Challenges to the Deployment of CCS in the Energy Intensive Industries

(Part 1: Iron and Steel Sector)

Stanley Santos

IEA Greenhouse Gas R&D Programme

Cheltenham, UK

CHINESE STEEL INDUSTRY DEPLOYMENT OF CCS… WHAT ARE THE CHALLENGES???

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Regional Ironmaking Capacity in China

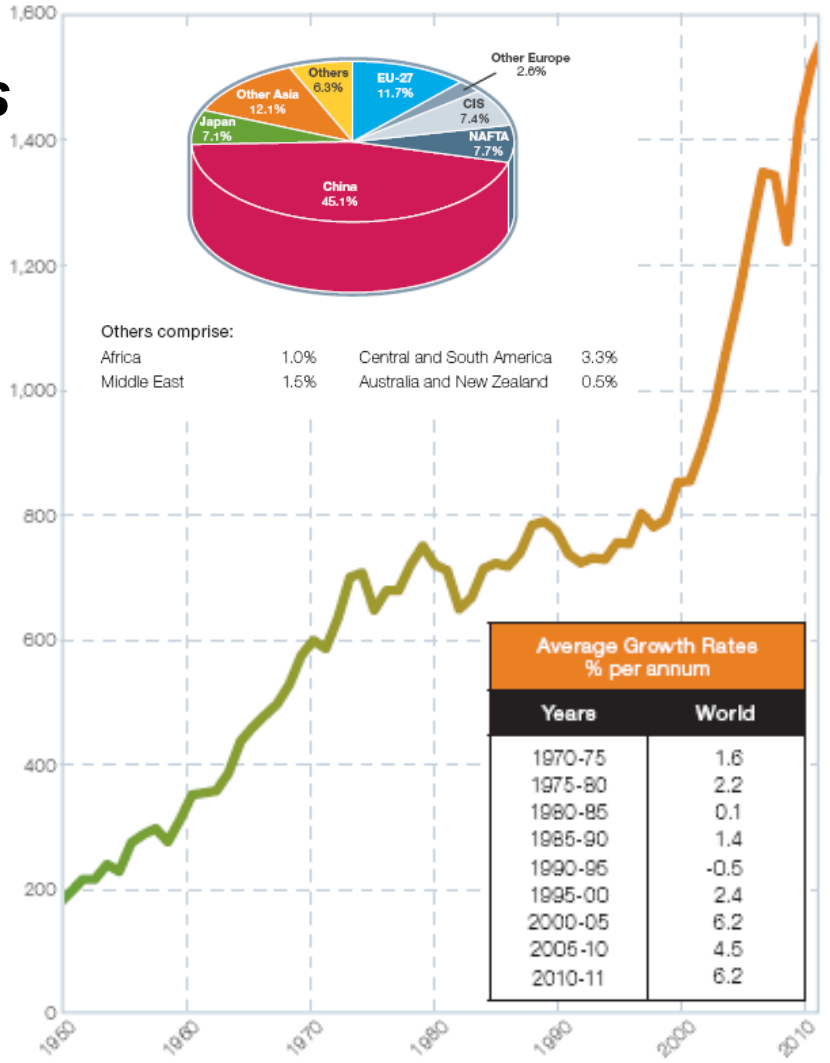
ArcelorMittal

Except for Tibet and Hainan Island, all 31 provinces and administrative regions have ironmaking facilities

World Crude Steel Production

(Data and Figure from World Steel)

- ***Total Crude Steel Production has reached 1.49 Billion Tonnes of crude steel in 2011.***
  - As compared to 2001 crude steel production has increased by ~80% from 851 million tonnes
- ***Major Steel Producing Regions***
  - China (683.3 million tonnes)
  - EU27 (177.4 million tonnes)
  - NAFTA (118.9 million tonnes)
  - CIS (112.4 million tonnes)
  - Japan (107.6 million tonnes)
  - India (72.2 million tonnes)

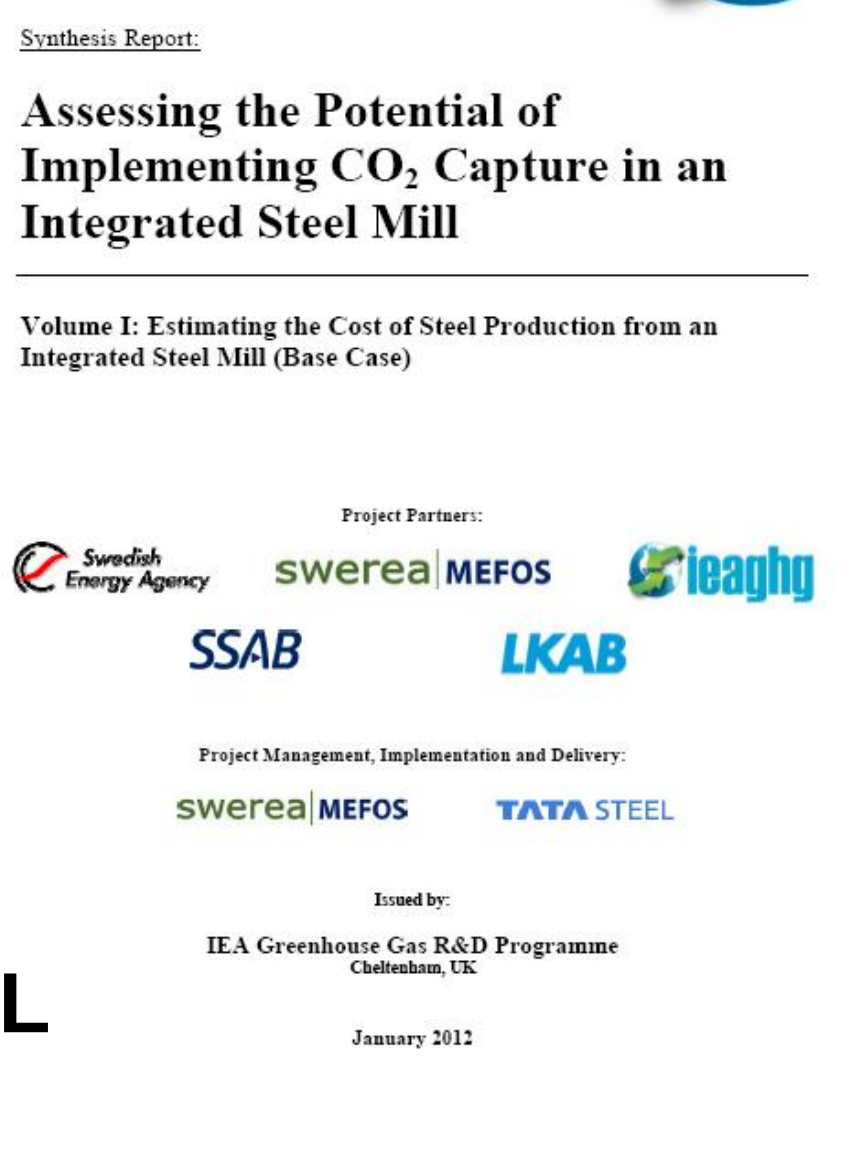


Top 10 Steel Producers in the World

(Data from World Steel Association)

	2001		2011	
Global Steel Production (in tonnes)	851,073,000		1,490,060,000	
Top 10 Producers (in million tonnes)	Arcelor (now w/ AM)	43.1	ArcelorMittal (AM)	97.2
	POSCO	27.8	Hebei Group	44.4
	Nippon Steel	26.2	Baosteel Group	43.3
	Ispat Int'l (now w/ AM)	19.2	POSCO	39.1
	Shanghai Baosteel	19.1	Wuhan Group	37.7
	Corus (now w/ Tata)	18.1	Nippon Steel	33.4
	ThyssenKrupp	16.2	Shagang Group	31.9
	Riva	15.0	Shougang Group	30.0
	NKK (now w/ JFE)	14.8	JFE	29.9
	Kawasaki (now w/ JFE)	13.3	Ansteel Group	29.8

CHALLENGES OF DEPLOYING CCS IN AN INTEGRATED STEEL MILL



Synthesis Report:

Assessing the Potential of Implementing CO_2 Capture in an Integrated Steel Mill

Volume I: Estimating the Cost of Steel Production from an Integrated Steel Mill (Base Case)

Project Partners:

Swedish Energy Agency · swerea MEFOS · ieaghg · SSAB · LKAB

Project Management, Implementation and Delivery:

