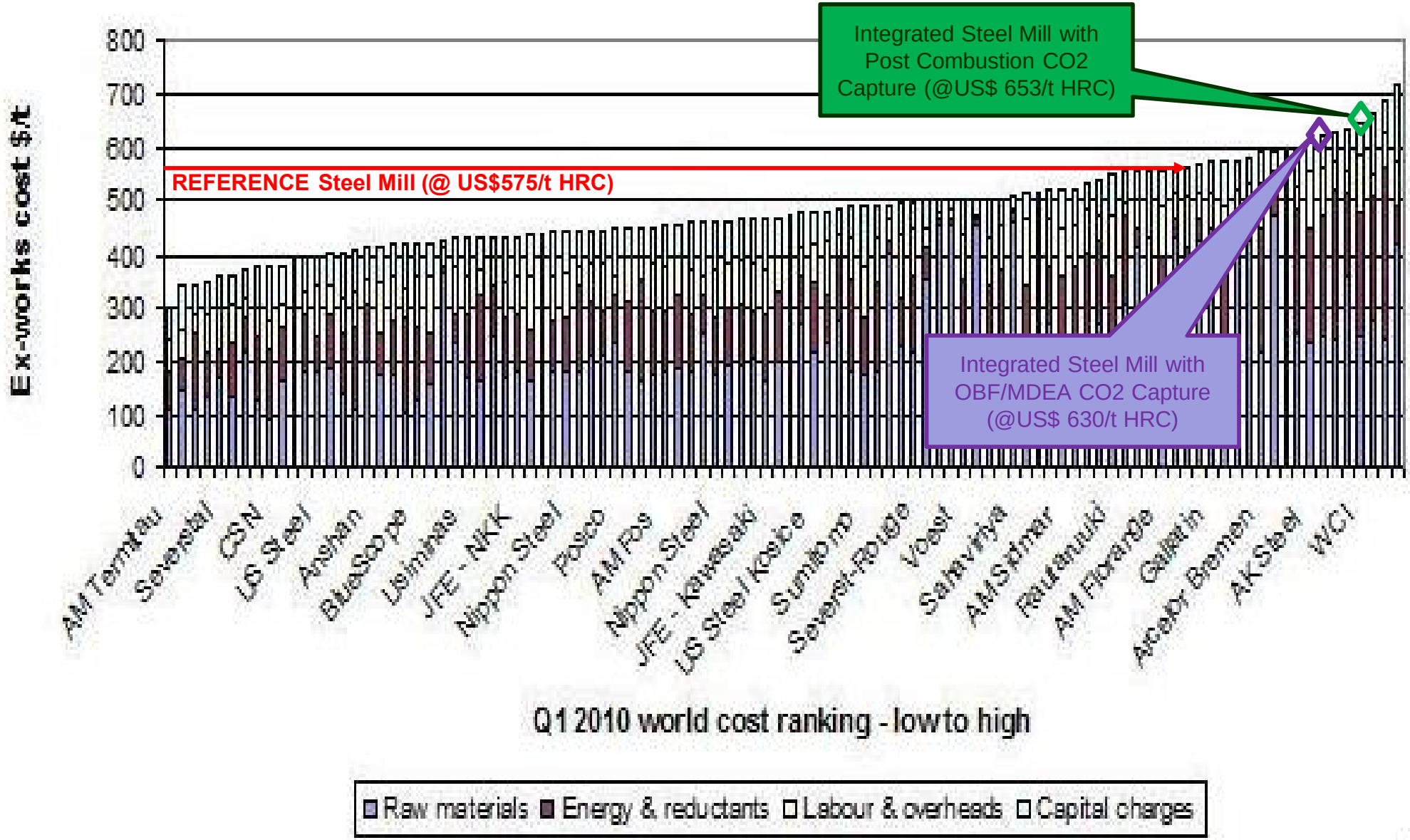
Note:

- Case study presented only illustrates one of the many options available for oxy-blast furnaces

- This do not represents the choice made by the ULCOS Programme.
  - Florange Project
  - Eisenhüttenstadt Project

