EVALUATION OF THE CAPABILITIES OF DIRECT AND SMELTING REDUCTION PROCESSES TO ENHANCE THE ENERGY EFFICIENCY AND TO REDUCE THE CO₂ EMISSION OF THE STEEL PRODUCTION IN EUROPE

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Outline of presentation

• State of the art technology and penetration of iron production with DR and SR processes
• Boundary conditions and requirements for the DR and SR processes to produce iron in Europe
• Possible concepts for integration of DR and SR processes into existing integrated iron and steelworks
• Comparison of energy consumption of the process routes
• Comparison of emissions of the process routes
• Hydrogen production and hydrogen reduction
Process Routes for Production of Crude Steel

Routes with Direct Reduction and Smelting Reduction

Raw materials
- Lump ores
- Fine ores
- Iron ores
- Lump ores, Fine ores
- Lump ores
- Fine ores
- Scrap

Agglomeration/Screening
- Coal
- Sinter
- Pellets
- Coke

Hot metal and DRI production
- Blast furnace
  - Oil, gas
  - or coal
  - Hot blast
  - O₂
- Hot metal
- Scrap
- O₂

Crude steel production
- O₂-converter

Crude steel

Source: Stahlfibel (Herausgegeben vom Verein Deutscher Eisenhüttenleute, 1999)
Production of Crude Steel, Hot Metal and DRI/HBI (1994 – 2014)

- Hot Metal from BF is ~ 71 % of Crude Steel Production
- DRI/HBI is ~ 5 % of Crude Steel Production
- Hot Metal from SR ~ 0.3 % of Crude Steel Production

Quelle: World Steel Association, Steel Statistical Yearbook 2014, own data
Classification of Direct Reduction Processes

**Iron Ore Source**
- Pellets / Lump Ore
- Fine Ore

**Reduction Stage**
- Shaft Furnace
- Fluidized Bed
- Rotary Hearth
- Rotary Kiln

**DR Processes**
- MIDREX®
- COREX®
- COREX® DR-Shaft
- FINMET®
- FIOR², Circoled®²
- Circofer®¹
- COMET¹
- FASTMET³
- RedIron³
- Iron Dynamics³

**Gas Production**
- Gas Reforming
- Coal Gasification

**Energy Source**
- Natural Gas
- Coal

¹ Process tested in pilot scale, ² Operation stopped, ³ Recycling of residues

Plants in industrial scale are in operation.
DRI/HBI Production by Process
(production 2014: 74.6 million t)

- **Gas reduction**: 79.4 %
  - Midrex: 47.10 million t
  - HyL Energiron: 12.10 million t
  - Other gas based: 0.00 million t

- **Coal reduction**: 20.6 %
  - Coal reduction: 15.40 million t

Source: Midrex
DRI/HBI Production by Region 2000/2014

Source: Midrex Corp.
World DRI/HBI Production and Transports

DRI = Direct Reduced Iron
HBI = Hot Briquetted Iron

DRI/HBI production

Source: Midrex
Classification of Smelting Reduction Processes

Iron Ore Source
- Pellets / Lump Ore
- Fine Ore (Sinter and Pellet Feed)

Pre-reduction Stage
- Shaft Furnace
- Fluidized Bed
- Cyclone

SR Processes
- OxyCup
- TECNOPRED
- COREX
- FINEX

Smelting Stage
- Char Bed In-Bed Processes
- Metal / Slag Bath In-Bath Processes

Energy Source
- Coal

Electrical Smelting
- Coal/Electricity

IDI Redsmelt Fastmelt

1 Process tested in pilot or semi-industrial scale, 2 Pilot tests under execution, 3 Operation stopped

Plants in industrial scale are in operation
# Overview of Corex and Finex Plants (as of August 2015)