swerea MEFOS · TATA STEEL

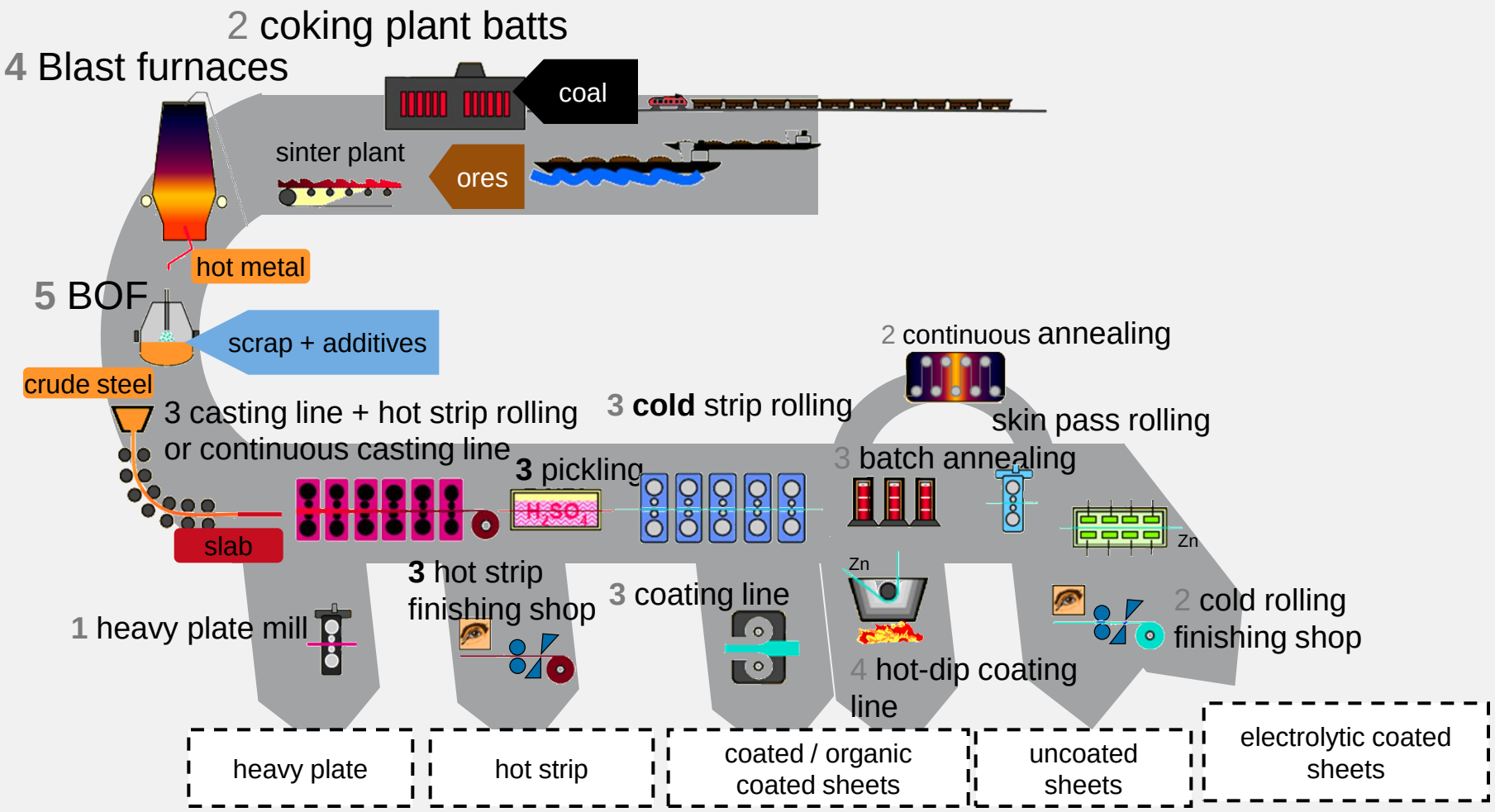
Issued by:

IEA Greenhouse Gas R&D Programme
Cheltenham, UK

January 2012

An integrated steel mill is composed by numerous facilities

From iron ore to steel products



高炉 The Pioneer and Leader: Baosteel

ArcelorMittal

Baosteel: Ironmaking Facilities

- 1 raw materials yard with an annual handling capacity of 0.14 billion tons of materials.
- 3 sinter machines with a 495 m^2 grate area each. Annual sinter production is 17.7 million tons.
- 12 coke batteries with 50 ovens each. Annual coke production is 5.35 million tons.
- 4 BFs with an inner volume 4,000 – 5,000 m^3. Annual hot metal production is 15 million tons.
- 2 Corex-3000. Annual hot metal production for No. 1 Corex is 1.1 million tons.

Baosteel: No. 1 Blast Furnace KPIs

1BF	Productivity t/d.m^3	PCI kg/tHM	Coke rate kg/tHM	Fuel rate kg/tHM
1998	2.121	140.2	348.7	498.3
1999	2.263	237.9	265.1	503.0
2000	2.290	228.3	269.0	497.3
2001	2.281	234.1	262.8	496.8
2002	2.293	233.9	262.2	496.1
2003	2.221	209.3	286.1	495.4
2004	2.237	211.7	287.0	498.6
2005	2.181	202.5	295.6	498.3
2006	2.213	204.1	288.5	492.5

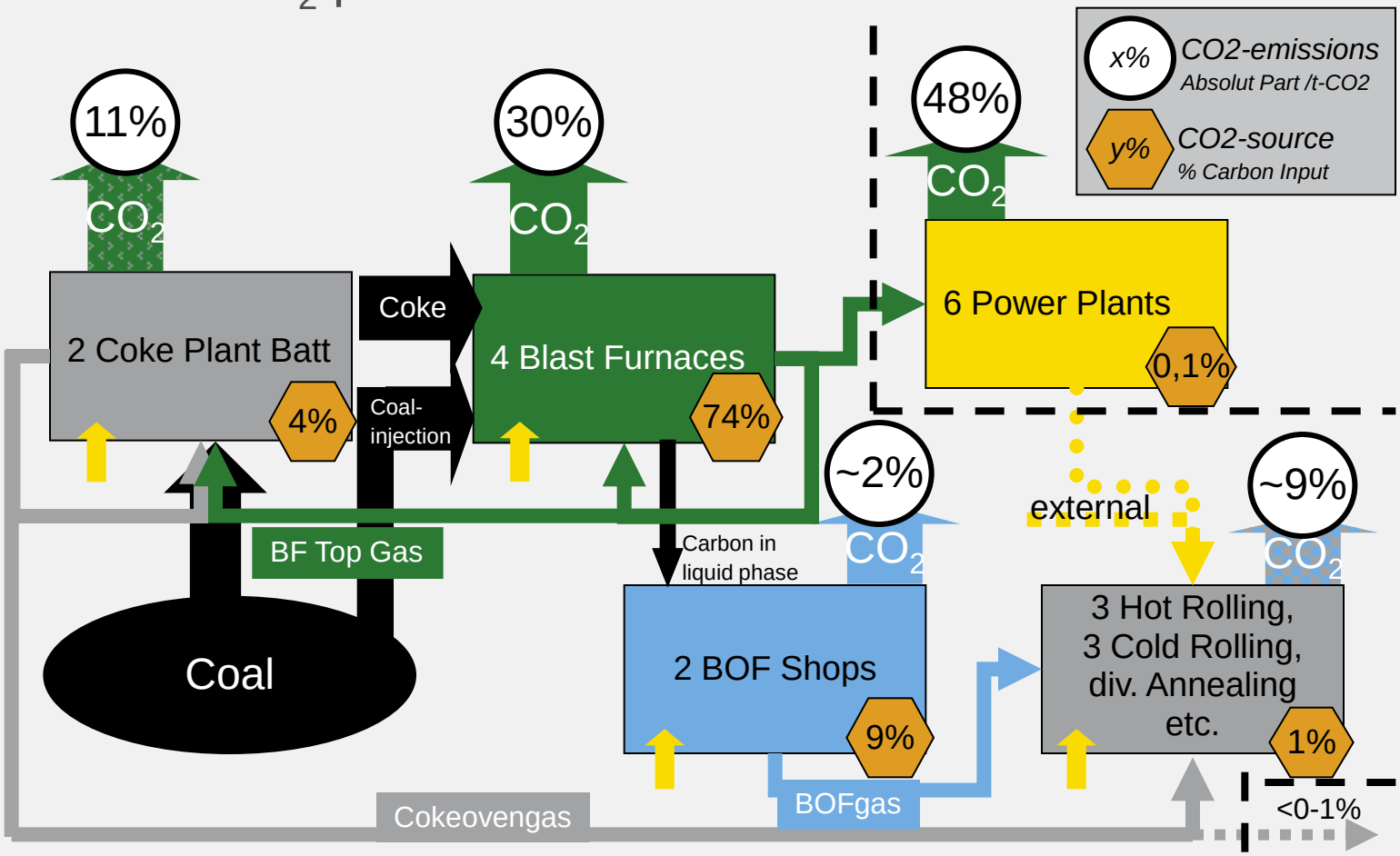
ThyssenKrupp

First Challenge...

- ***There are no steel mill in this world which are alike...***
  - Steel are produced with different processes
  - Steel are produced with different type of finished or semi-finished products
  - Steel are produced with different grades
  - ...

ThyssenKrupp Steel Europe – Main CO_2-Emitters (schematically)

up to 20 mio t CO_2 p.a.

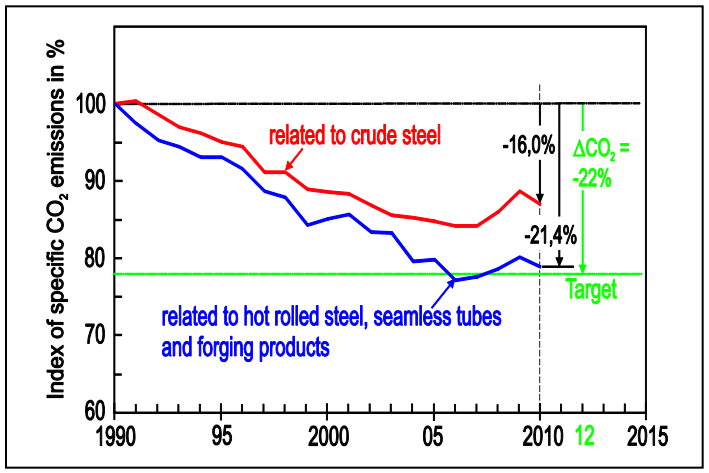


2nd and 3rd Challenges...