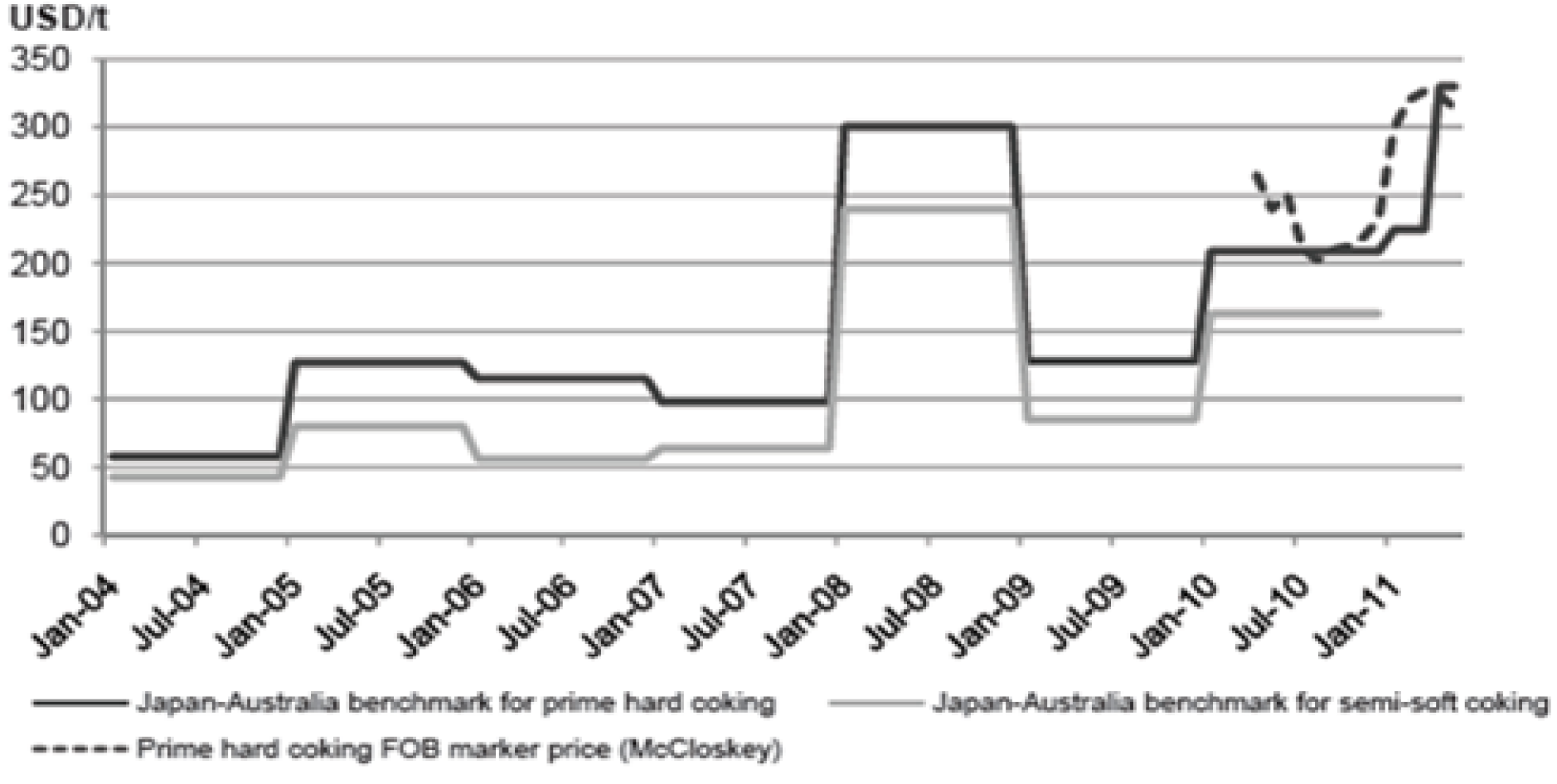
Relative Cost Competitiveness of Steel Production with CO_2 Capture

(2010 Global Cost Curve Data from Metal Consulting Int'l Ltd.)



Evolution of Coking Coal Price

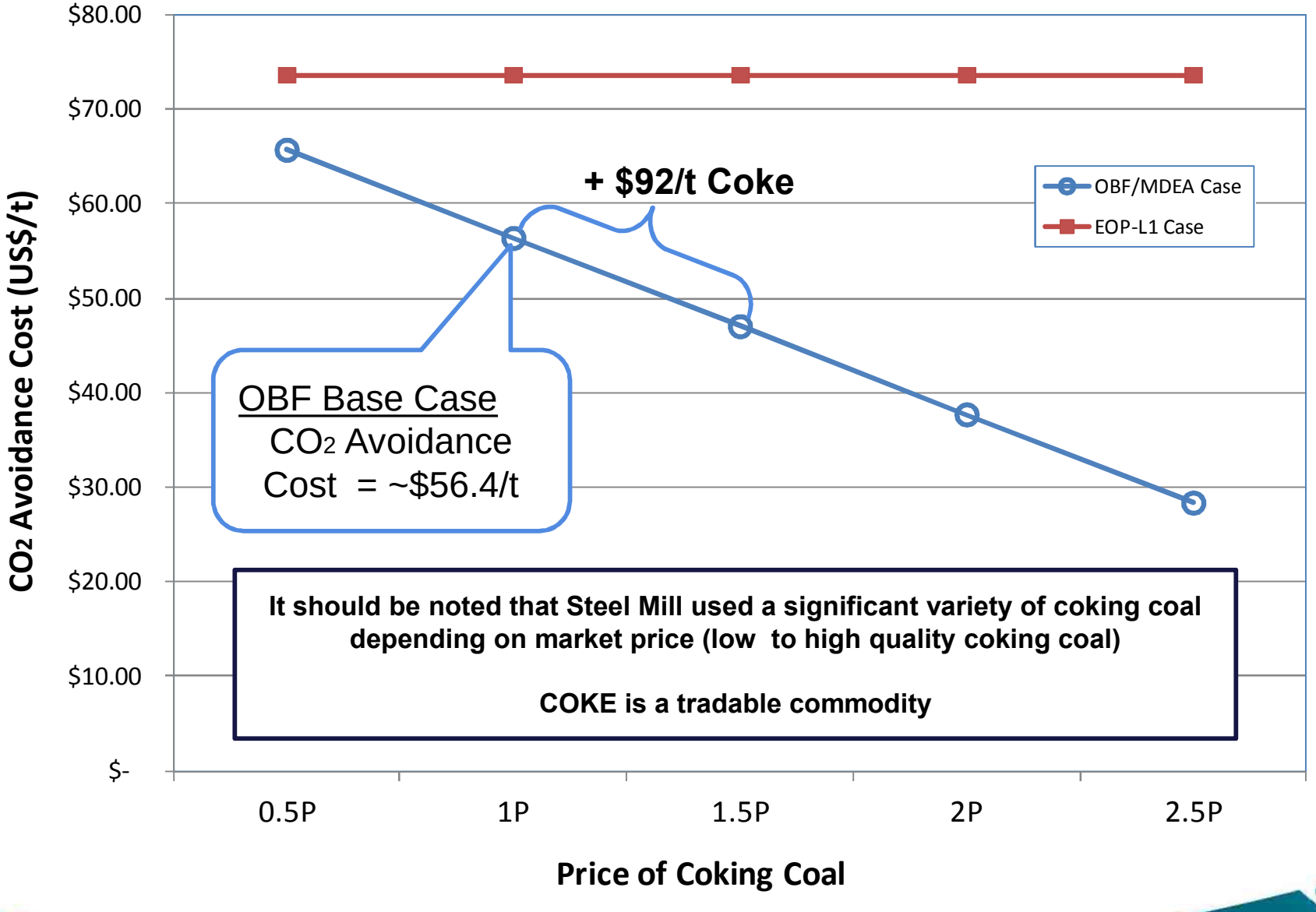
(Data provided by P. Baruya – IEA CCC)



Source: McCloskey (2011); ABARES (2011a).

