ULCORED
Direct Reduction Concept for ULCOS

a brief introduction

Peter Sikström
LKAB

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OUTLINE

• Introduction
• Todays dominating processes
• Potential for new DR-process
• Proposal for new processes
  – Natural gas based
  – Coal based
• Summary
INTRODUCTION

Requirements for a new DR-Process proposed 2006:

1. Different from existing processes like Midrex or HYL.
2. The Plant should only have one source where CO$_2$ leave the process.
3. The Energy consumption has to be less than 8,4 GJ / t DRI.
4. Equipment and operation has to be simple.
5. Potential for use of fuels other than natural gas.
6. Investment costs has to be comparable to existing plants / plant concepts.
7. There must be good reasons for tests – technically and economic.
TODAY'S DOMINATING PROCESSES

Midrex

HYL
Midrex process configuration

**Reactions**
- Reduction:
  - \( \text{Fe}_3\text{O}_4 + 3\text{H}_2 \rightarrow 2\text{Fe} + 3\text{H}_2\text{O} \)
  - \( \text{Fe}_2\text{O}_3 + 3\text{H}_2 \rightarrow 2\text{Fe} + 3\text{H}_2\text{O} \)

- Carburization:
  - \( 3\text{Fe} + \text{CO} + \text{H}_2 \rightarrow \text{Fe}_3\text{C} + \text{H}_2\text{O} \)
  - \( 3\text{Fe} + \text{CH}_4 \rightarrow \text{Fe}_3\text{C} + 2\text{H}_2 \)

- Reforming:
  - \( \text{CH}_4 + \text{CO}_2 \rightarrow 2\text{CO} + 2\text{H}_2 \)
  - \( \text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2 \)

**Process Gas System**

- Flue Gas
- Natural Gas
- Process Gas Compressors
- CO\(_2\) Removal
- Top Gas Scrubber
- Top Gas Compressor
- Shaft Furnace

**Heat Recovery**

- Feed Gas
- Combustion Air
- Fuel Gas
- Natural Gas

**Notes:**
- Natural Gas + O\(_2\)
HYL PROCESS CONFIGURATION

Reducing gases
Possible sources:
- Natural Gas
- Reformed Gas
- COG
- Gasification
- Others

CO₂ removal

H₂O dryer

Iron Ore

Hydrogen

Heater

Oxygen

fuel

Optional DR products:

DRI

HYTEMP® Iron

EAF

Only for cold DRI

NG or COG

HBI
• Introduction
• Todays dominating processes
• **Potential for new DR-process**
• Proposal for new processes
  – Natural gas based
  – Coal based
• Summing-up
Dominating CO$_2$ emissions from DR – EAF route arises from the DR-plant.

The main features for ULCORED:

• Use of oxygen instead of air in DR-plants results in an off gas of 100 % CO$_2$, which needs only to be compressed.

• There should be possibilities to reduce the need of natural gas in DR-processes by 15 – 20 %.

• Coal-, biomass-, bio waste gasification and hydrogen can be an alternatives to natural gas.
## REACTIONS STARTING FROM METHANE

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Reaction Equation</th>
<th>( \Delta H_t ) (kJ/mol)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2) reforming</td>
<td>( CH_4 + CO_2 \leftrightarrow 2 CO + 2 H_2 )</td>
<td>247</td>
<td>Midrex</td>
</tr>
<tr>
<td>Steam Reforming</td>
<td>( CH_4 + H_2O \leftrightarrow CO + 3 H_2 )</td>
<td>206</td>
<td>HYL</td>
</tr>
<tr>
<td>Thermal cracking</td>
<td>( CH_4 \leftrightarrow C + 2 H_2 )</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Partial oxidation</td>
<td>( CH_4 + \frac{1}{2} O_2 \rightarrow CO + 2 H_2 )</td>
<td>-36</td>
<td>Ulcored</td>
</tr>
<tr>
<td>Water gas shift</td>
<td>( CO + H_2O \leftrightarrow CO_2 + H_2 )</td>
<td>-41</td>
<td></td>
</tr>
<tr>
<td>Boudouards reaction</td>
<td>( 2 CO \leftrightarrow C + CO_2 )</td>
<td>-173</td>
<td></td>
</tr>
<tr>
<td>Complete combustion</td>
<td>( CH_4 + 2 O_2 \rightarrow CO_2 + 2 H_2O )</td>
<td>-803</td>
<td></td>
</tr>
</tbody>
</table>