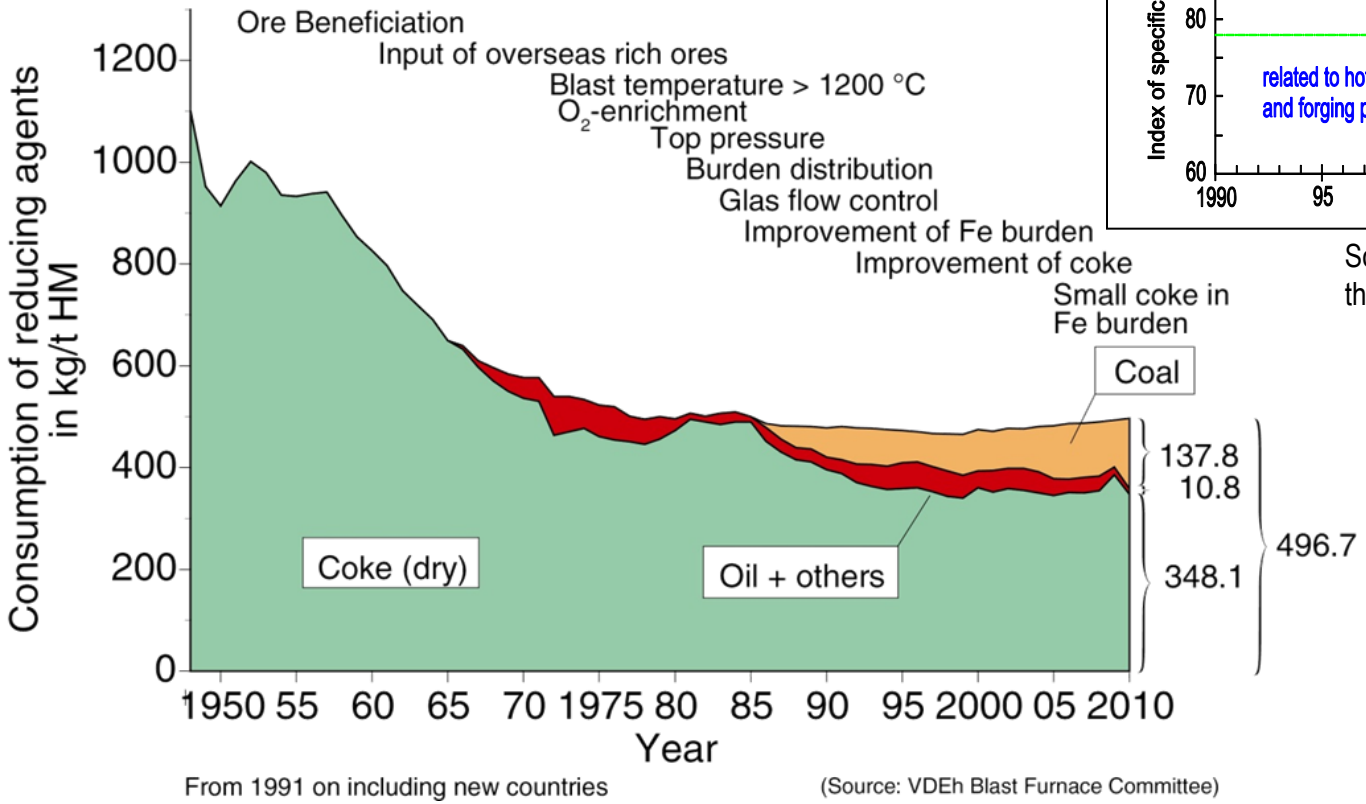
- ***There are no steel mill which are alike...***
- ***Emissions from the Integrated Steel Mills comes from multiple sources.***
- ***The source of CO_2 may not be the emitter of the CO_2.***
  - Strongly dependent on how you define Boundary Limit
  - In addition to the direct use of fossil fuels, the emissions is also strongly dependent on the management of the use of By-Product Gases

4th Challenge...

BF Technology is already near the Theoretical Limit of Efficiency



Source: 10th CO_2 monitoring report of the steel industry in Germany



From 1991 on including new countries

(Source: VDEh Blast Furnace Committee)

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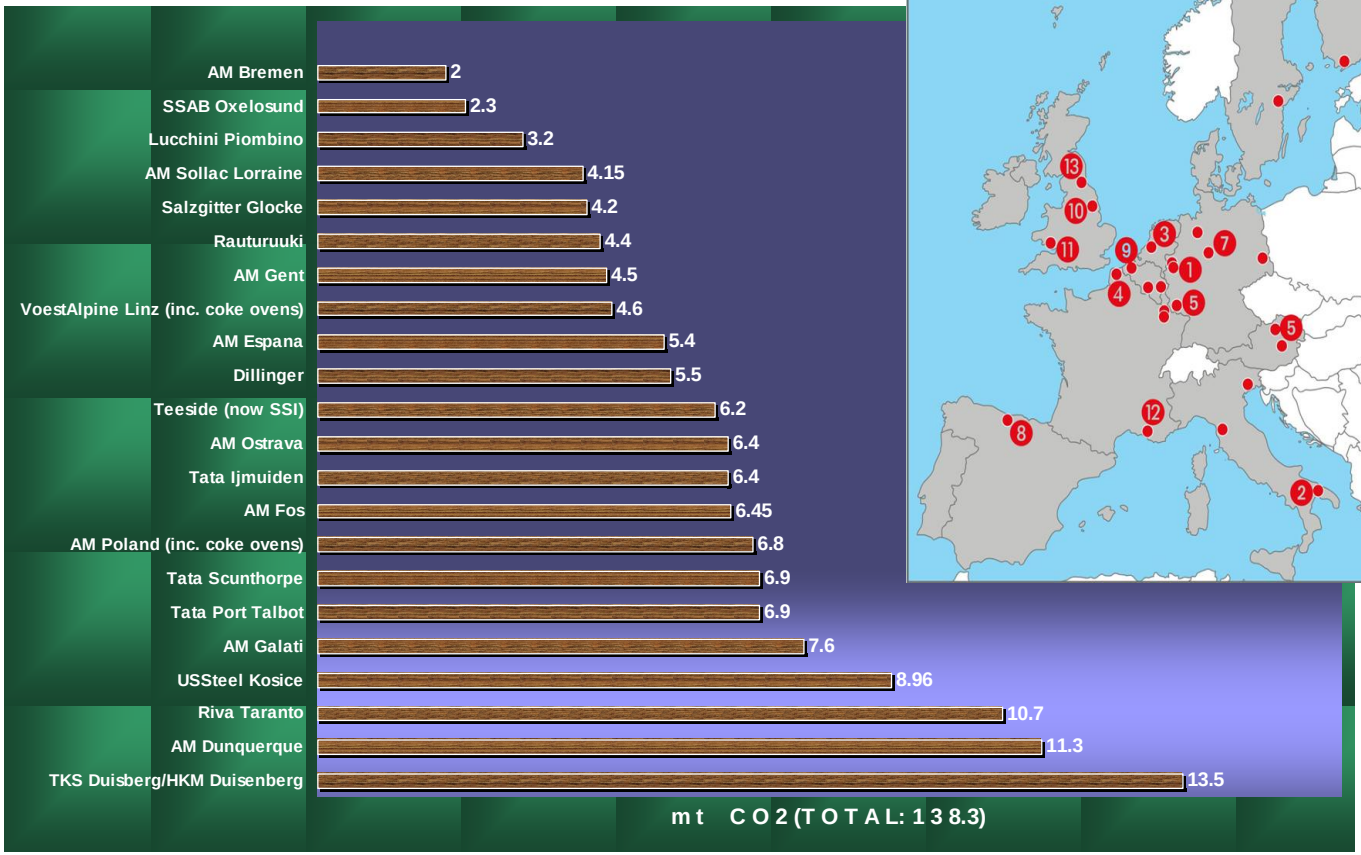
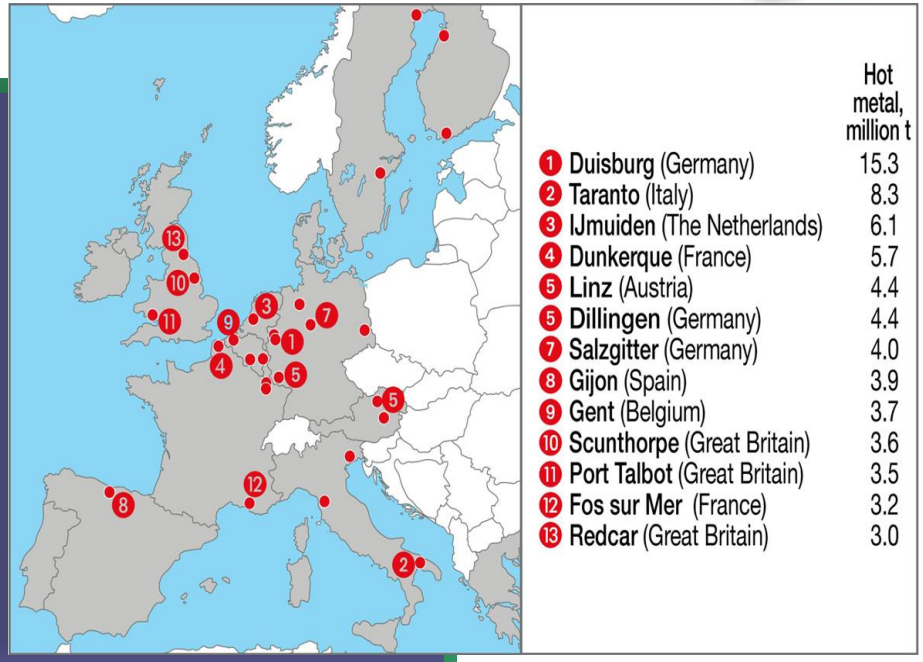
22 Sites with > 2 MT CO2 Emissions (2008)
(Data from C. Beauman – EBRD)





- ***5th Challenge…***

  Amount of CO_2 captured per site could be far greater than what we get from a single site of coal fired power plant.