Summary of Results

(Sensitivity to Coke Price)



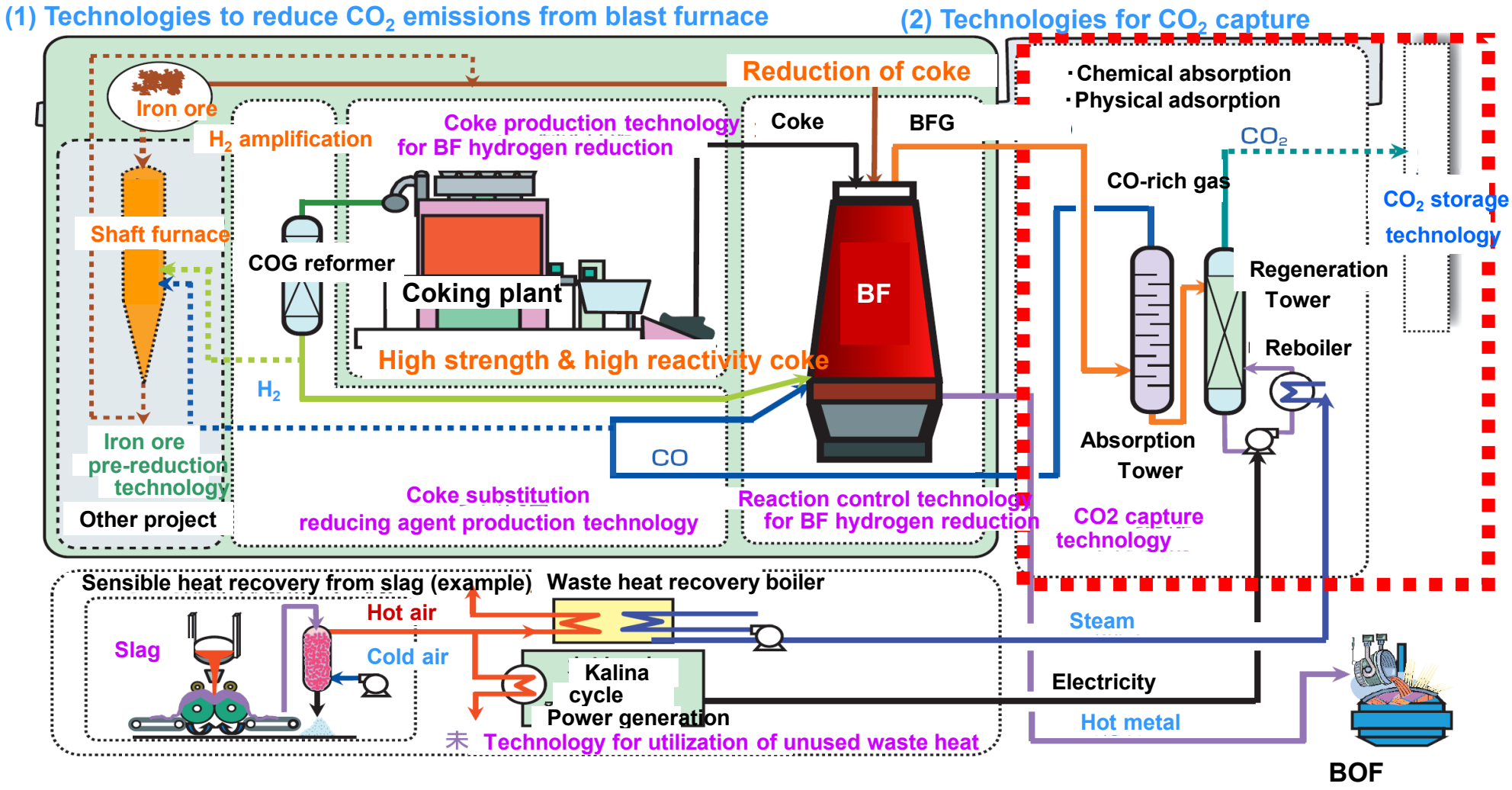
Key Messages from this Study

- **Key to the deployment of CO_2 capture technologies using top gas recycle to a blast furnace should also maximise the reduction in the coke consumption to make it cost competitive.**

- **Post-Combustion CO_2 Capture – i.e. capture of CO_2 from the flue gases of different stacks within the integrated steel mill - <u>is not a cost competitive option!</u>**
  - **This is not the options considered by the global steel community.**

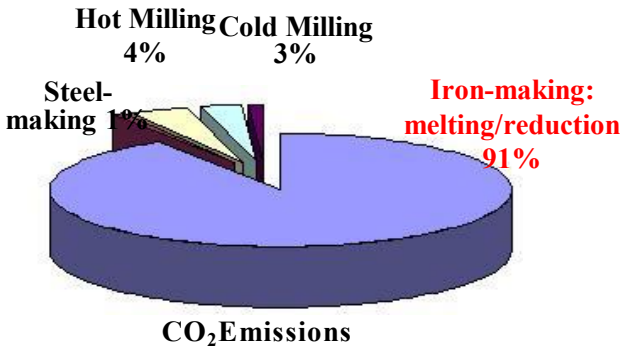
- REPORTING <u>CO_2 Avoidance Cost</u> for a complex industrial processes is meaningless ï without establishing the assumptions used for the REFERENCE Plant without CO_2 Capture.
  - **<u>This is not a good indicator for these cases yet we are trapped in it…</u>**