<table>
<thead>
<tr>
<th>Customer</th>
<th>Type of plant</th>
<th>Number of module</th>
<th>Year of start-up</th>
<th>Fe burden</th>
<th>Capacity in million t/a HM</th>
<th>Use of the export gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSCO, Pohang Works, Korea</td>
<td>Corex/Finex plant</td>
<td>01</td>
<td>1995/2003*)**)</td>
<td>Iron ore fines</td>
<td>0.8</td>
<td>Power plant, steel shop</td>
</tr>
<tr>
<td>POSCO, Pohang Works, Korea</td>
<td>Finex plant</td>
<td>02</td>
<td>2007</td>
<td>Iron ore fines</td>
<td>1.5</td>
<td>Power plant, steel shop</td>
</tr>
<tr>
<td>POSCO, Pohang Works, Korea</td>
<td>Finex plant</td>
<td>03</td>
<td>2014</td>
<td>Iron ore fines</td>
<td>2</td>
<td>Power plant, steel shop</td>
</tr>
<tr>
<td>Jindal South West Steel, Toranagallu, India</td>
<td>Corex plant</td>
<td>01</td>
<td>1999</td>
<td>Lump ore, pellets</td>
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<td>ArcelorMittal Steel South Africa; Saldanha Works, South Africa</td>
<td>Corex plant</td>
<td></td>
<td>1998</td>
<td>Lump ore, pellets</td>
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<td>Baosteel, Luojing/ Shanghai, China</td>
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<td>1.5</td>
<td>Power plant, steel shop</td>
</tr>
<tr>
<td>Bayi Steel, Xinjiang</td>
<td>Corex plant</td>
<td>01</td>
<td>2015****</td>
<td>Pellets, Sinter</td>
<td>1.5</td>
<td>Power plant, steel shop</td>
</tr>
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<td>Baosteel, Luojing/ Shanghai, China</td>
<td>Corex plant</td>
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<td>Corex plant</td>
<td>02</td>
<td>2017****</td>
<td>Pellets, Sinter</td>
<td>1.5</td>
<td>DR plant (?), steel shop</td>
</tr>
<tr>
<td>Essar Steel, Hazira, India</td>
<td>Corex plant</td>
<td>01</td>
<td>2011</td>
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</table>

*) Conversion of a Corex plant to a Finex plant  
**) Idled 2014  
***) Idled 2012 and (to be) relocated from Shanghai (Baosteel) to Xinjiang (Bayi Steel)  
****) Relocated from Shanghai (Baosteel)  

Source: Primetals
Available Plant Capacities for Ironmaking Technologies

- **Biggest DR- und SR-Plant Modules are in the Capacity Range of Midsized Blast Furnaces**

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Capacity (Tons per Day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast Furnace</td>
<td>500</td>
</tr>
<tr>
<td>DR-Shaft (MIDREX, HYL)</td>
<td>6500</td>
</tr>
<tr>
<td>DR-Fluidized Bed (FINMET, CIRCORED)</td>
<td>1375</td>
</tr>
<tr>
<td>DR-Rotary Hearth</td>
<td>1400</td>
</tr>
<tr>
<td>DR-Rotary Kilin</td>
<td>1000</td>
</tr>
<tr>
<td>COREX/FINEX</td>
<td>5750</td>
</tr>
<tr>
<td>SR-Rotary Hearth</td>
<td>1400</td>
</tr>
</tbody>
</table>
Primary Energy Use – Comparison of Routes

- **Coal**
- **Iron Ore**
- **Scrap (25% Fe)**
- **FINEX® Plant**
- **Hot Metal (75% Fe)**
- **BF Route**
- **Crude Steel**
- **EAF**
- **BOF**
- **Hot Metal (75% Fe)**
- **FINEX® Plant**
- **DRI (75% Fe)**
- **DR Shaft**
- **Crude Steel**
- **Iron Ore**
- **Coal**
- **Natural Gas**
Remark: The average conversion efficiency in Germany for electric energy production from fossil fuels was 43% in 2013 (Source: Deutsches Bundes Umweltamt)
Direct Emissions
- Conversion of fossil carbon and calcination in the process (no credits considered)

Indirect Emissions
- Production and transport of raw materials (pellets, sinter, coke, burnt lime)
- Production of electric energy and oxygen

Indirect CO\(_2\) Emissions:
- 0 kg CO\(_2\)/kWh (BF + FINEX)
- 0 kg CO\(_2\)/Nm\(^3\) O\(_2\) (BF + FINEX)
- 0.6 kg CO\(_2\)/kWh (DR+EAF)
- 0.3 kg CO\(_2\)/Nm\(^3\) O\(_2\) (DR+EAF)
- 162 kg CO\(_2\)/t Pellet
- 1400 kg CO\(_2\)/t Burnt Lime

Substantial lower CO\(_2\) emissions for DR-Shaft + EAF Route
Total: \sim 35\%
Direct: \sim 60\%
Direct Emissions
• Conversion of fossil carbon and calcination in the process (no credits considered)

Indirect Emissions
• Production and transport of raw materials (pellets, sinter, coke, burnt lime)
• Production of electric energy and oxygen

Indirect CO₂ Emissions:
• 0 kg CO₂/kWh (BF + FINEX)
• 0 kg CO₂/Nm³ O₂ (BF + FINEX)
• 0,6 kg CO₂/kWh (DR+EAF)
• 0,3 kg CO₂/Nm³ O₂ (DR+EAF)
• 162 kg CO₂/t Pellet
• 1400 kg CO₂/t Burnt Lime