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Jingtang Steel: The New Kid on the Block

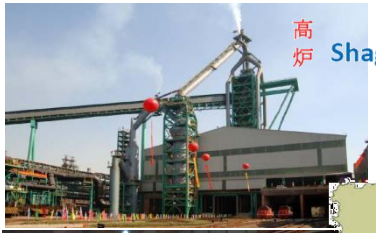
On February 21, 2012, Shougang Jingtang Steel achieved a record for daily hot metal production (total 26,900 metric tons). **~9.9 MTPY Hot Metal**

Largest dry-dedusting equipment in the world

Pioneer in Top Fired Hot Stoves reaching 1315°C

Design Features of 2 x 5,500 m³ BFs

Parameter	Factor	Parameter	Factor
Effective inner volume	5,500 m^3	Blast temperature	1,300°C
Productivity	2.3t/m^3/d	Number of tuyeres	42
Annual production capacity	8.98MM t	Top pressure	0.28 MPa
Coke rate	290 kg/t	Oxygen enrichment ratio	3.5%,
Coal injection rate	200 kg/t	Overall smelting rate	1.035 t/m^3/d
Fuel rate	490 kg/t	Clean gas dust concentration	5 mg/m^3
Sintered and/or pelletized charge in burden	90%	TRT power generation	45 kWh/t
Overall Fe content of the charge	61%	Ironmaking process energy consumption	404 kgce/t
Slag ratio	250 kg/t	One generation campaign life	25 years
Number of tapholes	4		



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Shagang: Bigger Is Better

Shagang:
Record Production with the World's Largest (5,800 m³) BF…and Still Growing

Design Features

	Design	Maximum
Inner volume, m^3	5,800	
Daily production, thm/d	12,876	14,500
Productivity, thm/m^3/d	2.22	2.50
Wind, Nm^3/min	8,300	9,500
Blower discharge P, KPa	520	550
Top pressure, KPa	250-280	300
Hot blast temperature, C	1,250	1310
Coke rate, kg/thm	< 290	
PCI, kg/thm	> 200	250
Slag rate, kg/thm	< 300	
Fe% in ores	> 59	
Metallic burdens	77%Sinter + 18%PE + 5%Ore	
Campaign life, years	> 20	
Stove lifespan, years	30	

In September 2011, their 5,800 m^3 blast furnace achieved a daily record for hot metal production of **14,500** metric tons.

Company target is 15,000 tons of hot metal per day.

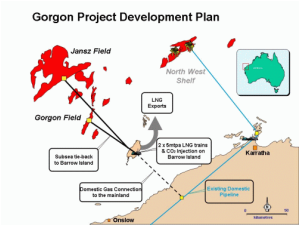
Industry Application of CCS (to date)

Sleipner
1Mt/y CO_2

Weyburn
2.5 Mt/y CO_2

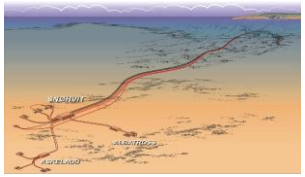
In-Salah
1.2 Mt/y CO_2

Snohvit
0.7Mt/y CO_2



Gorgon
3Mt/y CO_2

350km overland pipeline



160km sub sea pipeline

WE HAVE NOT DONE ENOUGH THAT IS REQUIRED BY THE STEEL INDUSTRY TO DEPLOY CCS

1996 1998 **2000** 2002 **2004** 2006 **2008** 2010 2012 2014 2016 2018

Essential to CCS Deployment

- Accounting of CO_2 Emissions that could be comparable is an Essential Activity for Deployment of CO_2 Capture Technology in the Iron and Steel Sector.
- Accounting of CO_2 Emissions should be based on a globally consistent methodology that will allow production normalised CO_2 emission comparable between regions that are not possible today.
- This should result to a better benchmarking – therefore providing a meaningful number for CO_2 Avoidance Cost.

IEA Greenhouse Gas Study – Brief Overview and Key Results

UNDERSTANDING THE COST OF INCORPORATING CO_2 CAPTURE IN AN INTEGRATED STEEL MILL

Acknowledgement

- ***PROJECT PARTNERS***

Swedish Energy Agency

swerea | MEFOS

SSAB

LKAB

ieaghg

- ***PROJECT DELIVERY***

swerea | MEFOS

TATA STEEL

SINTEF

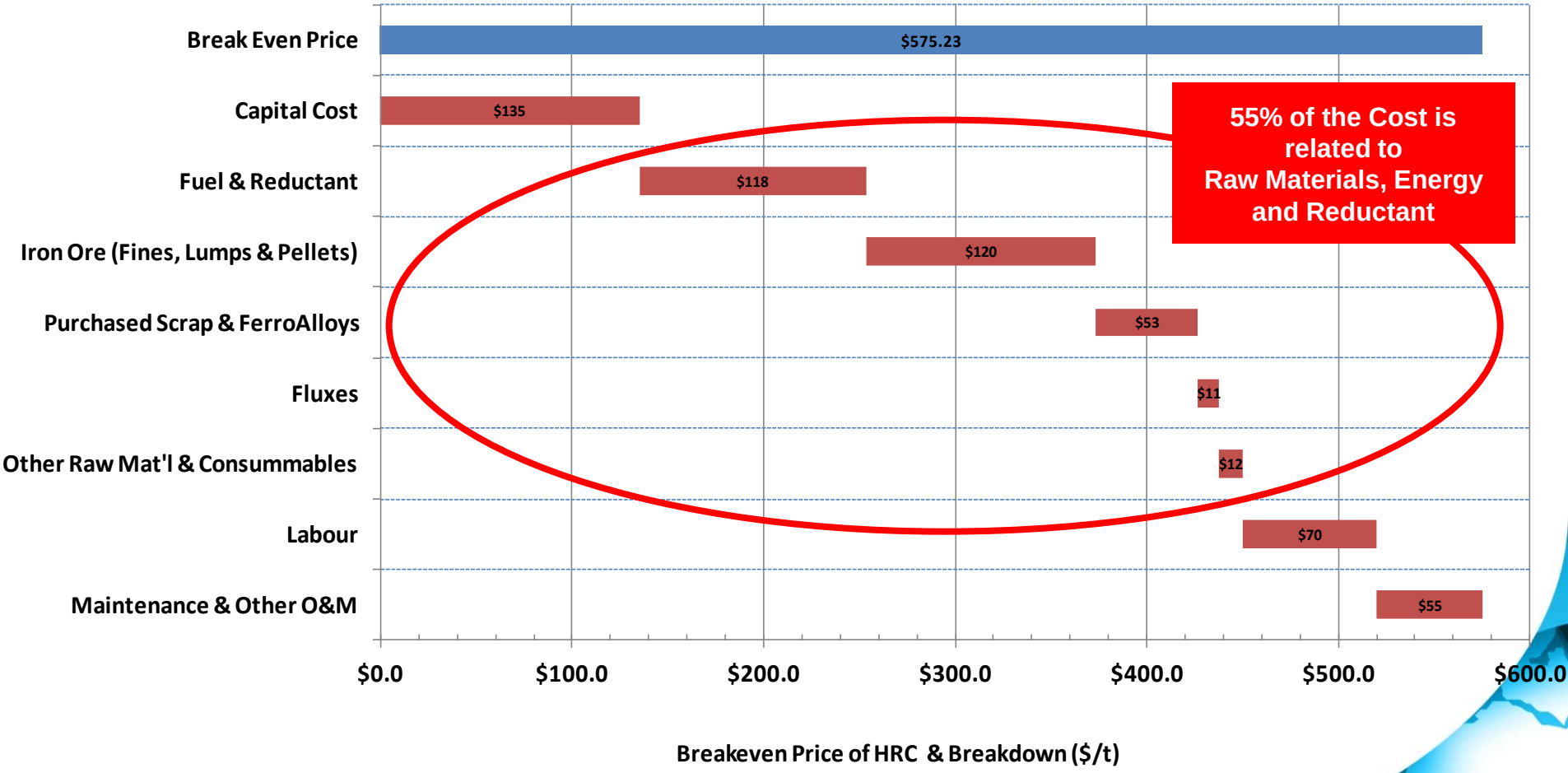
Total value of the Project: ~4.4 million SKr
IEA GHG Contribution: ~1.2 million SKr

Objectives of the Study

- ***To specify a "REFERENCE" steel mill typical to Western European configuration and evaluate the techno-economic performance of the integrated steel mill with and without CO_2 capture.***

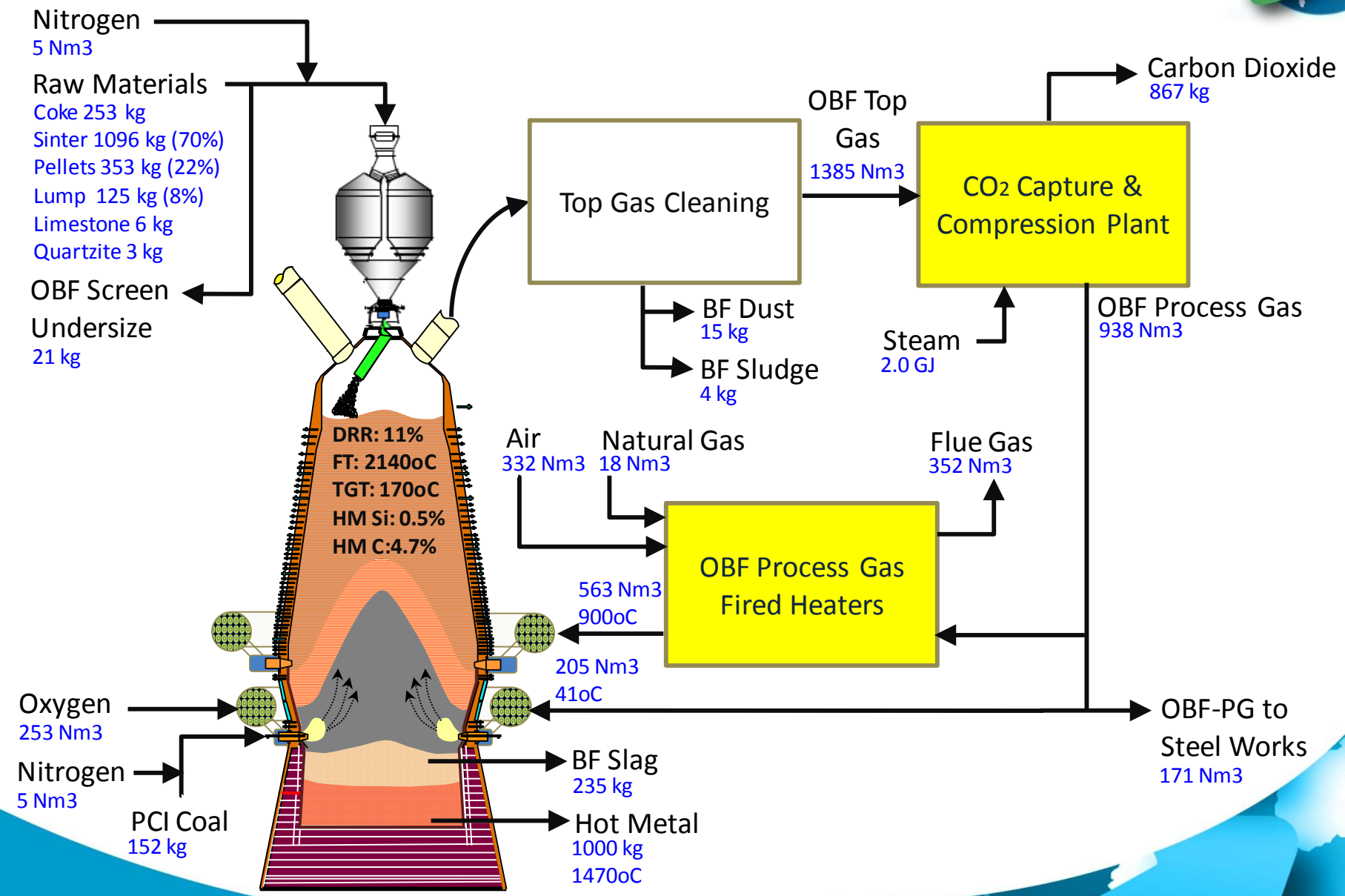
- ***To determine the techno-economic performance, CO_2 emissions and avoidance cost of the following cases:***
  - An integrated steel mill typical to Western Europe as the base case.
  - An end of pipe CO_2 capture using conventional MEA at two different levels of CO_2 capture rate
  - An Oxygen Blast Furnace (OBF) and using MDEA for CO_2 capture.