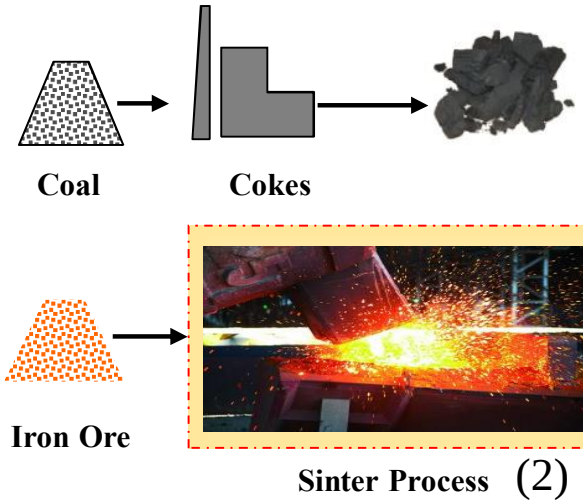
Japanese “Course 50 Programme”

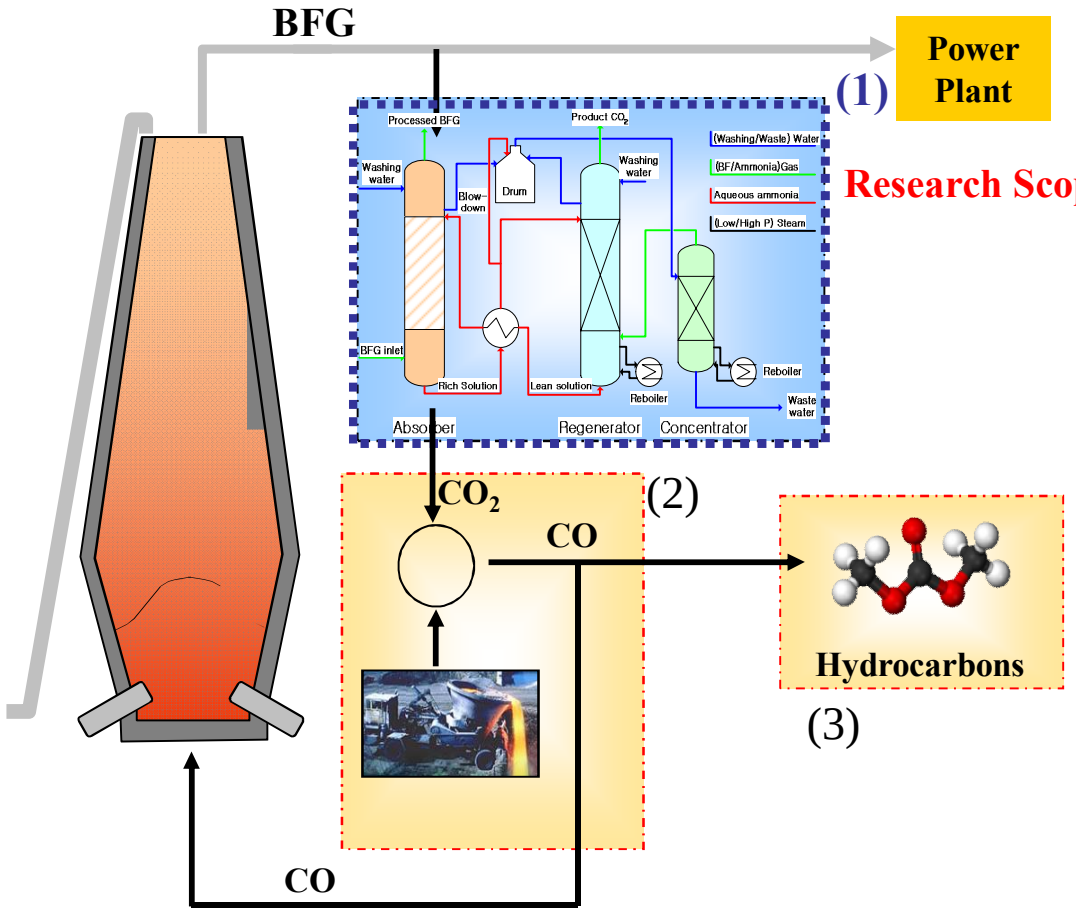


COURSE50 / CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50

Ideas/Projects for CO_2 Reduction







- Research Activities of CO_2 Project in RIST
  - (1) CO_2 Capture from BFG stream using aqueous ammonia
  - (2) Waste heat recovery from molten slag and hot sinter
  - (3) CO_2 utilization

