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Potential for CO$_2$ Mitigation of the European Steel Industry

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Introduction and background

Baseline CO₂ emissions calculation of EU27 steel industry in 1990 and 2010

Technology review

Incremental CO₂ reduction Potentials

Forecast for 2050 EU27 steel production and scrap availability

CO₂ reduction for 2050 scenarios

CO₂ mitigation by steel application

Conclusions
Introduction and background

- European Union defined ambitious target for CO₂ emission reduction for European Industry of 80 to 95% compared to 1990 until 2050

- Therefore EUROFER contracted the Boston Consulting Group in collaboration with the Steel Institute VDEh to obtain a realistic view of the EU 27 steel sector's CO₂ mitigation capabilities based on physical / technical limits as well as economic considerations

- A functioning steel industry is crucial for Europe, hence BCG/VDEh do not assume a deindustrialization of Europe, but rather evaluate:-

  - Steels own CO₂ mitigation potential by sharing best practices, implementing incremental improvements and alternative steel-making technologies as well as combinations with CCS as an end-of-pipe option
  
  - Indirect effects of steel as a mitigation enabler, i.e. the CO₂ savings by applications where steel and only steel leads to CO₂ savings
### Overview of iron- and steel-making routes

<table>
<thead>
<tr>
<th>Raw material</th>
<th>BOF steel</th>
<th>EAF steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lump ore</td>
<td>lump ore</td>
<td>lump ore</td>
</tr>
<tr>
<td>Fine ore</td>
<td>fine ore</td>
<td>fine ore</td>
</tr>
</tbody>
</table>

#### Raw material preparation

- **Integrated route**
  - Lump ore
  - Fine ore

- **Smelting reduction**
  - Lump ore
  - Fine ore

- **Direct reduction**
  - Lump ore
  - Fine ore

- **Scrap**
  - Lump ore
  - Fine ore

#### Iron making

- **Blast furnace**
  - Coal, oil, or natural gas
  - Blast furnace
  - Hot metal

- **Blast furnace**
  - Coal, oil, or natural gas
  - Blast furnace
  - Hot metal

- **Melter-gasifier**
  - Reducing gas
  - Fluidized bed

#### Steel making

- **BOF steel**
  - Crude steel
  - Finished products (flat & long)

- **EAF steel**
  - Crude steel
  - Finished products (flat & long)
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System boundaries mirror steel's CO₂ footprint originated in EU27

Scope I—direct CO₂ emissions from the following facilities:
- Sintering
- Pelletizing
- Coke making
- Iron making
- Steel making
- Casting + hot rolling

Cold rolling + further processing

Scope II—indirect CO₂ emissions from purchased electricity

Scope III—indirect CO₂ emissions from purchased materials (produced in EU27):
- Pellets
- DRI
- Pig iron
- Graphite electrodes
- Credits for process gases
- Oxygen
- Steam
- Coke
- Burnt lime
- Credits for slag

System boundaries for base line

Sources: World Steel Association; Project team analysis.
1. The utilization of byproducts, such as process gases or waste heat, is not counted as a credit, because such use helps reduce the energy consumption of aggregates. Only byproduct gases that are sold to a second party can be counted as a credit, because they help to reduce emissions of a different sector. 2. Currently no credits are given for the CO₂ savings through slag usage in cement production.
The starting point: EU27's specific CO₂ intensity decreased 14%, absolute emissions in 2010 dropped by 25%, from 1990 figures

![Diagram showing specific emissions, production shares, and total CO₂ emissions from 1990 to 2010.]

| Specific emissions x Production share = Avg. CO₂ intensity x Crude steel production = Total CO₂ emissions |
|-------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|
| kg CO₂/t crude steel | % | kg CO₂/t crude steel | Mt | Mt CO₂ |
| 1,968 | 66 | 1,508 | 298 |
| 1,888 | 28 | 1,293 | 223 |
| 1990 | 1990 | | 1990 |
| 455 | 41 | 173 | |
| 2010 | 2010 | | 2010 |

-32% -14% -12% -25%

-4% +46% +46%

Note: Figures include the process step of hot rolling.