Cost of Steel Production - Breakdown



Oxy-Blast Furnace Operation

(Picture of OBF courtesy of Tata Steel)



Impact of the OBF/MDEA CO_2 Capture Plant to the Breakeven Cost of HRC Production

(Very Specific to this Study & Cost Does Not include Transport & Storage)

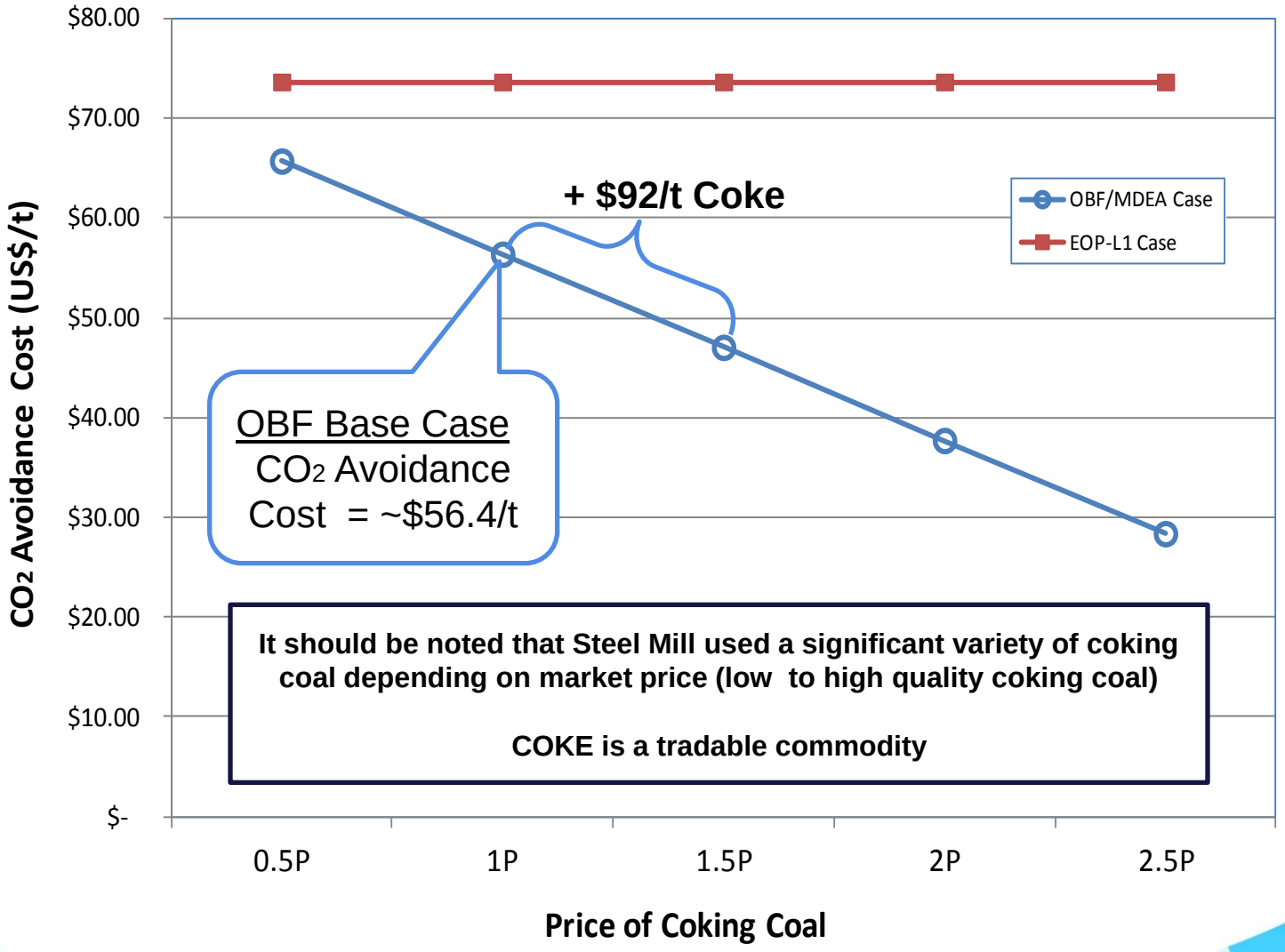
Breakevan Cost of HRC Production for OBF @ $630/t

(An Increase of $55/t as compared to the REFERENCE Plant)

- ***Capital Cost*** — ***increased by 18.8%***
- ***Fuel and Reductant Cost*** — ***increased by 17.3%***
  - Coking Coal Cost – decreased by ~24%
  - Natural Gas Cost – increased by ~495%
- ***Iron Burden Cost*** — ***increased by 1.0%***
  - Iron Ore (Fines, Lumps and Pellets), Purchased Scrap & Ferroalloys
- ***Fluxes Cost*** — ***decreased by 9.4%***
  - Significant reduction of limestone and quartzite consumption
- ***Other Consumable Cost*** — ***increased by 15.7%***
  - Increased in cost of raw water consumption
  - Additional cost due to Chemicals & Consumables used by SGP.
  - Additional cost due to MDEA/Pz Solvent Make Up
- ***Labour Cost*** — ***increased by 1.4%***
- ***Maintenance and Other OPEX*** — ***increased by 10.4%***

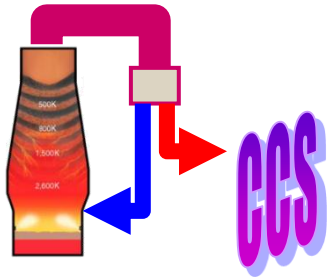
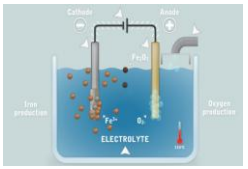
Summary of Results

(Sensitivity to Coke Price)