Challenges of CCS Deployment in the Steel Industry

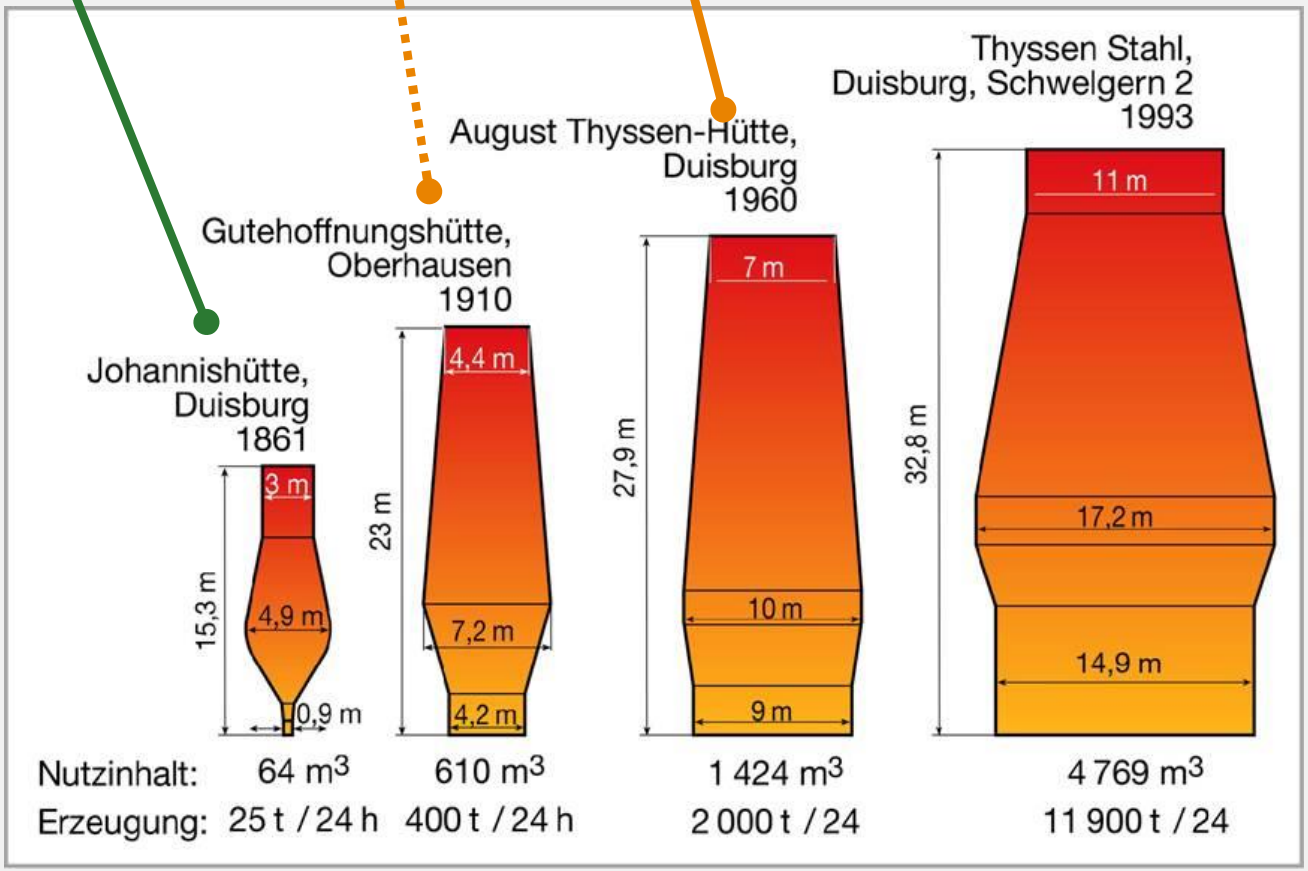
- Technical Challenges:
  - Several technology options for CO_2 Capture ï Currently, the most viable options has been identified, evaluated in pilot scale ï however, necessary to be demonstrated for a period of **at least 10 years continuous operation**.
  - Key to the success of any CO_2 capture deployment is achieving the coke reduction potential to make it cost competitive.
  - Emerging technologies ï like smelting technologies ï are not yet ready and will require to go through growing pains.

ULCOS-Technologies for huge BF`s are not available before 2030-40

ULCOS I
2003-2009

ULCOS IIa
2014- 2016

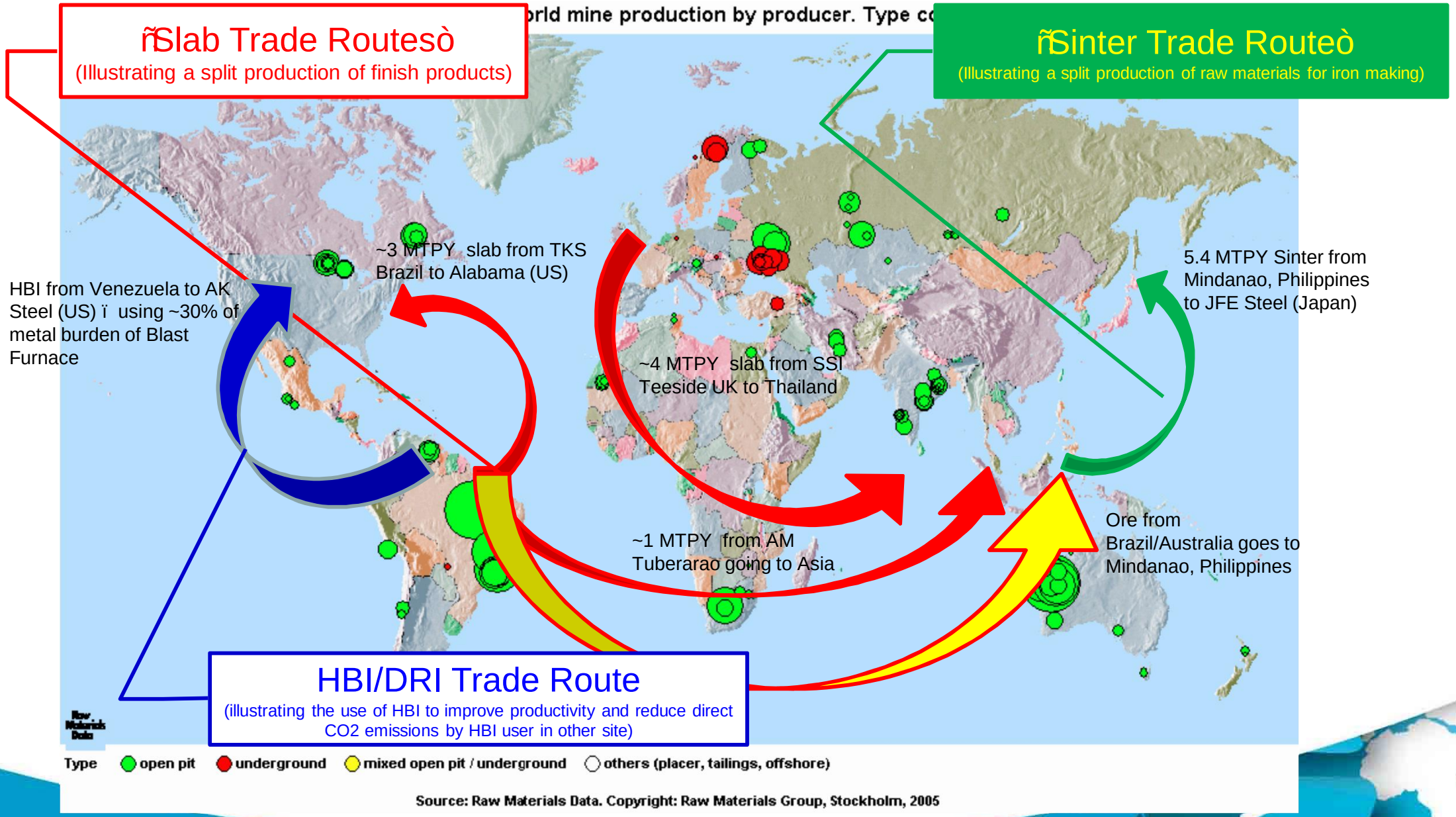
ULCOS II b
2016-2020 (?)



