CCS – Necessary Action to Reduce CO₂ 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 CO₂ Capture & Storage in the Energy Intensive Industries?
Nearly half of the 123 Gt CO$_2$ by 2050 should be from industrial applications

**Key point**

Between 2015 and 2050, almost 123 Gt CO$_2$ 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.
Global CO₂ Emissions from Industrial Sources
(Data from IEA ETP 2012)

Figure 3. Proportion of CO₂ generated globally that is captured and stored through CCS in the sectors analysed in the 2DS

By 2050 - 38%, 35% & 28% of global CO₂ 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 issue 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

MODERN STEELMAKING PROCESSES

Source: BCG-VDEh

BOF steel

<table>
<thead>
<tr>
<th>Integrated route</th>
<th>Smelting reduction</th>
<th>Direct reduction</th>
<th>Scrap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>Lump ore</td>
<td>Lump ore</td>
<td>Scrap</td>
</tr>
<tr>
<td></td>
<td>Fine ore</td>
<td>Fine ore</td>
<td></td>
</tr>
<tr>
<td>Raw material</td>
<td>Coke</td>
<td>Pallate</td>
<td></td>
</tr>
<tr>
<td>preparation</td>
<td>Coal</td>
<td>Fluidized bed</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Coal</td>
<td></td>
</tr>
<tr>
<td>Iron making</td>
<td>Blast furnace</td>
<td>Shaft furnace</td>
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<tr>
<td></td>
<td>Coal, oil or</td>
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<tr>
<td></td>
<td>natural gas</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Steel making</td>
<td>Hot metal</td>
<td>Hot metal</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casting</td>
<td>Liquid steel</td>
<td>Liquid steel</td>
<td></td>
</tr>
<tr>
<td>Rolling/processing</td>
<td>Liquid steel</td>
<td>Liquid steel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Finished products (flat &amp; long)</td>
<td>Finished products (flat &amp; long)</td>
<td></td>
</tr>
</tbody>
</table>
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 CO₂ Emissions
(An Overview)

![Bar chart showing specific CO₂ emissions for different steel production methods.](chart)

**Current average blast furnace:** basic oxygen furnace
**Best performing blast furnace:** basic oxygen furnace
**Direct reduced iron (gas):** electric arc furnace
**Direct reduced iron (coal):** electric arc furnace
**Scrap: electric arc furnace**

**Range of IEA 2050 Blue map Scenario**

**Specific CO₂ Emissions (kilogram/tonne of crude steel)**

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**Note:** Reported values are for crude steel only (i.e. up to casting) and excludes any emissions from rolling or finishing mills. Variations in the values include the range of CO₂ 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). CO₂ utilisation from gas-based DRI (for example – HYL/Energiron) are not included.

**Source:** Adapted from “IEA Tracking Industrial Energy Efficiency and CO₂ 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

Global Steel CO$_2$ emissions, tCO$_2$/tHRC

Weighted average: 1.86 tCO$_2$/tHRC

Data: CRU Steel Cost Model.
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 – Integrated Steel Mill producing 4MTPY situated at Coastal Region of Europe.

Case 2A: Steel Mill with Post-Combustion CO₂ Capture – capturing CO₂ 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 CO₂ Capture (achieving 47% avoidance)
Summary of Results (CO₂ Emissions)

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

Steel Mill with Post Combustion CO₂ Capture (CASE 2A) (1042 kg per tonne of Hot Rolled Coil)
- CO₂ Captured: 1243 kg/t HRC
- CO₂ Avoided: 50.2%

Steel Mill with OBF, MDEA CO₂ Capture, & TGR (CASE 3) (1115 kg per tonne of Hot Rolled Coil)
- CO₂ Captured: 860 kg/t HRC
- CO₂ Avoided: 46.7%
Carbon Balance of Ironmaking Process

Carbon Input (kg C/thm) | Carbon Output (kg C/thm)
---|---
Coke | 312.4
Limestone | 1.5
PCI Coal | 132.2
COG | 1.3
| | BFG Flared | 5.4
Coke Plant’s Flue Gas | 114.1
Total | 447.5

For this case study, it was demonstrated that the ironmaking process is responsible for 78% of the total carbon input of the steel mill. BUT only 21% of the carbon emitted as CO2 emissions is attributed to this process. The rest of the carbon emitted as CO2 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 CO₂ Capture)

Direct CO₂ Emissions of an Integrated Steel Mill (with OBF & MDEA CO₂ Capture) Producing 4 MTPY Hot Rolled Coil
1115 kg CO₂/t HRC (1124 kg CO₂/thm)

<table>
<thead>
<tr>
<th>Carbon Input (kg C/thm)</th>
<th>Carbon Output (kg C/thm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke</td>
<td>227.7</td>
</tr>
<tr>
<td>Limestone</td>
<td>0.7</td>
</tr>
<tr>
<td>PCI Coal</td>
<td>132.2</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>12.0</td>
</tr>
<tr>
<td>PG Heater Flue Gas</td>
<td>12.0</td>
</tr>
<tr>
<td>CO₂ Captured</td>
<td>236.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>372.7</strong></td>
</tr>
<tr>
<td>Hot Metal</td>
<td>47.0</td>
</tr>
<tr>
<td>BF Screen Undersize</td>
<td>4.6</td>
</tr>
<tr>
<td>Dust &amp; Sludge</td>
<td>8.0</td>
</tr>
<tr>
<td>OBF PG Export</td>
<td>64.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>372.4</strong></td>
</tr>
</tbody>
</table>

Carbon Balance of Ironmaking Process

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 CO₂ emissions could only be achieved by CCS.
The Ulcos Blast Furnace Concepts

Top gas (CO, CO2, H2, N2) -> Gas cleaning -> Gas net (N2 purge) -> CO2 scrubber -> CO2 400 Nm³/t

Coke (CO, H2, N2) -> Re-injection

Oxygen, PCI

Expected C-savings:
- V4: 900 °C -> 25 %
- V3: 1250 °C (X)
- V1: 25 °C -> 24 %
- 21 %
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 CO₂ Capture
(2010 Global Cost Curve Data from Metal Consulting Int’l Ltd.)