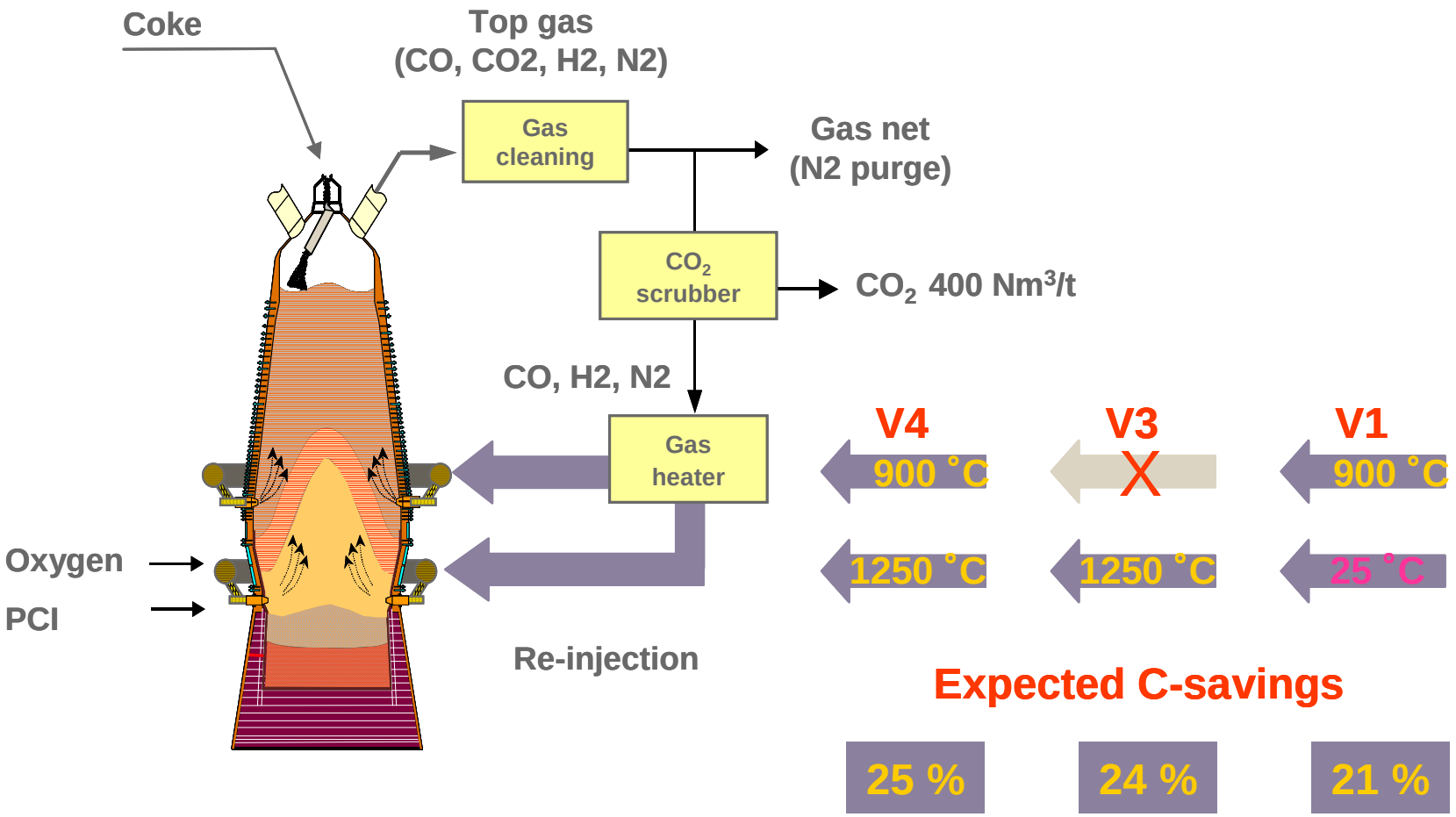


OVERVIEW OF SOME OF THE MAJOR CCS R&D PROJECTS WORLDWIDE

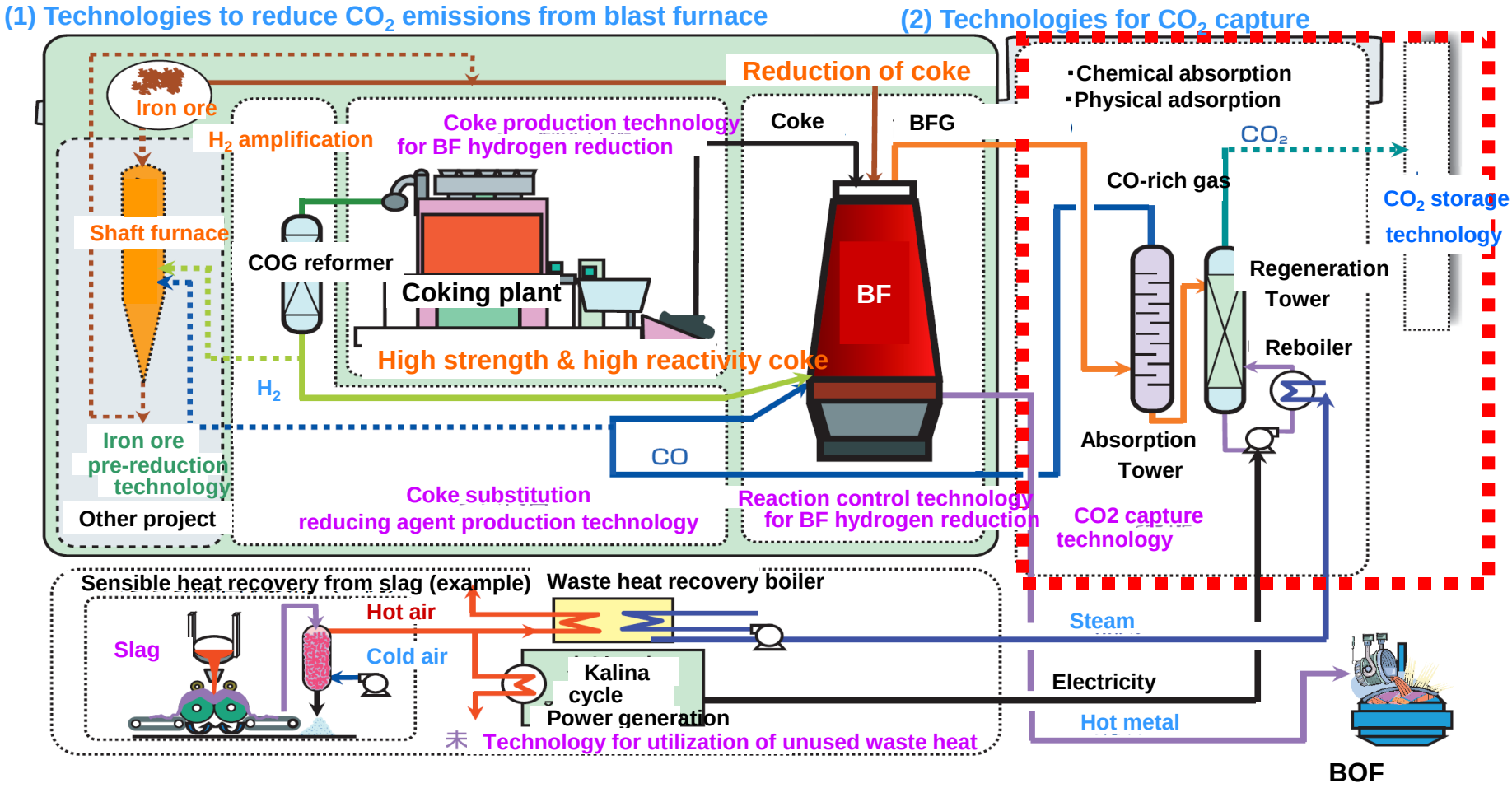
The 4ulcos process routes

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

The Ulcos Blast Furnace Concepts



Project Outline

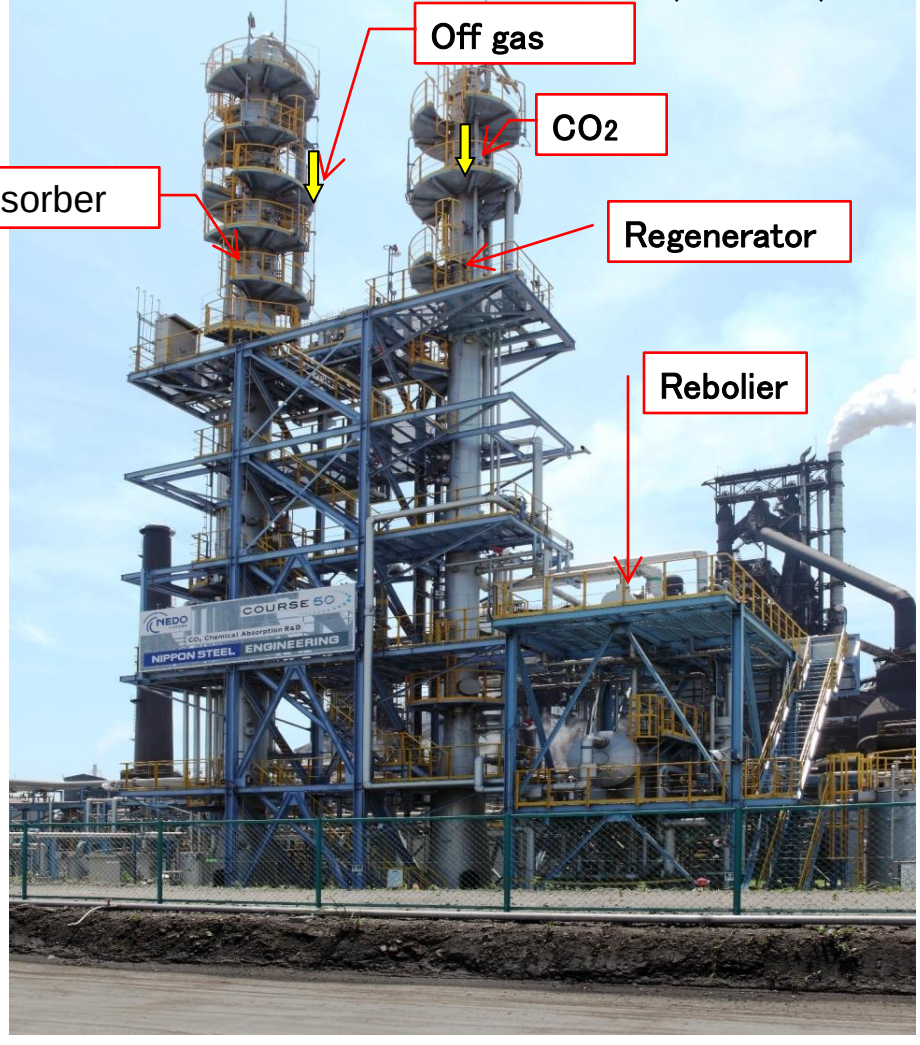


COURSE50 ／ CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50

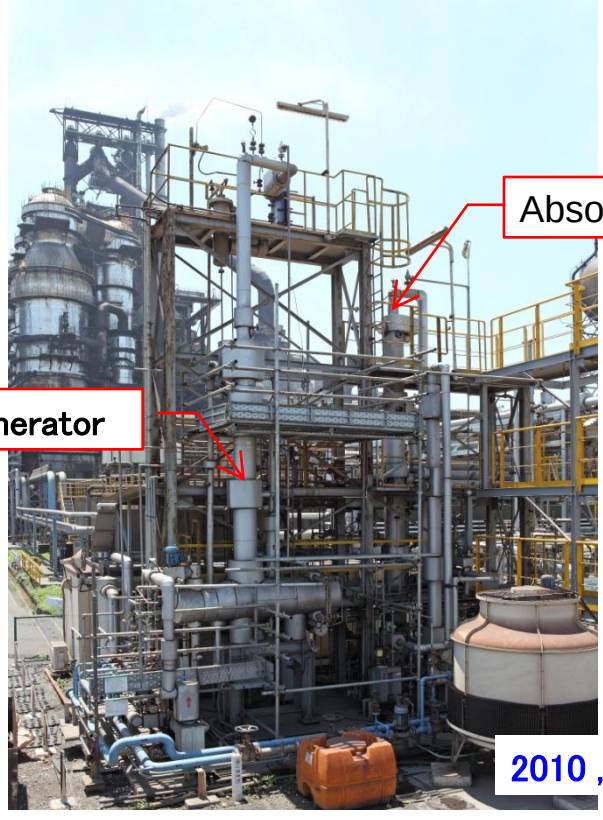
Development of the chemical absorption process

