Development of the HIsarna process

Alternative Ironmaking technology with CO₂ capture potential

Koen Meijer
Christiaan Zeilstra
Tata Steel Research, Development & Technology

Industry CCS Workshop, VDEh, Düsseldorf
8 - 9 November 2011
Content

1. Sustainability
2. The ULCOS project
3. HIsarna technology
4. HIsarna and CCS
5. HIsarna development
6. First Campaign
7. Preliminary results
8. Conclusions
1. Sustainability

Steel industry strives for continuous improvement of their environmental performance and sustainability

- Steel is 100% recyclable
- New steel qualities improve sustainability of our customers' products
- Steel industry is committed to ongoing energy saving and reduction of CO₂ emission
- Steel accounts for 5% of man-made CO₂
1. Sustainability

1.1. Challenge

Growth
World steel consumption will double in 2050

Sustainability
Ambition to cut CO₂ emissions by 50% in 2050
1. Sustainability

1.2. Need for breakthrough developments

- Focus on Ironmaking (80 – 90 % of CO₂)
- Present operation close to “Best Practice”

  → Further energy saving will **not** deliver long term target
  
  → **Breakthrough** development needed
2. The ULCOS project

Objective:

50% reduction in CO₂ emissions per ton of steel from iron ore based steel production by 2050

- Globally the largest Steel Industry project on Climate Change
- Core partners: ArcelorMittal, Tata Steel, ThyssenKrupp, Ilva, Voestalpine, LKAB, Dillingen/Saarstahl, SSAB, Rautaruukki
- Co-partners: over 40 Institutes, Universities, Engineering companies, etc

- Budget: 70 M€
- Duration phase I: 2004 - 2010
2. The ULCOS project

2.1. ULCOS subjects

1. Efficiency of carbon use
   *New and improved processes*

2. Replacement of fossil carbon
   *Biomass*
   *Hydrogen*
   *Electricity*

3. Capture
2. The ULCOS project

2.1. ULCOS subjects

HI’sarna process

[Diagram showing the relationships between different subjects including Biomass, Natural gas, Electrolysis, Hydrogen, CO2 capture & Storage, New Smelting Reduction, New Blast Furnace, and Scenarios & Sustainability modelling.]
2. The ULCOS project

2.2. Ironmaking process selection

Criteria
- CO₂
- Economical
- Technical maturity
- Social
- Other environmental aspects
- Fit with existing configuration
2. The ULCOS project

2.2. Ironmaking process selection

- **ULCOS - I Project** (2004)
  - CO₂ and sustainability modelling
  - Inventory process routes

- **ULCOS - II Project** (2010)
  - 4 processes selected
    - Top Gas recycling BF
    - Hlsarna
    - Gas based reduction
    - Electrolysis of iron ore

- **2018**
3. HIsarna technology

3.1. Comparison with the BF route

Iron ore $\rightarrow$ sinter $\rightarrow$ Liquid iron

coal $\rightarrow$ coke $\rightarrow$ Blast furnace
3. HIsarna technology

3.1. Comparison with the BF route

Blast furnace

Direct use of coal and ore
No coking and agglomeration
3. HIsarna technology

- Iron ore
- Oxygen
- Coal
- CO₂

Iron → CO₂
3. HIsarna technology
Melting cyclone technology

Melting and partial reduction of fine iron ores

“2 Fe₂O₃(s) + 2 CO(g) → 4 FeO(l) + 2 CO₂(g) ”

- The cyclone product is a molten mixture of Fe₃O₄ and FeO (~ 20 % reduced)
- Pure oxygen is injected to generate the required melting temperature
- The fines are separated from the gas by centrifugal flow of the gas
3. HIsarna technology
Smelter technology

Post combustion of smelter gas

- Utilisation of the post combustion (CO → CO₂) heat is essential for the process
- The heat of post combustion is captured by the slag splash that circulates through the freeboard
- This splash also protects the cooling panels from the post combustion flames
3. HIsarna technology
Smelter technology

“2 FeO(l) + 2 C(s) → 2 Fe(l) + 2 CO(g) ”

- The iron oxides in the slag are reduced at the slag/metal interface
- Granular coal injection supplies the carbon and creates intense mixing
- Due to this mixing the FeO in the slag is relatively low

Final reduction on slag/metal interface
3. HIsarna technology
Benefits of the HIsarna process

Environmental:

- 20 % reduction of CO$_2$ per ton steel product
- Well suited for CO$_2$ storage (nitrogen free off gas)
- 80 % reduction with CO$_2$ storage
- Substantial reduction of other emissions (dust, NOx, SOx, CO)

Economical:

- Low cost raw material
- Reduced CAPEX
4. HIsarna and CCS

4.1. Why an attractive combination?

HIsarna flue gas:

- Oxygen based process with Nitrogen free flue gas
- All ironmaking flue gases at a single stack (85 % of CO₂ from integrated site)
- Fully utilised gas, (almost) no remaining calorific value
4. HIsarna and CCS

4.2 Flowsheet without CCS

Required:
- Dust removal (staged)
- Heat recovery
- De-sulphurisation
4. HIsarna and CCS

4.3. Flowsheet with CCS

Gas quality requirements?
4. HIsarna and CCS

4.4. Gas quality requirements

- Technical requirements
  - Corrosion
  - Hydrate formation
  - Compression energy