Source: TUDelft

Endothermic

Exothermic
Steam Methane Reforming (SMR):
Endothermic: heating necessary

Auto-Thermal Reforming (ATR):
Combined oxidation and steam reforming $\rightarrow$ heat is balanced

Partial Oxidation (POx).
Steam used for enhancing CH$_4$ conversion and avoid soots

<table>
<thead>
<tr>
<th></th>
<th>SMR</th>
<th>ATR</th>
<th>Pox</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>reactants</strong></td>
<td>CH$_4$ + steam</td>
<td>CH$_4$ + O$_2$ + steam</td>
<td>CH$_4$+O$_2$ +steam</td>
</tr>
<tr>
<td><strong>inlet T°</strong></td>
<td>500-600 °C</td>
<td>750 °C</td>
<td>NG 450°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O$_2$ 200°C</td>
</tr>
<tr>
<td><strong>outlet T°</strong></td>
<td>870 °C</td>
<td>900-1000 °C</td>
<td>1300-1400 °C</td>
</tr>
<tr>
<td><strong>H/C in syngas</strong></td>
<td>3 - 6</td>
<td>1,8 – 3,7</td>
<td>1,6 – 1,9</td>
</tr>
<tr>
<td><strong>H$_2$O content</strong></td>
<td>5 %</td>
<td>18 %</td>
<td>10-13 %</td>
</tr>
<tr>
<td><strong>estimated cost without piping, for ~ 40 000 Nm$^3$/h</strong></td>
<td>10 M€</td>
<td>20 M€ ?</td>
<td>20 M€ (POx without shift)</td>
</tr>
</tbody>
</table>
CO₂ reforming

\[ \text{CH}_4 + \text{CO}_2 + \text{Heat} \leftrightarrow 2 \text{CO} + 2 \text{H}_2 \]

CO₂ + N₂ in off gas

Steam reforming

\[ \text{CH}_4 + \text{H}_2\text{O} + \text{Heat} \leftrightarrow \text{CO} + 3 \text{H}_2 \]

CO₂ + (N₂) in off gas

Partial oxidation

\[ \text{CH}_4 + \frac{1}{2} \text{O}_2 \leftrightarrow \text{CO} + 2 \text{H}_2 + \text{Heat} \]

CO₂ in off gas
POX PILOT AT LINDE

- Tested in two campaigns
- New designed burner for H₂ rich feed gas
- Tube reactor with preheated gas
  - 60% H₂
  - 40% CH₄
CONCLUSIONS BY LINDE

• The burner and reactor could be operated without problems.

• A stable flame without significant noise production could be demonstrated.

• The soot production is expected lower than 300-460 mg/Nm³ wet gas volume.

• Due to the atm pressure, the CO₂ and CH₄ content will be higher than the pre-calculations on the basis of assumed equilibrium.
  • A higher operation pressure up to 7 bar(a) will reduce this contents
• Introduction
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ULCORED

• No reformer
• No heater
• High pressure

- Less gas velocity in the shaft, gives less fluidisation, less fines leaving the shaft
- CO$_2$-removal and POx units are smaller than Midrex/HYL shifter/reformer
- Less electric power need for recycle compressor
- PSA instead of VPSA can be used
In depth studies of ULCORED

Fundamental modeling

– Pellet scale models
  • LSG2M and NTNU
    – Reduction models – reduction kinetics

– Shaft models
  • LSG2M, NTNU and SSSA

– Process models by flow sheet simulations
  • MEFOS developed an HSC-model in SP 12
  • IRMA developed in SP 2 by Corus
  • ASPEN developed by LSG2M in SP 9
Achievements from modeling

Fundamental reduction modelling
  – Fundamental understanding of the DR process including dissemination of knowledge to the Universities

Flow sheet modelling
  – Optimisation of the process layout to fit the ULCORED process in steel plant environment
  – Process understanding including dynamics

Different approaches - similar results
  – Create credible basis for evaluation of the concept in different scenarios
Natural gas ULCORED