Nippon Steel Kimitsu Works No. 4BF

Test Equipment:
Process Evaluation Plant（30t/D）

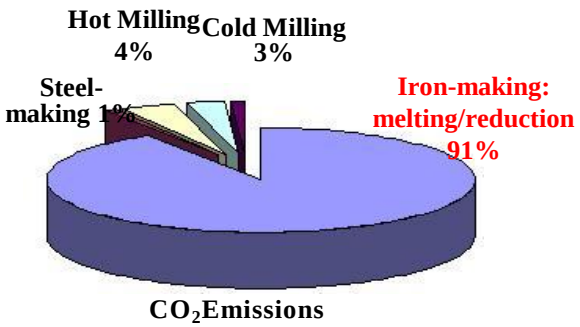


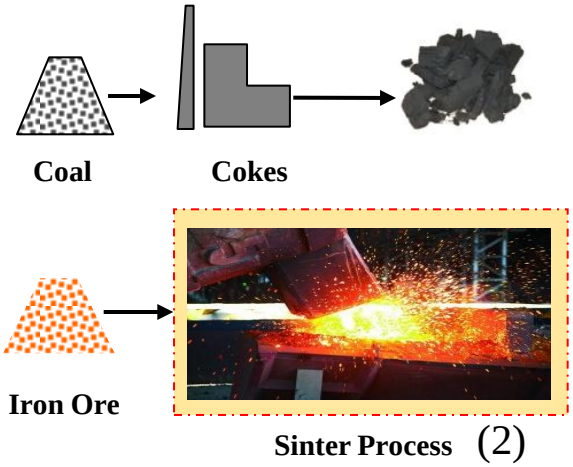
Bench Plant（1t/D）

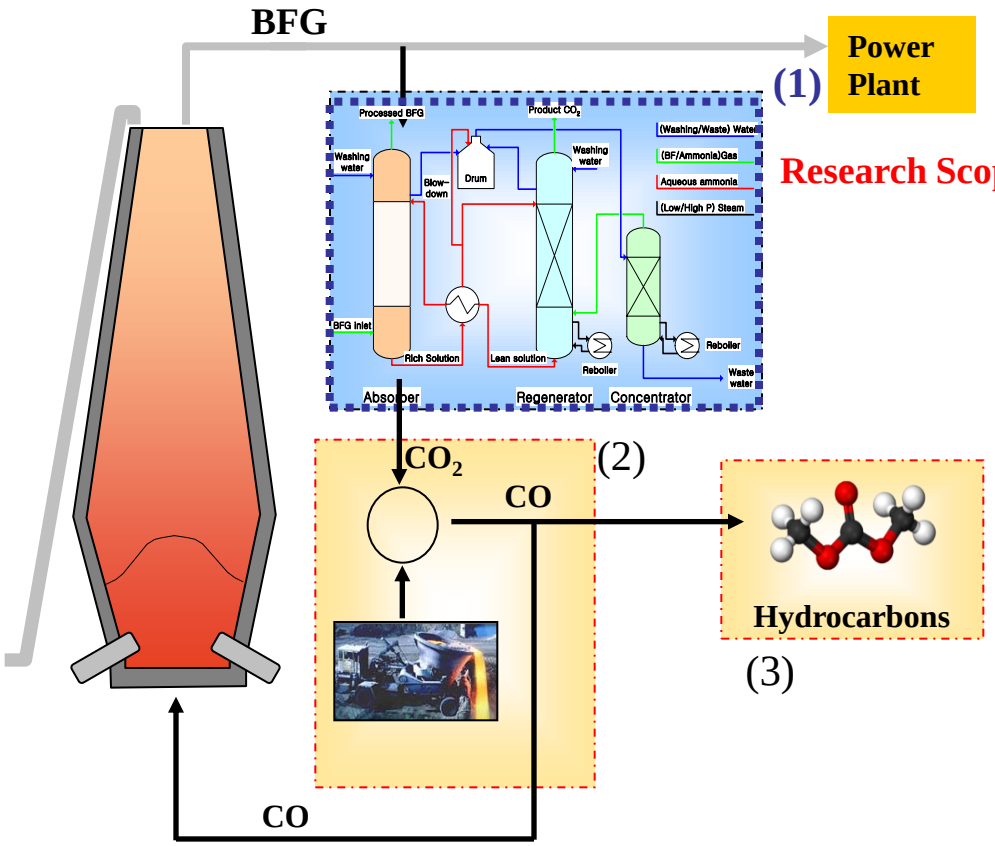


2010 ,17 June

Ideas/Projects for CO_2 Reduction





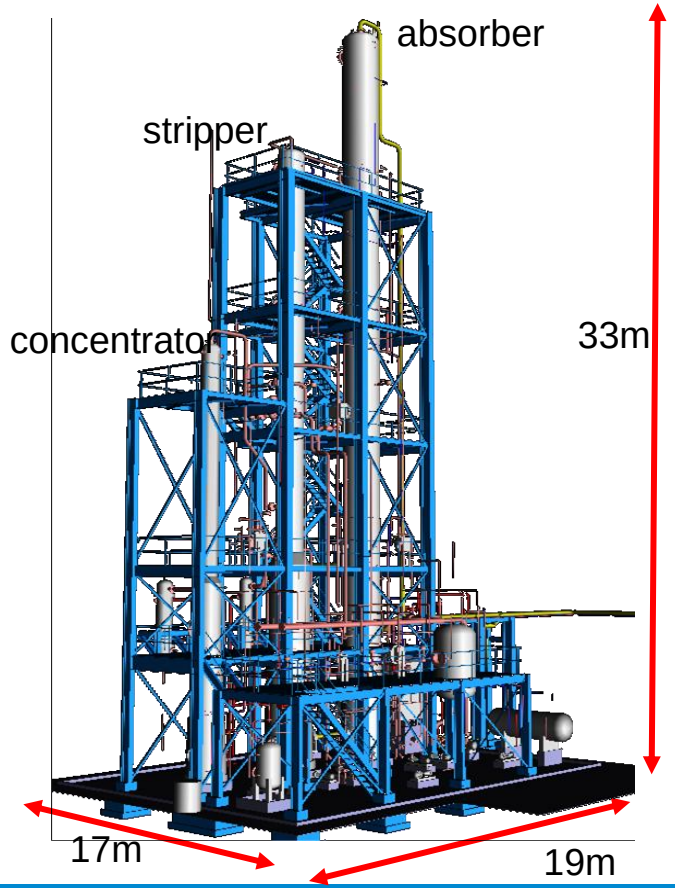


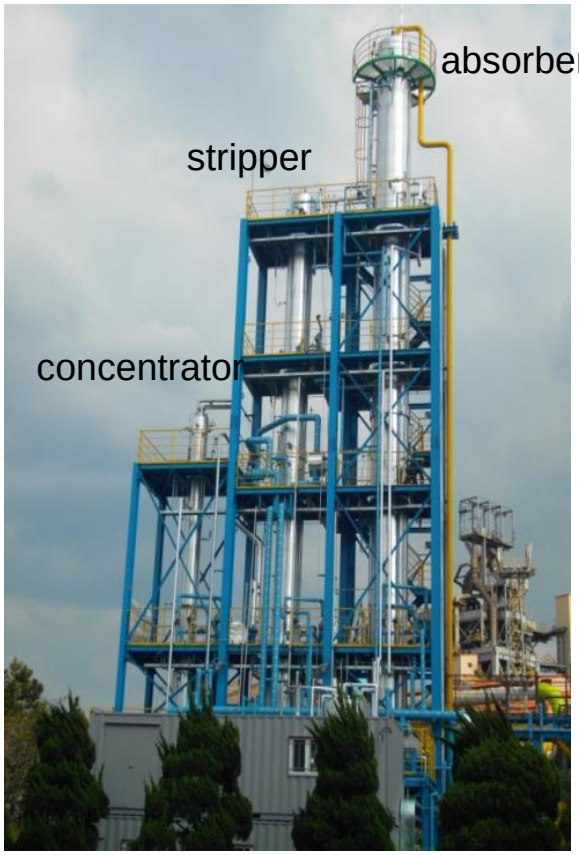
- Research Activities of CO_2 Project in RIST
  - (1) CO_2 Capture from BFG stream using aqueous ammonia
  - (2) Waste heat recovery from molten slag and hot sinter
  - (3) CO_2 utilization

2nd Stage pilot plant

Operation of 2nd stage pilot plant (May. 2011~)

- Development of CO_2 capture process for commercialization using aqueous ammonia in iron & steelmaking In
  - Utilizing the waste heats at low and mid-temperature waste heat as regeneration energy
  - Ultimate goal: CO_2 removal > 90%, CO_2 purity > 95%, energy requirement < 2.0 GJ/ton-CO_2





- Dimensions
  : Absorber
  - D 1.4m, H 27m
  : Stripper
  - D 0.9m, H 20.6m
  : Concentrator
  - D 0.5m, H 11.7m
- Capacities
  : 1000 Nm^3-BFG/hr
  as 0.5 MW
  (CO_2 conc: 20~25%)

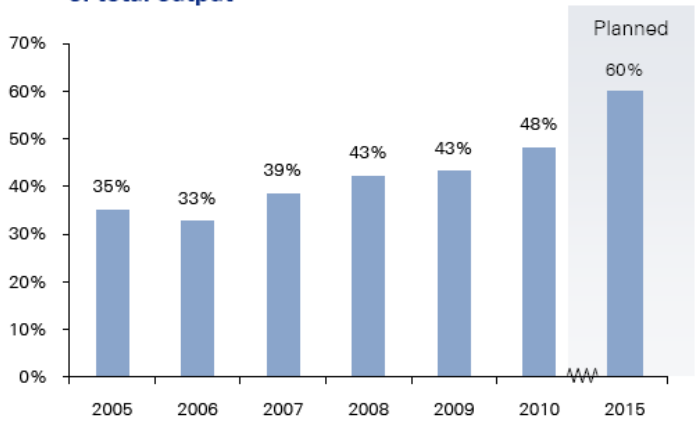
Concluding Remarks…

- ***CCS is an important technology for the steel industry to achieve deep CO_2 reduction.***
- ***We have recognised the different challenges to CCS deployment in the steel industry.***
- ***Demonstration is required to validate and gain the confidence in CCS for iron and steel production.***
  - It would take time to fully demonstrate its technical viability.
- ***Addressing storage requirement is an important aspect in the deployment of CCS in steel industry***
- ***We are only starting to understand the economics of CCS deployment in the steel industry…***
  - Study done by IEAGHG – providing detailed information on the techno-economics of incorporating CO_2 capture in an integrated steel mill is just touching the surface.