1. Includes BF-OHF share of 6 percent in 1990 and 0.4 percent in 2010, accounting for 3 and 0.2 Mt CO₂, respectively.
The development since 1990: Significant reduction of CO\textsubscript{2} emissions from 1990 to 2010, mainly driven by volume effects.
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CO\textsubscript{2} mitigation by steel application

Conclusions
## Technology review

<table>
<thead>
<tr>
<th>Incremental</th>
<th>Alternative (Substitution and Breakthrough)</th>
<th>Integrated route</th>
<th>EAF route</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agglomeration</strong></td>
<td></td>
<td><strong>Injection of H₂ rich reductants</strong>¹</td>
<td></td>
</tr>
<tr>
<td>- Sinter plant cooler heat recovery</td>
<td></td>
<td>- Injection of H₂ into shaft</td>
<td>- Heat recovery</td>
</tr>
<tr>
<td>- Coke dry quenching (CDQ)</td>
<td></td>
<td>- Optimization of Pellet ratio to Blast Furnace</td>
<td>- Optimization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Top gas recovery turbine</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Waste gas recovery</td>
<td>- Top gas recovery (TGR)</td>
</tr>
</tbody>
</table>

### Synergies between different technologies²
- Corex
- Finex
- HIsarna

### Combination of technologies with CCS³
- Midrex / HyL based on natural gas
- Finmet / Ulcored based on natural gas + fine ores

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¹ Includes the potential use of coke oven gas as reductant
² E.g., use of coke oven gas for DR, BF+Corex/Finex+DR, use of Corex/Finex gas for DR
³ BF: CCS after power plant, TGR with CCS, Corex/Finex with CCS, HIsarna with CCS, EAF: gas based DR with CCS, Ulcored with CCS
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Overview of the CO$_2$ abatement potential of incremental technologies applied in economically viable scenarios

### Per ton product: CO$_2$ saving potential

<table>
<thead>
<tr>
<th>Process</th>
<th>kg CO$_2$/t product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinter plant cooler heat recovery</td>
<td>16</td>
</tr>
<tr>
<td>CDQ$^1$</td>
<td>54</td>
</tr>
<tr>
<td>TRT</td>
<td>11</td>
</tr>
<tr>
<td>Optimization of pellet ratio to BF$^2$</td>
<td>132</td>
</tr>
<tr>
<td>COG inject. BF</td>
<td>94</td>
</tr>
<tr>
<td>TGR-BF</td>
<td>209</td>
</tr>
<tr>
<td>BOF gas recycling</td>
<td>23</td>
</tr>
<tr>
<td>EAF process optimization</td>
<td>19</td>
</tr>
</tbody>
</table>

### Per ton of crude steel: CO$_2$ saving potential

<table>
<thead>
<tr>
<th>Process</th>
<th>kg CO$_2$/t crude steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinter plant cooler heat recovery</td>
<td>13</td>
</tr>
<tr>
<td>CDQ$^1$</td>
<td>18</td>
</tr>
<tr>
<td>TRT</td>
<td>9</td>
</tr>
<tr>
<td>Optimization of pellet ratio to BF$^2$</td>
<td>119</td>
</tr>
<tr>
<td>COG inject. BF</td>
<td>54$^3$</td>
</tr>
<tr>
<td>TGR-BF</td>
<td>189</td>
</tr>
<tr>
<td>BOF gas recycling</td>
<td>24</td>
</tr>
<tr>
<td>EAF process optimization</td>
<td>20</td>
</tr>
</tbody>
</table>

**Penetration in 2010 (%):**

<table>
<thead>
<tr>
<th>Process</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinter plant cooler heat recovery</td>
<td>20</td>
</tr>
<tr>
<td>CDQ$^1$</td>
<td>10</td>
</tr>
<tr>
<td>TRT</td>
<td>45</td>
</tr>
<tr>
<td>Optimization of pellet ratio to BF$^2$</td>
<td>8</td>
</tr>
<tr>
<td>COG inject. BF</td>
<td>2</td>
</tr>
<tr>
<td>TGR-BF</td>
<td>0</td>
</tr>
<tr>
<td>BOF gas recycling</td>
<td>75</td>
</tr>
<tr>
<td>EAF process optimization</td>
<td>0</td>
</tr>
</tbody>
</table>