Concept details

Full CO₂ capture in the process

→ CO₂ storage potential

O₂ instead of air (low N₂ in system)

Reforming by a POX reactor

High H₂ content in reduction shaft by water-gas shifter

(CO + H₂O = H₂ + CO₂)

Bleed of H₂ containing N₂
Natural gas ULCORED

**Diagram Descriptions:**
- **H₂ rich gas**
- **Bleeding N₂ and for use in the steel plant**
- **Feed to the cooling zone to re-heat the gas to the POX**

**Processes:**
- **POX**
- **DRI reactor**
- **DRI cooler**
- **Shifter**
- **Gas cleaning**
- **CO₂ removal**
- **CO₂ storage**
- **Natural gas**
- **Oxygen**
Coal based ULCORED

Concept details
Reducing gas from coal in a gasifier, e.g. Shell gasifier
CO$_2$ storage
O$_2$ instead of air
High H$_2$ content in reduction shaft by WGS water-gas shifter
H$_2$ excess gas for external users
Coal based ULCORED

Dust and sulphur removal Hot or cold
Coal
Oxygen
CO₂ removal
CO₂ storage
Excess gas for external users
BROWN FIELD
GREEN FIELD
DRI
Shifter
Gas cleaning
DRI reactor
DRI cooler
Coal gasification

Coal based ULCoreD
The purpose of an integration of ULCORED into the existing steelmaking system is to utilise the possibility to have one CO$_2$ emission point from the system, instead of having one per heating gas consumer.
Material-Balance related to 1 t DRI (cold) (Metallization 92%, Carbon 2.76 %)