Challenges of CCS Deployment in the Steel Industry

- Market Challenges:
  - Steel industry is a globally market driven industry with thousands of different products traded.
  - **"Economic Carbon Leakage"** ï comes in different forms. This covers the trade of raw materials, intermediate products, final products; and also to include a shift in iron & steel production processes.
  - **"Technical Carbon Leakage"** ï is also a possibility where part of the direct CO_2 emissions could be reduced by producing by-products (i.e. methanol, ethanol, hydrocarbon, etcé)

Examples Illustrating the Possibility of “Economic Carbon Leakage”



Examples Illustrating the Possibility of “Economic Carbon Leakage”

voestalpine signs contract with Siemens and Midrex for DR Plant

July 04, 2013

Project to use MIDREX® Technology for 2.0 MTPY HBI facility in Texas, USA

The voestalpine Group has announced the signing of a contract with Siemens Industry Inc. and consortium partner Midrex Technologies, Inc. to build a new MIDREX® Direct Reduction Plant for its previously announced DR project in North America.

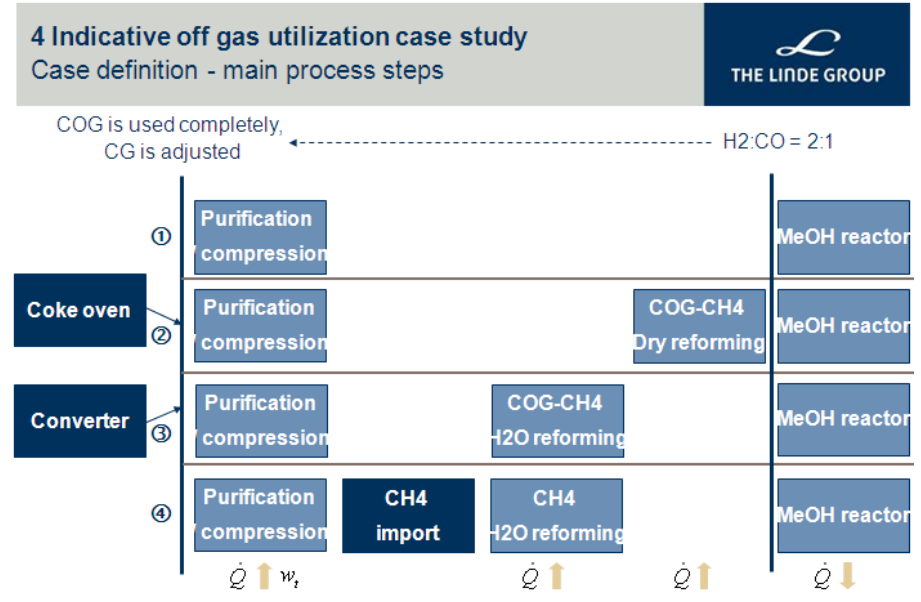
After deciding to locate the plant on the La Quinta Trade Gateway in San Patricio County near Corpus Christi, Texas (USA) and signing the memorandum of understanding with its first customer, Mexican company AHMSA, voestalpine has taken another step toward the realization of the planned direct reduction plant. As the technology decision was made in favor of the MIDREX® Process, a supply agreement was signed yesterday evening with Siemens Industry Inc. and its consortium partner, Midrex Technologies Inc. This means that, contingent on the final official permits, the green light has been given for the construction of the new direct reduction plant.

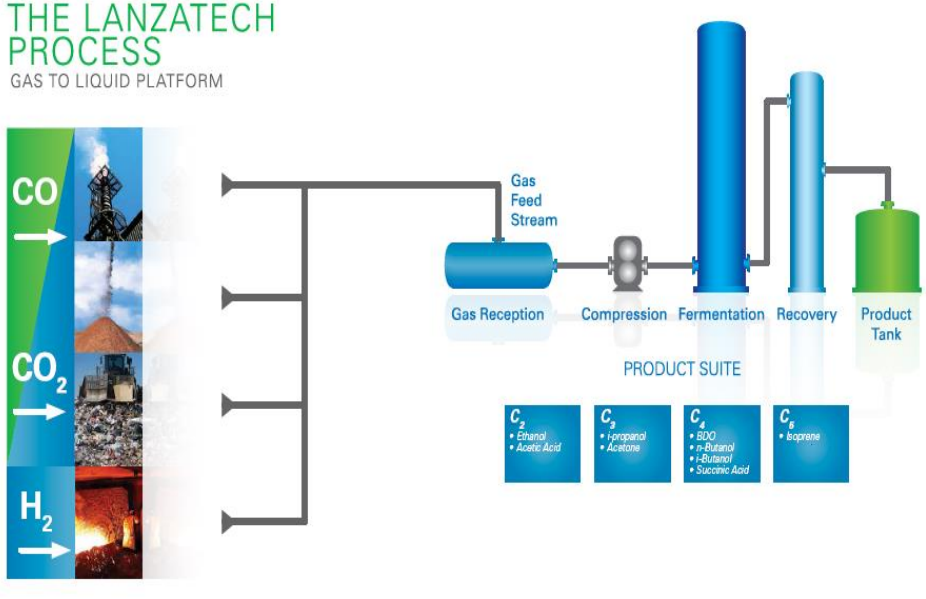
The new MIDREX® Direct Reduction Plant is designed for an annual capacity of two million tons of hot briquetted iron (HBI) and will be the largest single HBI producing module in the world.