1. It is sometimes argued that during wet quenching around 1 percent of the coke produced is lost because of burning when the coke is in contact with the surrounding air during transport to the quenching facility. This would reduce CO$_2$ savings from 54 to 22 kg CO$_2$ per ton of coke for 2010. Assuming a CO$_2$ intensity of 210 g CO$_2$ per kWh, this would even result in a negative CO$_2$ balance for CDQ of about 6 kg CO$_2$ per ton of coke.  
2. 100% pellet ratio assumed for calculations  
3. If credits for slag were to be taken into consideration, this would reduce the effect of 100 percent pellet-operated BFs by 72 kg CO$_2$ per ton of hot metal (or 65 kg CO$_2$ per ton of crude steel) because of a lower slag volume of around 130 kg (based on operational plant data). Depending on the grade of pellets, fluxes—which normally are bound into the sinter—may have to be charged directly into the BF, which could increase CO$_2$ emissions from blast furnace operations. In optimizing the pellet ratio the trade off between operational benefits due to lower slag volumes and less CO$_2$ savings in the cement industry pertaining to slag, have to be considered.

Note: Saving potential per ton of crude steel is calculated on the basis of respective material-input amounts as well as yield factors for each process step.
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The baseline forward: Moderate annual growth of crude steel production expected (0.8 percent from 2010 until 2050)

Historically, crude steel production stable in EU15 but declining in Eastern Europe

Going forward, slow growth expected for EU27, 2007 production level to be reached in 2032

Note: e = estimate
Source: World Steel Association; Project team analysis
Scrap availability forecasted to grow by 0.9 percent annually until 2050, mainly driven by obsolete scrap

Scrap availability driven by three scrap types

<table>
<thead>
<tr>
<th>Scrape availability</th>
<th>Crude steel production</th>
<th>Scrap rate (%)</th>
<th>Life-time (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New/prompt scrap</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Production waste and errors in conversion of crude to finished</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Depending on efficiency of production process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Home scrap</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Production waste and errors in steel-using sectors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Depending on industry sector</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Obsolete/old scrap</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Steel in products at the end of their life cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Depending on scrap recovery rate and life cycle per sector</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total available scrap in EU27 (in Mt)

- 103 Mt in 1990
- 94 Mt in 2005
- 20 Mt in 2007
- 111 Mt in 2009
- 84 Mt in 2010
- 18 Mt in 2011
- 112 Mt in 2030
- 26 Mt in 2050

Source: Project team analysis

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Overview of CO₂ intensity per route for 2010 and 2050

### Drivers

- **Scrap-EAF**
  - 2010: 0.46 t CO₂ / t crude steel (24%)
  - 2050: 0.33 t CO₂ / t crude steel (20%)

- **BF-BOF**
  - 2010: 1.89 t CO₂ / t crude steel (100%)
  - 2050: 1.66 t CO₂ / t crude steel (100%)

- **DRI-EAF¹**
  - 2010: 1.20 t CO₂ / t crude steel (63%)
  - 2050: 1.00 t CO₂ / t crude steel (60%)

- **Smelt. red.²-BOF**
  - 2010: 2.42 t CO₂ / t crude steel (128%)
  - 2050: 2.30 t CO₂ / t crude steel (139%)

### Notes

- **Best-practice sharing + incremental technologies**
- **Hot charging in 2050**
- **5% efficiency gain**

**CO₂ intensity of purchased electricity** (429 g CO₂ / kWh in 2010 and 221 g CO₂ / kWh in 2050)

### Sources

1. Based on Midrex direct reduction technology
2. Based on Finex smelting reduction technology

Note: Differences between routes in production of the by-product slag not considered in analysis

Sources: VDEh; Project team analysis

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1. Based on Midrex direct reduction technology
2. Based on Finex smelting reduction technology
The option space for possible CO₂ abatement until 2050

- CSP forecast + CO₂ intensity on 2010 level
- Increased EAF-share based on scrap availability + best-practice sharing
- 44% Scrap-EAF, 45% DRI-EAF, 11% BF-BOF; incremental improvements esp. for BF-BOF

