Techno-economic study of an integrated steelworks equipped with oxygen blast furnace and CO$_2$ capture

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- Integrated steelmaking, BF & OBF system
- CO₂ Capture & systems effects
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Purpose

- Determine the cost of avoiding CO$_2$ emissions from integrated steelmaking using an Oxygen Blast Furnace (and end of pipe – to be published)

\[
\text{CO}_2 \text{ Avoidance Cost} = \frac{\text{Cost} \_{\text{HRC, capture}} - \text{Cost} \_{\text{HRC, ref}}}{\text{CO}_2 \text{ emission, ref} - \text{CO}_2 \text{ emissions, capture}}
\]
BF

Coke
Iron ores

Heated air

BF gas *(Energy export)*

Recirculation of Energy via sensible heat

Hot stoves

Coal

Cold air

Flue gas *(Combustion of BF gas)*
OBF

Coke
Iron ores

CO₂-rich gas

OBF gas

Recirculation of Energy via gas

CO₂ capture

CO₂

Coal
Oxygen
Assumptions

- Western European Atlantic Coastal Site
- Access to natural gas and a CO₂ pipeline 110 bar
- Reference plant has typical European performance figures and operation with sinter, pellets, lump ore, PCI, some scrap in converter
- Production of 4 MT standard grade hot-rolled coil
- Cost of land not included
- Greenfield projects
## Assumptions - Boundary Limits

<table>
<thead>
<tr>
<th>Incoming streams:</th>
<th>Outgoing streams:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ores</td>
<td>Hot rolled coil</td>
</tr>
<tr>
<td>Scrap</td>
<td>By-products</td>
</tr>
<tr>
<td>Fluxes &amp; alloys</td>
<td>Solid wastes</td>
</tr>
<tr>
<td>Coking Coal</td>
<td>Flue gases</td>
</tr>
<tr>
<td>PCI Coal</td>
<td>Diffuse emission</td>
</tr>
<tr>
<td>Natural gas</td>
<td>No import or export of electricity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime production</td>
</tr>
<tr>
<td>Coke production</td>
</tr>
<tr>
<td>Sinter Production</td>
</tr>
<tr>
<td>Ironmaking</td>
</tr>
<tr>
<td>Ancillary operations</td>
</tr>
<tr>
<td>Steelmaking</td>
</tr>
<tr>
<td>Rolling mill</td>
</tr>
<tr>
<td>Oxygen production</td>
</tr>
<tr>
<td>Power &amp; steam production</td>
</tr>
<tr>
<td>CO₂ capture</td>
</tr>
</tbody>
</table>
Technical model

- Masmod integrated steelplant model (Excel)
  - All major units modeled
  - Calibrated to typical European operation
  - Static heat and mass balances, solved iteratively
  - Level of detail varies for different units

- Oxygen blast furnace
  - BF model modified to calculate OBF performance

- CO₂ capture
  - Protreat®, optimized with MDEA/Pz chemical absorption
  - Operating parameters input to Masmod model
Financial Modeling

- Discounted cash flow through-cost model
- Cost of HRC adjusted to Net Present Value = 0
- Discount rate 10%
- Project Lifetime 25 years
- Long term trend prices for materials
- Capital costs from database & vendor supplied information
- Base year 2010
Integrated steelmaking

- CO₂ capture
- O₂ plant
- Process gas
- Power plant
Reference Blast furnace

Iron ores
Coke 348 kg

Blast furnace gas export
22% CO
22% CO₂
3.7 GJ

Energy in: 15.3 GJ
Energy export: 5.2 GJ
Energy consumed: 10.1 GJ

Coal 152 kg

Heated air

Hot stove

Cold air + 4% O₂

Hot metal
4.7% C
1.5 GJ
Oxygen Blast furnace

Iron ores
Coke 348 -> 253 kg

CO₂ capture
Steam 2 GJ

OBF gas
22 -> 67% CO
22 -> 3% CO₂
3.7 -> 1.7 GJ

Energy in: 13.2 GJ (15.3)
Energy export: 3.3 GJ (5.2)
Consumed: 9.9 GJ (10.1)
+ Steam 2.0 GJ
Total: 11.9 GJ
+ Electricity (O₂, capture)

Coal 152 kg
Air -> 253 m³ O₂

Hot metal
4.7% C
1.5 GJ
**CO₂ Capture**

- MDEA with piperazine modeled and optimised
  - Established system, reliable performance & cost estimates
  - More suitable for high CO₂ concentration streams than MEA
  - Produces pipeline grade CO₂
  - 2.35 GJ/t CO₂ captured
System-changes with OBF

- CO$_2$ capture and compression added
- Steam boilers added
- Low purity O$_2$ plant added
- Smaller coke plant
- *Higher electricity production required*
- Less process gas available
## Steam & Electricity

<table>
<thead>
<tr>
<th>Power plant</th>
<th>Demand kwh/t HRC</th>
<th>Steam</th>
<th>Demand GJ/t HRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Plant</td>
<td>400</td>
<td>Steam recovery only from BOF</td>
<td>--</td>
</tr>
<tr>
<td>Steam cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32% eff BF, BOF, NG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OBF Plant</td>
<td>573</td>
<td>Steam boilers BF, BOF, NG</td>
<td>2</td>
</tr>
<tr>
<td>NGCC 57% eff. NG</td>
<td></td>
<td></td>
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</tbody>
</table>
## Overall Energy Consumption

<table>
<thead>
<tr>
<th>Fuel GJ/t HRC</th>
<th>Reference</th>
<th>OBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coking coal</td>
<td>16.3</td>
<td>12.4</td>
</tr>
<tr>
<td>PCI coal</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.8</td>
<td>5.0</td>
</tr>
<tr>
<td>SUM</td>
<td>22.2</td>
<td>22.5</td>
</tr>
</tbody>
</table>
Break-even cost of HRC

USD/t HRC

<table>
<thead>
<tr>
<th></th>
<th>Reference</th>
<th>OBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>135</td>
<td>161</td>
</tr>
<tr>
<td>Energy</td>
<td>56</td>
<td>61</td>
</tr>
<tr>
<td>Maintenance</td>
<td>70</td>
<td>71</td>
</tr>
<tr>
<td>Labour</td>
<td>65</td>
<td>67</td>
</tr>
<tr>
<td>Other raw materials &amp; consumables</td>
<td>120</td>
<td>121</td>
</tr>
<tr>
<td>Iron ores, pellets, lump ore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluxes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Emissions

Avoidance 975 kg (47%)
Cost of avoidance

56 USD/t CO₂ avoided
Sensitivity

- Energy, Capital

*represents a 50% change in the difference in investment cost*
Conclusions

- OBF system allows for fuel shift and increased CO$_2$ concentration in gas stream for improved capture
- Under the given assumptions the avoidance cost is 56 USD/t at nearly 50% CO$_2$ avoidance; highly sensitive to energy and capital costs
- Numerous complex system effects
- Further optimization is possible (e.g. CHP plant, waste heat integration)
- Pilot & demonstration scale developments will be very important
  - e.g. ULCOS (Europe); COURSE50 (Japan)
Thank you for your attention!