- Taking advantage of cheap natural gas but at the same time helps reduce the direct CO_2 emissions at their Austrian plant.
  - VAI ï one of the most profitable steel mill in Europe
  - ~50% of HBI/DRI produced at Texas goes to Austria (as feedstock to the blast furnace)

Some Examples of Possible "Technical Carbon Leakage"

- Depends on how the Regulation will develop
  - alternative production or additional processes that could be deployed to produce by-products that will lead to reduction of on-site emissions only (i.e. fuel substitution)





Composition of
BFG, OBF Top Gas, OBF Process Gas, BOFG and COG.

Wet Basis (%vol.)	Blast Furnace Gas (BFG)	Basic Oxygen Furnace Gas (BOFG)	OBF Top Gas (OBF-TG) to CO_2 Capture Plant	OBF Process Gas (OBF-PG) from CO_2 Capture Plant Recycled to BF
H_2	3.63	2.64	8.56	12.64
CO	22.10	56.92	45.69	67.46
CO_2	22.34	14.44	33.89	3.00
N_2	48.77	13.83	10.07	14.86
H_2O	3.15	12.16	1.79	2.04
LHV (MJ/Nm3) - wet	3.21	7.47	6.69	9.87

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

Use of OBF Technology could open up options for production of by-products rather than CCS.

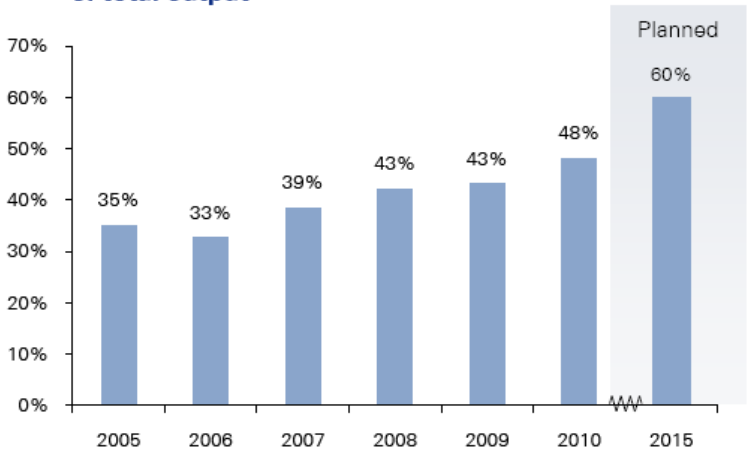
Challenges of CCS Deployment in the Steel Industry

- Market Challenges:
  - To have a successful CCS Deployment in the iron and steel sector ï China should play a bigger role & India should follow afterwards.
    - Currently China produces nearly 46% of global steel production (90% of which are based on BF-BOF routes)
    - China is also struggling in terms of cost competitiveness and overcapacity
    - Currently CCS in the steel sector is not part of their economic planning
    - Availability of Scrap in the next two decades is an important factor that could influence to the deployment of CCS in this sector

Challenges and Important Considerations in the Deployment of CCS in Chinese Steel Industry

- Several Chinese integrated steel mills are one of the most efficient globally.
- Upcoming consolidation of the industry should be expectedé
  - More M&A among different state enterprises.
  - Elimination of inefficient and small steel mills
- Relocation to coastal region has startedé
  - This should represents 40% of steel production in China by 2015.
  - Cost reduction in logistics and redistribution of environmental burdens are the main driversé
- What are the targets for CO_2 emissions reductioné
  - Promoting various efficiency improvement measures ï Is a Definite Yesé
  - **How about CCS(???)**

Output of the top 10 steel groups as a percentage of total output



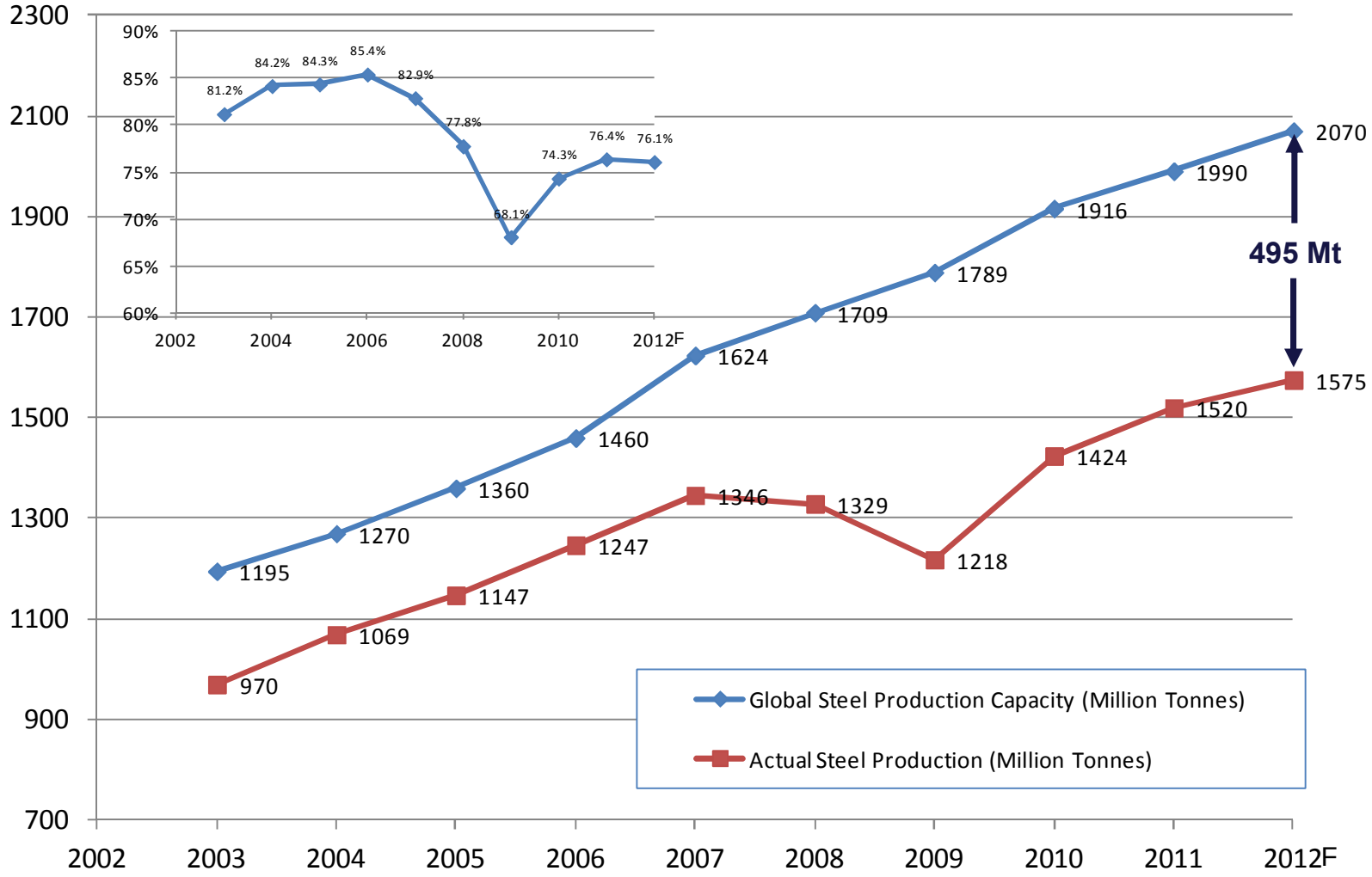
Sources: *(1) China InfoBank*
(2) China Iron and Steel Industry Statistics, 2005-2009