-60% and -80% compared to 1990

<table>
<thead>
<tr>
<th>Year</th>
<th>Crude Steel Production [Mt crude steel]</th>
<th>Specific CO₂ Intensity [kg CO₂/t crude steel]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>197.4</td>
<td>1,508</td>
</tr>
<tr>
<td>2009</td>
<td>139.3</td>
<td>1,293</td>
</tr>
<tr>
<td>2010</td>
<td>172.8</td>
<td>1,293</td>
</tr>
<tr>
<td>2030</td>
<td>204</td>
<td>1,145</td>
</tr>
<tr>
<td>2050</td>
<td>236</td>
<td>778</td>
</tr>
</tbody>
</table>

1. 2009 crude steel production with 2010 CO₂ intensity and 2010 Scrap-EAF share
Source: EUROFER Benchmark 2007/2008; VDEh data exchange 1990/2010; Project team analysis
Economic feasibility assessment of the technologies

- Economic feasibility was computed by comparing costs (CAPEX and OPEX) with the potential savings over considered investment period, depending on different price scenarios.

- The price scenarios included a reference-price scenario (inflation only), medium-price scenario (doubling of real input factor costs) and high-price scenario (fivefold increase of input factor costs).

- The economically feasible technologies were gradually implemented based on varying adaptation curves for the different scenarios.
A comparison of capital expenditures for alternative steel-making technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>2010 CAPEX (€/t CS)</th>
<th>BF-BOF retrofit</th>
<th>Scrap-EAF</th>
<th>Smelting reduction</th>
<th>DRI-EAF</th>
<th>BF-BOF greenfield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>108</td>
<td></td>
<td>231</td>
<td>243</td>
</tr>
</tbody>
</table>

 Costs normalized BF-BOF retrofit = 100

1. BOF: 50 percent of Greenfield investment  
2. BF: 50 percent of Greenfield investment  
3. Sinter: 30 percent of Greenfield investment  
4. Coke: 15 percent of Greenfield investment  

Note: CS = crude steel

Source: Diemer et. al., 2011; Steel Institute VDEh; Project team analysis
A comparison of the operating expenses of alternative steel-making technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>OPEX 2010 (€/t CS)</th>
<th>Other OPEX</th>
<th>OPEX—input factor costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF-BOF</td>
<td>100</td>
<td>76%</td>
<td>24%</td>
</tr>
<tr>
<td>DRI-EAF&lt;sup&gt;1&lt;/sup&gt;</td>
<td>103</td>
<td>13%</td>
<td>87%</td>
</tr>
<tr>
<td>Smelting reduction&lt;sup&gt;2&lt;/sup&gt;</td>
<td>114</td>
<td>18%</td>
<td>82%</td>
</tr>
<tr>
<td>Scrap-EAF</td>
<td>133</td>
<td>12%</td>
<td>88%</td>
</tr>
</tbody>
</table>

Note: CS = crude steel

1. Based on Midrex direct reduction technology  2. Based on Finex smelting reduction technology

Source: Steel Institute VDEh; Project team analysis
CO$_2$ Abatement Economic Scenarios for 2050: Around 10-13 Percent as Compared with 1990 (Close to Point B)

Abatement cost of moving from existing BF-BOF to DRI-EAF: 260 to 700€/tCO$_2$

**Upper boundary**
- Crude steel production forecast & CO$_2$ intensity on 2010 level
- Increased EAF-share on the basis of scrap availability & best-practice sharing

**Economic scenarios**

**Lower theoretical boundary without CCUS**
- 44% Scrap-EAF, 45% DRI-EAF, 11% BF-BOF; increased improvements, especially for BF-BOF

### Crude steel production [Mt crude steel]

- 1990: 197.4
- 2009: 139.3
- 2010: 172.8
- 2030: 204
- 2050: 236

### Specific CO$_2$ intensity [kg CO$_2$/t crude steel]

- 1990: 1,508
- 2009: 1,293
- 2010: 1,219
- 2030: 1,145
- 2050: 778

1. 2009 crude steel production with 2010 CO$_2$ intensity and 2010 Scrap-EAF share
   Source: EUROFER Benchmark 2007/2008; VDEh data exchange 1990/2010; Project team analysis
Development of average specific CO₂ intensity for different scenarios (without CCUS)

kg CO₂/t crude steel (including hot rolling)