<table>
<thead>
<tr>
<th></th>
<th>Nat.Gas Make up (1)</th>
<th>Rec. gas to Cooling (2)</th>
<th>Cooling gas in (3)</th>
<th>Cooling gas out (4)</th>
<th>Oxygen (5)</th>
<th>from Generator (6)</th>
<th>Recycle gas (7)</th>
<th>to Reduction (8)</th>
<th>Topgas from Red. (9)</th>
<th>T.gas from Shifter (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2 Vol.%</td>
<td>0.00</td>
<td>95.43</td>
<td>57.17</td>
<td>61.00</td>
<td>0.00</td>
<td>70.31</td>
<td>95.43</td>
<td>79.57</td>
<td>51.31</td>
<td>59.64</td>
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<tr>
<td>H2O Vol.%</td>
<td>0.00</td>
<td>2.38</td>
<td>1.43</td>
<td>1.40</td>
<td>0.00</td>
<td>7.70</td>
<td>2.38</td>
<td>5.74</td>
<td>36.61</td>
<td>27.18</td>
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<tr>
<td>CO Vol.%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>19.93</td>
<td>0.00</td>
<td>12.58</td>
<td>8.34</td>
<td>11.59</td>
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<tr>
<td>CO2 Vol.%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.87</td>
<td>0.00</td>
<td>0.55</td>
<td>3.25</td>
<td>0.00</td>
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<tr>
<td>CH4 Vol.%</td>
<td>98.22</td>
<td>0.00</td>
<td>39.37</td>
<td>35.60</td>
<td>0.11</td>
<td>0.00</td>
<td>2.20</td>
<td>1.56</td>
<td>1.59</td>
<td>1.59</td>
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<tr>
<td>N2 Vol.%</td>
<td>1.78</td>
<td>2.03</td>
<td>2.03</td>
<td>1.11</td>
<td>1.19</td>
<td>2.20</td>
<td>2.15</td>
<td>1.56</td>
<td>1.59</td>
<td>1.59</td>
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<tr>
<td>O2 Vol.%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Flow Nm3</td>
<td>258.01</td>
<td>386.61</td>
<td>653.93</td>
<td>159.93</td>
<td>0.00</td>
<td>1773.34</td>
<td>653.93</td>
<td>365.36</td>
<td>1742.41</td>
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<tr>
<td>Temperature °C</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>1200</td>
<td>400</td>
<td>910</td>
<td>494</td>
<td>5.9</td>
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<tr>
<td>Temperature bar</td>
<td>12</td>
<td>6.50</td>
<td>6.5</td>
<td>6.30</td>
<td>8</td>
<td>6.20</td>
<td>6.2</td>
<td>6.2</td>
<td>6</td>
<td>6.2</td>
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<tr>
<td>Flow kg</td>
<td>186.67</td>
<td>50.79</td>
<td>237.46</td>
<td>228.37</td>
<td>453.87</td>
<td>86.14</td>
<td>540.01</td>
<td>904.12</td>
<td>904.12</td>
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<table>
<thead>
<tr>
<th></th>
<th>T.gas after Recog. Preh. (11)</th>
<th>T.gas after Condens. (12)</th>
<th>Condensate (13)</th>
<th>T.gas after Compressor (14)</th>
<th>after CO2 Removal (14a)</th>
<th>CO2 from Desorber (15)</th>
<th>to Package Boiler (16)</th>
<th>to recycle (17)</th>
<th>N2 Adsorber (18)</th>
<th>after N2 Adsorber (19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2 Vol.%</td>
<td>59.64</td>
<td>80.90</td>
<td>100.00</td>
<td>80.00</td>
<td>95.08</td>
<td>95.08</td>
<td>100.00</td>
<td>100.00</td>
<td>95.08</td>
<td>95.08</td>
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<tr>
<td>H2O Vol.%</td>
<td>27.18</td>
<td>1.22</td>
<td>0.00</td>
<td>1.22</td>
<td>2.38</td>
<td>2.38</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>CO Vol.%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>15.72</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>CO2 Vol.%</td>
<td>11.59</td>
<td>15.72</td>
<td>0.00</td>
<td>0.00</td>
<td>100.00</td>
<td>100.00</td>
<td>2.53</td>
<td>2.53</td>
<td>2.53</td>
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<tr>
<td>CH4 Vol.%</td>
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<td>0.00</td>
<td>2.15</td>
<td>5.53</td>
<td>5.53</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>N2 Vol.%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>O2 Vol.%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Flow Nm3</td>
<td>1742.41</td>
<td>1284.4</td>
<td>1284.4</td>
<td>1092.86</td>
<td>201.9</td>
<td>49.60</td>
<td>1043.26</td>
<td>3.71</td>
<td>1039.56</td>
<td>40</td>
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<tr>
<td>Temperature °C</td>
<td>380</td>
<td>25</td>
<td>25</td>
<td>6.8</td>
<td>6.70</td>
<td>6.70</td>
<td>6.70</td>
<td>6.7</td>
<td>0.01</td>
<td>6.65</td>
</tr>
<tr>
<td>Temperature bar</td>
<td>5.7</td>
<td>5.5</td>
<td>5.5</td>
<td>6.8</td>
<td>6.70</td>
<td>6.70</td>
<td>6.70</td>
<td>6.7</td>
<td>0.01</td>
<td>6.65</td>
</tr>
<tr>
<td>Flow kg</td>
<td>904.17</td>
<td>536.35</td>
<td>536.35</td>
<td>148.25</td>
<td>396.41</td>
<td>6.53</td>
<td>141.72</td>
<td>4.63</td>
<td>136.93</td>
<td>40</td>
</tr>
</tbody>
</table>

*Remark: The CO-Content in the Gas after Shifter has been (for simplification reason) put on Zero; in reality this is not possible. There is a certain distance from the equilibrium. The negligence of the CO-Content will not affect the results of the overall calculation.*
Mass-Balance for new DR-Concept (cold DRI)

\[ \Sigma N = 4.63 \text{ kg} \]

\[ \Sigma H = 0.92 \text{ kg} \]
\[ \Sigma O = 7.40 \text{ kg} \]
\[ \Sigma N = 8.32 \text{ kg} \]

\[ \Sigma C = 108.10 \text{ kg} \]
\[ \Sigma O = 288.30 \text{ kg} \]

\[ \Sigma H = 4.33 \text{ kg} \]
\[ \Sigma O = 0.84 \text{ kg} \]
\[ \Sigma N = 1.36 \text{ kg} \]

\[ \Sigma O = 380.3 \text{ kg} \]
\[ C = 16.55 \text{ kg} \]
\[ \Sigma H = 40.87 \text{ kg} \]
\[ \Sigma O = 326.96 \text{ kg} \]
\[ \Sigma C = 367.83 \text{ kg} \]

\[ \Sigma N = 1.36 \text{ kg} \]