Steel development areas in the 5YP	
Development of key categories	• Steel designed for high-speed railways • High-grade non-oriented silicon steel (used in high-end equipment such as electric motors) • High magnetic induction grain-oriented silicon steel (used in high-end equipment such as transformers) • High-strength mechanical steel
Key technology development	• Non-blast furnace technology • Clean steel production
Carbon reduction technology	• Development of energy management systems • Use of afterheat • Sintering flue gas desulfurization
Access to raw materials	• Develop a resource base for key supplies (e.g. – iron ore)

Source: *China's 12th Five-Year Plan, Chapter 9*

CCS Challenges - Capacity Under Utilisation

(Data from Worldsteel Association, OECD)

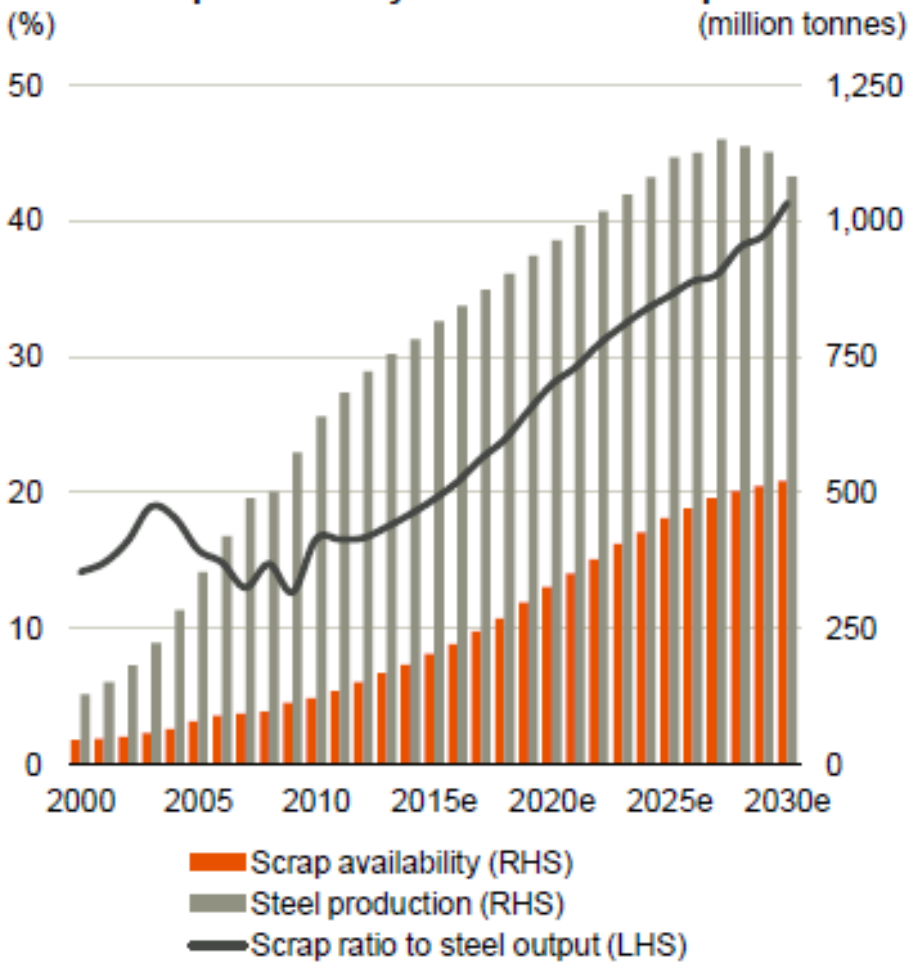


China has an overcapacity of nearly 200 million tonnes in 2012

Scrap usage in China will increase substantially

- Scrap availability in China is expected to quadruple from 2010 to 2030
- Increased usage of scrap in basic oxygen furnaces will see pig iron growth rates decline
- Electric arc furnaces are expected to contribute a significant share of total Chinese steel production by 2030

China scrap availability to total steel output



Source: BHP Billiton; World Steel Association.

Summary

- CCS will play an important role in CO_2 emissions for the steel industry.
  - Cost study presented helped us understand the economics of deploying CO2 capture technology in an integrated steel mill
- Demonstration is needed and this is only the first step.
- Addressing the market competitiveness is important
- Carbon market alone will not promote CCS deployment
  - This should be a mixture of different policies and regulations to make it work.
  - Global sector agreement is possibly a necessary step to develop a level playing field.
- China will play an important role to future CCS deployment

Thank You

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