Substantial lower CO₂ emissions for DR- Shaft + EAF Route
Total: ~ 35 %
Direct: ~ 60 %
Conversion of Crude Steel Routes from BF+ BOF to DR-Shaft+EAF
Effect on Overall Energy Consumption in EU28

<table>
<thead>
<tr>
<th></th>
<th>EU 28 - Status 2013</th>
<th>DR-Route instead of BF-Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1666</td>
<td>1656</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>197</td>
<td>197</td>
</tr>
<tr>
<td>Coal</td>
<td>557</td>
<td>557</td>
</tr>
<tr>
<td>Non-Renewable Energies &amp; Others</td>
<td>387</td>
<td>425</td>
</tr>
<tr>
<td>Renewables Energies</td>
<td>226</td>
<td>226</td>
</tr>
<tr>
<td>Nuclear Heat</td>
<td>557</td>
<td>287</td>
</tr>
<tr>
<td>Gas</td>
<td>287</td>
<td>235</td>
</tr>
<tr>
<td>Crude Oil &amp; Petroleum Products</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Solid Fossil Fuels</td>
<td>226</td>
<td>0</td>
</tr>
</tbody>
</table>

Total 0.6 % decrease
Natural Gas 11 % increase
Coal 18 % decrease

* 1 toe = 41,867 GJ (≈ 10⁷ kcal)

Basis: Crude Steel Production with BF+BOF 2013 in EU28
103.2 million tons
Use of Coke Oven Gas for DRI Production in Integrated Route

Case Study:
100 % of Coke Oven Gas is utilized for Steelmaking with DR-Shaft – EAF Route
Overall Effect for Integrated Steel Works by Utilization of COG for DR-Shaft-EAF

- 3 % lower total energy consumption
- 15 % lower fossil energy consumption
- Production increase by 17 %
Overall Effect for Integrated Steel works by Utilization of COG for DR-Shaft+EAF:

- 11% lower direct CO$_2$ Emission
- 10% lower total CO$_2$ Emission

Upstream Substitution of COG by NG for hot rolling is considered in CO$_2$ Balance.
Use of Coke Oven Gas for DRI Production in Integrated Route

Case Study: Use of DRI in BF
100 % of Coke Oven Gas is utilized for DRI Production for BF
Overall Effect for Integrated Steel Works by Utilization of COG to produce DRI for BF

- 3 % lower total energy consumption
- 11 % lower fossil energy consumption
- Production increase by 5 to 7 %
Overall Effect for Integrated Steel Works by Utilization of COG to produce DRI for BF

- 6 % lower direct CO₂ Emission
- 6 % lower total CO₂ Emission
Combination of BF-Route and Smelting Reduction

Use of LRI (Low Reduced Iron) produced in FINEX as substitute for Sinter in Blast Furnace

Reduction in comparison to separate routes
• Coal: 40 kg/t HM
• CO$_2$-Emission: up to 100 kg/t Steel
Race Between Fossil Fuels and Renewable Energies

In 2013 the world has added more capacity for renewable power each than coal, natural gas, and oil combined for the first time.
Conversion of Energies into Chemical Power

H₂ drives the convergence between energy & industry markets

Source: Siemens, Presentation at VDEh, WG "Efficiency increase and CO₂ mitigation along the value added chain steel", Oct. 12, 2015
Production of Steel on Renewable Energies

Process Concept of DR-Shaft and Electric Arc Furnace was investigated in ULCOS. Direct Reduction Shaft Process is operated with 100 % H₂.
Summary and Conclusions

• Annual production of DRI/HBI and hot metal in SR plants corresponds to 5.3% of world steel production

• Overall energy consumption of the steelmaking routes (BF + BOF, FINEX + BOF and DR-Shaft + EAF) are nearly the same

• Steelmaking route of DR-Shaft + EAF has significantly lower CO$_2$-emission as BF + BOF and FINEX + BOF

• Prospective for DR- and SR-Technologies in Europe: Integration of BF + BOF route with DR- und SR-Technologies
  • Reduction of specific energy consumption
  • Reduction of CO$_2$ emissions
  • Increase of capacity and productivity of existing plants

• Growth of electric power production from renewable energies will drive the convergence between energy market and industries.
  • Supply of hydrogen enables low CO$_2$ steel production
  • Steel industry in Europe has to become prepared for the challenges and chances of this change in the next decades
THANK YOU FOR YOUR ATTENTION

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