\[ \Sigma O = 0.257 \text{ kg} \]
\[ \Sigma H = 46.12 \text{ kg} \]
\[ \Sigma C = 135.68 \text{ kg} \]

\[ \Sigma C (\text{in}) = 135.68 \text{ kg} \]
\[ \Sigma C (\text{out}) = 135.68 \text{ kg} \]

\[ \Sigma H (\text{in}) = 46.13 \text{ kg} \]
\[ \Sigma H (\text{out}) = 46.12 \text{ kg} \]

\[ \Sigma O (\text{in}) = 616.10 \text{ kg} \]
\[ \Sigma O (\text{out}) = 616.10 \text{ kg} \]

\[ \Sigma N (\text{in}) = 6.00 \text{ kg} \]
\[ \Sigma N (\text{out}) = 6.00 \text{ kg} \]

\[ \text{DRI} = 1000 \text{ kg} \]
Energy-Balance for new DR-Concept (cold DRI)
## Energy consumption and CO₂ emissions

### General

<table>
<thead>
<tr>
<th></th>
<th>Midrex (normal module)</th>
<th>Midrex Oxy</th>
<th>Hyl (with reformer)</th>
<th>Hyl (zero reformer)</th>
<th>new process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption (GJ / t DRI)</td>
<td>9.83 10.5</td>
<td>n.n</td>
<td>9.88 10.3</td>
<td>?</td>
<td>7.95 8.3</td>
</tr>
<tr>
<td>Cold discharge</td>
<td>130</td>
<td>115</td>
<td>85</td>
<td>105</td>
<td>60</td>
</tr>
<tr>
<td>Hot discharge</td>
<td>1.3</td>
<td>1.3</td>
<td></td>
<td>1.3</td>
<td>0</td>
</tr>
<tr>
<td>El. Power consumption (kWh / t DRI)</td>
<td>max.20</td>
<td>&gt; 50</td>
<td>max.20</td>
<td>40-50</td>
<td>160</td>
</tr>
<tr>
<td>Oxygen consumption (Nm3 / t DRI)</td>
<td>1.3</td>
<td>1.3</td>
<td></td>
<td>1.3</td>
<td>0</td>
</tr>
<tr>
<td>Water consumption (m³ / t DRI)</td>
<td>538</td>
<td>?</td>
<td>541</td>
<td>514</td>
<td>435</td>
</tr>
<tr>
<td>CO₂-Emission (kg / t DRI)</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

**Equipment**

<table>
<thead>
<tr>
<th></th>
<th>Midrex (Standard)</th>
<th>Midrex oxy+</th>
<th>Hyl (with reformer)</th>
<th>Hyl (zero reformer)</th>
<th>new Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heater</td>
<td>no</td>
<td>yes (big)</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Reformer</td>
<td>no</td>
<td>yes (smaller)</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Generator for partial oxydation</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>CO₂ Removal</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

*includes the Carbon in the DRI / cold DRI
## Capex & Opex

### DR-Plant (new concept)

<table>
<thead>
<tr>
<th>Proc. / t DRI</th>
<th>Prod. Mo t/a</th>
<th>unit</th>
<th>€ / unit</th>
<th>€ / t</th>
<th>€ / t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallisierung</td>
<td>%</td>
<td>92</td>
<td></td>
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<td></td>
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<tr>
<td>Kohlenstoff</td>
<td>%</td>
<td>2.76</td>
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<tr>
<td>Temperatur DRI</td>
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</tr>
<tr>
<td>Pellets (%)</td>
<td>100</td>
<td>t</td>
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<td>1.39</td>
<td>100.08</td>
</tr>
<tr>
<td>lump (%)</td>
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<td>t</td>
<td>63</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Iron ore total</td>
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<td>1.39</td>
<td>100.08</td>
<td></td>
</tr>
<tr>
<td>Process-Gas (Nat.gas)</td>
<td>GJ</td>
<td>7</td>
<td>7.95</td>
<td>55.65</td>
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<tr>
<td>Fuel (Nat.gas)</td>
<td>GJ</td>
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<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>Energy total</td>
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<td>55.65</td>
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<tr>
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<td>60</td>
<td>3.6</td>
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<tr>
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<tr>
<td>Nitrogen</td>
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<tr>
<td>DMDS</td>
<td>kg</td>
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<td>0.005</td>
<td>0.009</td>
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</tr>
<tr>
<td>MDEA</td>
<td>Removal</td>
<td>lt</td>
<td>1.8</td>
<td>0.005</td>
<td>0.009</td>
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<tr>
<td>Coating</td>
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<tr>
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<td>% of inv.</td>
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<td>4.8</td>
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<tr>
<td>Labor</td>
<td>mh</td>
<td>35</td>
<td>0.09</td>
<td>3.08</td>
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</tr>
<tr>
<td>Others</td>
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<tr>
<td>Total Operation</td>
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</tr>
<tr>
<td>Int. Transport</td>
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<td>1</td>
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<tr>
<td>Total Total</td>
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### DR-Plant (Midrex)