- REFERENCE Steel Mill (@ US$575/t HRC)
- Integrated Steel Mill with Post Combustion CO₂ Capture (@US$ 653/t HRC)
- Integrated Steel Mill with OBF/MDEA CO₂ Capture (@US$ 630/t HRC)
Evolution of Coking Coal Price
(Data provided by P. Baruya – IEA CCC)

Source: McCloskey (2011); ABARES (2011a).
Summary of Results
(Sensitivity to Coke Price)

It should be noted that Steel Mill used a significant variety of coking coal depending on market price (low to high quality coking coal)

COKE is a tradable commodity
Key Messages from this Study

Å 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.

Å Post-Combustion CO$_2$ Capture – i.e. capture of CO$_2$ from the flue gases of different stacks within the integrated steel mill - is not a cost competitive option!
   Å This is not the options considered by the global steel community.

Å REPORTING CO$_2$ Avoidance Cost for a complex industrial processes is meaningless i without establishing the assumptions used for the REFERENCE Plant without CO$_2$ Capture.
   Å This is not a good indicator for these cases yet we are trapped in it...
Japanese “Course 50 Programme”

(1) Technologies to reduce CO₂ emissions from blast furnace

- Iron ore pre-reduction technology
- H₂ amplification
- Coke production technology for BF hydrogen reduction
- High strength & high reactivity coke
- Coke substitution reducing agent production technology
- Reaction control technology for BF hydrogen reduction
- Sensible heat recovery from slag (example)
- Waste heat recovery boiler
- Kalina cycle Power generation
- Technology for utilization of unused waste heat

(2) Technologies for CO₂ capture

- Chemical absorption
- Physical adsorption
- CO₂ storage technology
- CO₂ capture technology
- Coking plant
- Shaft furnace
- COG reformer
- BFG
- BF
- Coke
- Regeneration Tower
- Reboiler
- Absorption Tower
- CO-rich gas
- Steam
- Hot metal
- BOF
- Waste heat recovery boiler
- Hot air
- Cold air
- Kalina cycle Power generation
- Technology for utilization of unused waste heat

COURSE50 / CO₂ Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50

Challenges & Opportunities of CCS in the Iron & Steel Industry, IEA-GHG, Düsseldorf, 8-9 November 2011
Ideas/Projects for CO₂ Reduction

(1) CO₂ Capture from BFG stream using aqueous ammonia
(2) Waste heat recovery from molten slag and hot sinter
(3) CO₂ utilization
Challenges of CCS Deployment in the Steel Industry

Technical Challenges:

Several technology options for CO$_2$ Capture are currently under evaluation in pilot scale, however, necessary to be demonstrated for a period of at least 10 years of 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 like smelting technologies 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” 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” is also a possibility where part of the direct CO₂ emissions could be reduced by producing by-products (i.e. methanol, ethanol, hydrocarbon, etc.)
Examples Illustrating the Possibility of “Economic Carbon Leakage”

- **Slab Trade Routes**: Illustrating a split production of finish products.
  - HBI/DRI Trade Route (illustrating the use of HBI to improve productivity and reduce direct CO2 emissions by HBI user in other site)
  - Sinter Trade Route (illustrating a split production of raw materials for iron making)
  - Ore from Brazil/Australia goes to Mindanao, Philippines
  - 5.4 MTPY Sinter from Mindanao, Philippines to JFE Steel (Japan)
  - ~3 MTPY slab from TKS Brazil to Alabama (US)
  - ~4 MTPY slab from SSI Teeside UK to Thailand
  - ~1 MTPY from AM Tubararao going to Asia
  - ~3 MTPY from AM Tubararao going to Asia
  - HBI from Venezuela to AK Steel (US) using ~30% of metal burden of Blast Furnace
  - 1 MTPY from AM Tubararao going to Asia
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 CO₂ emissions at their Austrian plant.

VAI is 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)
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, China should play a bigger role, and 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 expected:

- More M&A among different state enterprises.
- 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(???)
China has an overcapacity of nearly 200 million tonnes in 2012

<table>
<thead>
<tr>
<th>Year</th>
<th>Global Steel Production Capacity (Million Tonnes)</th>
<th>Actual Steel Production (Million Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>1195</td>
<td>970</td>
</tr>
<tr>
<td>2003</td>
<td>1270</td>
<td>1069</td>
</tr>
<tr>
<td>2004</td>
<td>1360</td>
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<tr>
<td>2005</td>
<td>1460</td>
<td>1218</td>
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<tr>
<td>2006</td>
<td>1624</td>
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<td>1709</td>
<td>1329</td>
</tr>
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<td>2008</td>
<td>1789</td>
<td>1424</td>
</tr>
<tr>
<td>2009</td>
<td>1916</td>
<td>1520</td>
</tr>
<tr>
<td>2010</td>
<td>1990</td>
<td>1575</td>
</tr>
</tbody>
</table>

Data from Worldsteel Association, OECD
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

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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