- Legal requirements
  - European directive: “Overwhelmingly CO₂”
  - Dynamis recommendation: CO₂ > 95.5 %

- For HIsarna a slightly less strict CO₂ concentration would be very beneficial. According to the directive there is room for negotiation.
## 4. HIsarna and CCS

### 4.5. Dynamis recommendation

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration</th>
<th>Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$O</td>
<td>500 ppm</td>
<td>Technical: below solubility limit of H$_2$O in CO$_2$. No significant cross effect of H$_2$O and H$_2$S, cross effect of H$_2$O and CH$_4$ is significant but within limits for water solubility.</td>
</tr>
<tr>
<td>H$_2$S</td>
<td>200 ppm</td>
<td>Health &amp; safety considerations</td>
</tr>
<tr>
<td>CO</td>
<td>2000 ppm</td>
<td>Health &amp; safety considerations</td>
</tr>
<tr>
<td>O$_2$</td>
<td>Aquifer &lt; 4 vol%, EOR 100 – 1000 ppm</td>
<td>Technical: range for EOR, because lack of practical experiments on effects of O$_2$ underground.</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>Aquifer &lt; 4 vol%, EOR &lt; 2 vol%</td>
<td>As proposed in ENCAP project</td>
</tr>
<tr>
<td>N$_2$</td>
<td>&lt; 4 vol % (all non condensable gasses)</td>
<td>As proposed in ENCAP project</td>
</tr>
<tr>
<td>Ar</td>
<td>&lt; 4 vol % (all non condensable gasses)</td>
<td>As proposed in ENCAP project</td>
</tr>
<tr>
<td>H$_2$</td>
<td>&lt; 4 vol % (all non condensable gasses)</td>
<td>Further reduction of H$_2$ is recommended because of its energy content</td>
</tr>
<tr>
<td>SO$_x$</td>
<td>100 ppm</td>
<td>Health &amp; safety considerations</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>100 ppm</td>
<td>Health &amp; safety considerations</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>&gt;95.5%</td>
<td>Balanced with other compounds in CO$_2$</td>
</tr>
</tbody>
</table>
5. Development

7 years of preparation before the first experiments
5.1. Site construction

- Suitable location (former de-S plant) at Tata Steel IJmuiden

- Project execution:
  - Tata Steel Engineering
  - Tata Steel Research
  - European steelmakers
  - European equipment suppliers
  - Rio Tinto
6. The first campaign (A.)

- The plant was operated from April 18 to June 11
- The team:
  - Tata Steel Operations
  - Tata Steel Research
  - ULCOS partners
  - Rio Tinto
- 4 start-ups took place
### 6. The first campaign (A.)

<table>
<thead>
<tr>
<th>Week 16</th>
<th>Week 17</th>
<th>Week 18</th>
<th>Week 19</th>
<th>Week 20</th>
<th>Week 21</th>
<th>Week 22</th>
<th>Week 23</th>
</tr>
</thead>
<tbody>
<tr>
<td>April-18</td>
<td>April-25</td>
<td>May-2</td>
<td>May-9</td>
<td>May-16</td>
<td>May-23</td>
<td>May-30</td>
<td>June-6</td>
</tr>
</tbody>
</table>

- Heat-Up
- Test A-1
- Plant improvements
- Test A-2
- Test A-3
- Test A-4

- First start-up failed
- Various improvements required
- 3 successful start-ups followed
First metal tap at May 20\textsuperscript{th} (test A-2)

Forehearth runner
Hlsarna plant
7. Results first HIsarna campaign

- After many “teething problems” the plant and all its support systems were finally operational
- 3 successful start-ups were carried out
- 60% of the design capacity was achieved
- Available data indicates that process works as expected but more operating hours are needed to prove this
- The number of operating hours was below expectation
7.1. HISarna and CCS likely?

Test results relevant for CCS:

- Use of 100 % oxygen successful
- High gas utilisation partly achieved
  - Achieved: 78 % post combustion at top of cyclone
  - Target: > 85 % post combustion

- Nitrogen in off gas during tests was 17 % in dry gas
  - Nitrogen used for coal and lime injection (35 % of N₂)
  - Air used for iron ore injection (60 % of N₂)
  - Camera purge etc. (5 % of N₂)

- For industrial applications alternative iron ore carrier gas considered
- Test results indicate that combination with CCS is attractive
8. Further campaigns

**Pilot plant experiments**

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction pilot plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campaigns</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Industrial scale demonstration**  2014 - 2018

**Industrial implementation**  2020 - .......
9. Conclusions

- With the ULCOS and HIsarna project the European steel industry is proactively approaching the Climate Change issue

- In the HIsarna project knowledge and experience of steelmakers and equipment suppliers from all over Europe is brought together

- HIsarna is a high risk/high reward innovation that can potentially have a strong **environmental** and **economical** impact on the steel industry

- Environmental impact:
  - Without CO\(_2\) capture and storage 20 % reduction
  - With CO\(_2\) capture and storage 80 % reduction
  - Strong reduction of other emission (dust, CO, NOx, SOx)

- No quick fix: HIsarna not ready for industrial implementation before 2020
  CCS available before 2020?
Aknowledgement

The HIsarna project is made possibly with the support of:

- 9 steelmakers
- Leading equipment Engineers and Suppliers
- Rio Tinto/HIsmelt
- EU FP6
- RFCS
- Dutch Ministery of Economic Affairs