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

- ***Chinese integrated steel mills are one of the most of efficient globally.***
- ***Upcoming consolidation of the industry should be expected…***
  - More M&A of state enterprise.
  - Elimination of inefficient and small steel mills
- ***Relocation to coastal region has started…***
  - This should represents 40% of steel production in China by 2015.
  - Cost reduction in logistics and redistribution of environmental burdens are the main drivers…
- ***What are the targets for CO_2 emissions reduction…***
  - Promoting various efficiency improvement measures – Is a Definite Yes…
  - 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

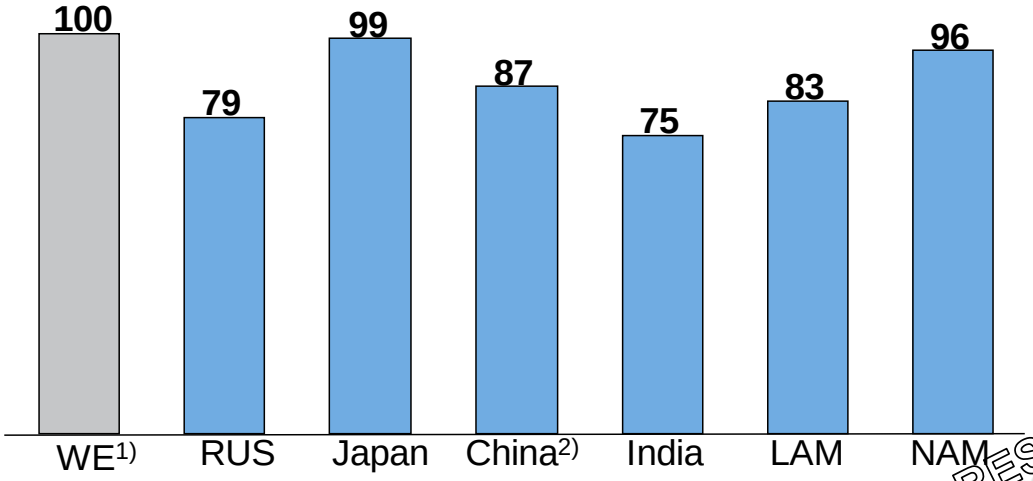
Development of key categories	• Steel designed for high-speed railways • High-grade non-oriented silicon steel (used in high-end equipment such as electric motors) • High magnetic induction grain-oriented silicon steel (used in high-end equipment such as transformers) • High-strength mechanical steel
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

Cash-costs slab, BOF-route, 2010/11 (% costs / t)

Data from TKS Presentation at 1st IEAGHG Iron and Steel CCS Workshop

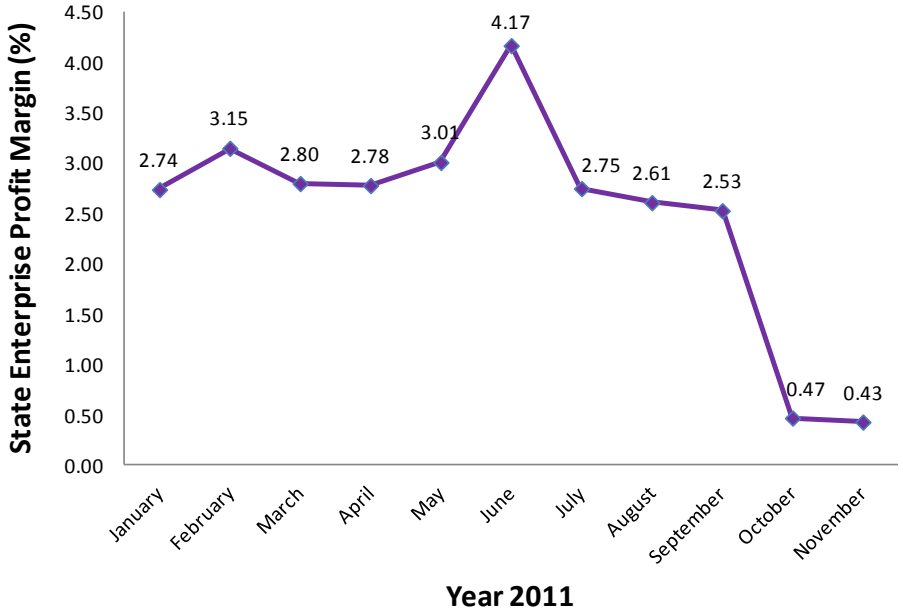
Calculation:
1,40 US-Dollar is 1,00 Euro
1) Western Europe
2) Exporting Producer



TO DEPLOY CCS WOULD REQUIRE ADDRESSING MARKET COMPETIVENESS

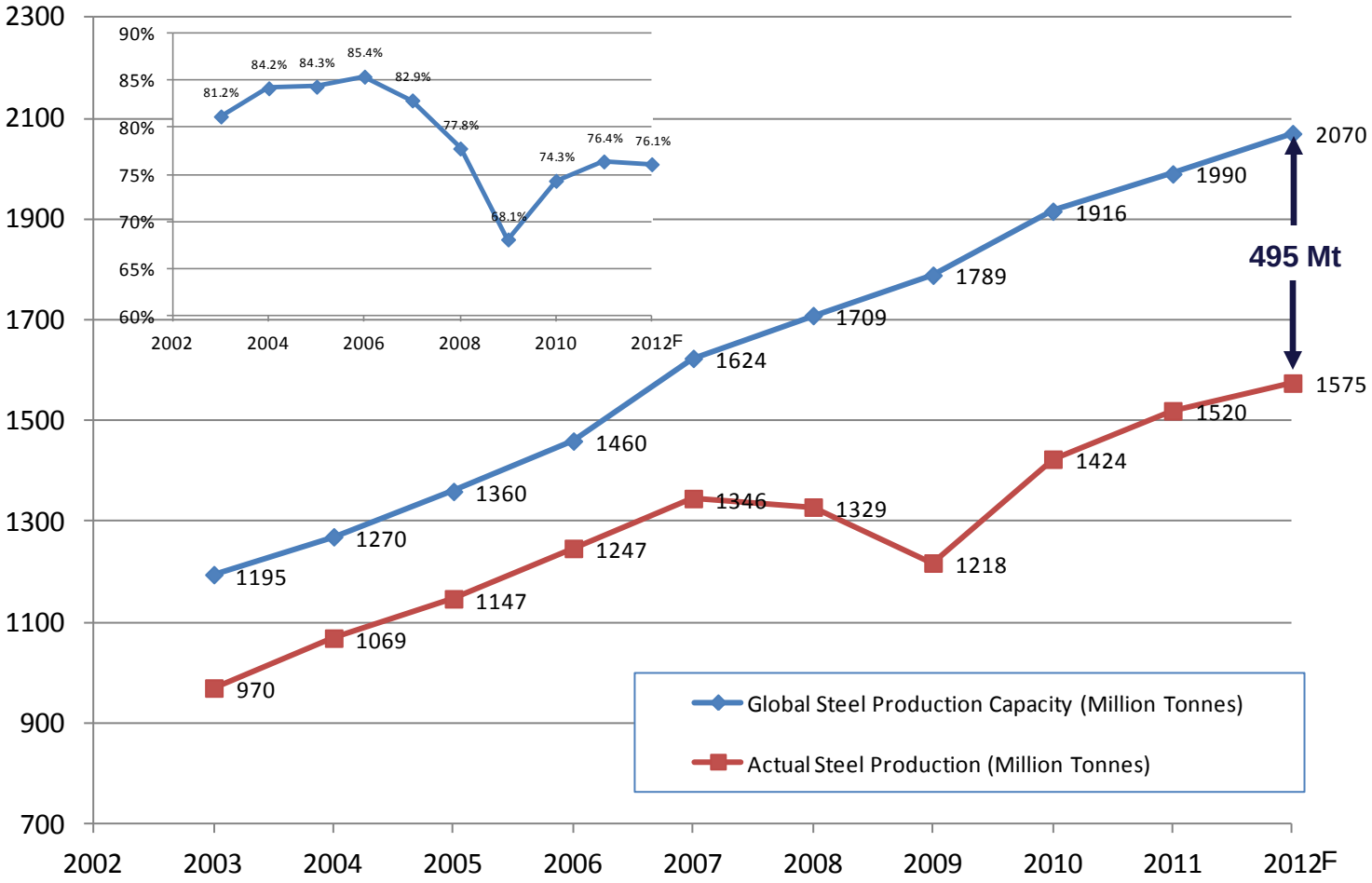
Profit Margin of All State Enterprise

Data from Chinese Iron and Steel Association



CCS Challenges - Capacity Under Utilisation

(Data from Worldsteel Association, OECD)



China has an overcapacity of nearly 200 million tonnes in 2012

Acknowledgement