<table>
<thead>
<tr>
<th>Proc. / t DRI</th>
<th>Prod. Mo t/a</th>
<th>unit</th>
<th>€ / unit</th>
<th>€ / t</th>
<th>€ / t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallisierung</td>
<td>%</td>
<td>92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kohlenstoff</td>
<td>%</td>
<td>2.5</td>
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<tr>
<td>Temperatur DRI</td>
<td>°C</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Pellets (%)</td>
<td>100</td>
<td>t</td>
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<td>104.4</td>
</tr>
<tr>
<td>lump (%)</td>
<td>0</td>
<td>t</td>
<td>63</td>
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</tr>
<tr>
<td>Iron ore total</td>
<td></td>
<td></td>
<td>1.45</td>
<td>104.4</td>
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<tr>
<td>Process-Gas (Nat.gas)</td>
<td>GJ</td>
<td>7</td>
<td>10.2</td>
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<tr>
<td>Fuel (Nat.gas)</td>
<td>GJ</td>
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<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>Energy total</td>
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<td>10.2</td>
<td>71.4</td>
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<td>ele. Power</td>
<td>kWh</td>
<td>0.06</td>
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<td>Oxygen</td>
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<td>Water</td>
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<tr>
<td>MDEA</td>
<td>Removal</td>
<td>lt</td>
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<tr>
<td>Coating</td>
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<tr>
<td>Chemicals for Water</td>
<td>kg</td>
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<tr>
<td>Maintenance</td>
<td>% of inv.</td>
<td>2</td>
<td>2.4</td>
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<tr>
<td>Labor</td>
<td>mh</td>
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<td>0.09</td>
<td>3.08</td>
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<tr>
<td>Others</td>
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<td></td>
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<td>Total Operation</td>
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<td>Int. Transport</td>
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<td>1</td>
<td>0</td>
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<tr>
<td>Total Total</td>
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<td></td>
<td>184.41</td>
</tr>
</tbody>
</table>

- Estimated investment for Capex: **160 Mio €**
- Estimated investment for Opex: **120 Mio €**
SUMMARY

• Can be "quick-fix" for a brown field improvement of CO$_2$ emissions, especially where natural gas is relatively cheap.

• By integration in a steel plant, LRI can be a choice considering the successful tests made in the LKAB Experimental BF.
  – The LRI-tests with a DR-product reduced to only 65% metallization degree respond very positive in the BF with stable operation and coke consumption at 200 kg/tHM.

• Tests has to be done to prove the concept.
EXPERIMENTAL DR PLANT

- Production: 1 ton Fe/h
- Recirculation of top gas
- Working pressure (shaft) 0-8 bar (g)
- Gas flow: ~1700-3100 Nm3/h
- Temp to shaft: 900-1050 ºC
EXPERIMENTAL DR PLANT
WE STRIVING FOR A SUSTAINABLE FUTURE

THANK YOU
**CHARGING A PRE-REDUCED BURDEN INTO EBF**

**Trials during 2 campaigns in the Experimental BF**

- **DRI at 15, 30 and 60 % of the burden**
  - Reductant rate decrease up to 26 %
  - Emission of CO$_2$ decreased up to 24%
  - DRI metallisation degree over 90 %.

- **LRI at 50 and 100 % of the burden**
  - Reductant rate decrease up to 33 %
  - Emission of CO$_2$ decreased up to 37%
  - LRI metallization degree about 65%

**Significant productivity increase with increasing amount of pre-reduced iron ore**