-14%

-24%

-26% to -28%

-48%

1. Input factor prices adjusted for inflation
2. Doubling of (real) input-factor prices from 2010 until 2050
3. Fivefold increase of (real) input-factor prices from 2010 to 2050

Note: All scenarios are without CCUS
Source: EUROFER Benchmark 2007/2008; VDEh data exchange 1990/2010; Project team analysis
Absolute CO₂ emissions in 2050 could be almost 60% lower than in the 1990s with the full implementation of CCUS

Abatement cost of moving from existing BF-BOF to DRI-EAF: 260 to 700€/tCO₂

Crude steel production [Mt crude steel]
- 197.4 (1990)
- 139.3 (2009)
- 172.8 (2010)
- 204 (2030)
- 236 (2050)

Specific CO₂ intensity [kg CO₂/t crude steel]
- 1,508 (1990)
- 1,293 (2010)
- 1,219 (2030)
- 1,145 (2050)

Economically viable
Not economically viable

1. 2009 crude-steel production with 2010 CO₂ intensity and 2010 Scrap-EAF share
Source: EUROFER Benchmark 2007/2008; VDEh data exchange 1990/2010; Project team analysis

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Stringent four-step logic applied to isolate the case studies for evaluating steel's own mitigation potential

**Initial list**
- Weight reduction cars
- Onshore/offshore wind power
- Leaf springs
- Rubber-enforcing steel structures for tires
- Motor systems
- Assembled camshafts
- CCS
- Structural steel
- ...  

**Focus on EU-27**

1. **Geography**
2. Potential impact vs. 2010
3. Substitution of materials
4. Absolute potential

**Selection:** Only savings that are 100% attributable to steel are taken into account

*Sources: VDEh; BCG/VDEh analysis.*
Eight case studies for EU27 show annual CO₂ savings of about 440 Mt attributed to steel and only 70 Mt of extra CO₂ Emissions.

<table>
<thead>
<tr>
<th>Case study</th>
<th>Net CO₂ reduction potential²</th>
<th>Emissions in the steel production</th>
<th>Ratio between CO₂ reduction / emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficient fossil fuel PPs</td>
<td>103.0</td>
<td>0.7</td>
<td>~ 155:1</td>
</tr>
<tr>
<td>Offshore wind power</td>
<td>69.7</td>
<td>3.0</td>
<td>~ 23:1</td>
</tr>
<tr>
<td>Other renewables¹</td>
<td>22.2</td>
<td>0.16</td>
<td>~ 148:1</td>
</tr>
<tr>
<td>Efficient transformers</td>
<td>19.6</td>
<td>1.2</td>
<td>~ 17:1</td>
</tr>
<tr>
<td>Efficient e-motors</td>
<td>6.9</td>
<td>3.2</td>
<td>~ 2:1</td>
</tr>
<tr>
<td>Weight reduction cars</td>
<td>6.3</td>
<td>14.0</td>
<td>~ 4:1</td>
</tr>
<tr>
<td>Weight reduction trucks</td>
<td>6.3</td>
<td>5.3</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Combined heat / power</td>
<td>49.6</td>
<td>5.3</td>
<td>~ 9:1</td>
</tr>
</tbody>
</table>


Note: PP = power plant
Source: BCG/VDEh analysis.

Total CO₂ emissions: Σ ~ 443 Mt / yr.
Total CO₂ reduction: Σ ~ 70 Mt / yr.
Ratio: ~ 6:1
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Conclusion to CO₂ Reduction Potential of the EU 27 Iron and Steel Industry until 2050

- The equipment of the European iron and steel industry are already operated at very high efficiency level.

- Existing potentials of energy and heat recovery provide only small contributions to increase efficiency and reduce CO₂ emissions but request high investment and operating costs.

- Steel will not be able to come anywhere near the requested CO₂ reduction of about 80% for the ETS sector between 1990 and 2050.

- A reduction of 38% seems possible with a transition from coal-based to gas based reduction method. However, this would require access to raw material, scrap and energy at competitive prices, incentives for further investment and full offset of distortive CO₂ costs.

- A CO₂ reduction of 56% seems possible with the implementation of CCS.

- The use of steel makes a significant contribution to CO₂ emission reduction.
Thanks for your attention