LIFE CYCLE ASSESSMENT OF THE INTEGRATED PRODUCTION OF STEEL AND CHEMICALS

Berlin, October 28, 2020
Dr. Daniel Maga, Dr. Nils Thonemann, Dr. Markus Hiebel
Goal and scope

Goal

- Comparative life cycle assessment of the integrated production of steel and chemicals in comparison to standalone production

Investigated scenarios

- Integrated production of steel and
  - Methanol
  - Urea
  - Higher alcohols
  - Methanol and polycarbonates

System boundary

Quelle: [MEV-Verlag](https://www.thyssenkrupp-steel.com/de/)
Quelle: Thyssen Krupp presents innovative concept for green transformation of Duisburg steel mill (562765)
Handling of multi-functionality

Approach to compare stand-alone production of steel and chemicals with integrated production

- System expansion
  - Functional unit covers steel and chemical production

Example of steel and methanol production

System boundaries of integrated steel mill

- **Main inputs**
  - Iron ore
  - Coal
  - Steam
  - Lime
  - Oxygen

- **Produced steel mill gases (SMG)**
  - Blast furnace gas (BFG)
  - Basic oxygen furnace gas (BOFG)
  - Coke oven gas (COG)
System boundaries of integrated steel and chemical production

- Electricity from the power plant is used in integrated steel mill
- Additional electricity demand is supplied
  - by the grid mix in 2030 (ESDP*)
  - by wind power (wind)

* ESDP = Energy System Development Plan
Power supply

- Data from Energy System Development Plan (ESDP)
  - tool to calculate energy generation, consumption, and conversion flows for a concrete national or regional energy system
  - Time horizon 2030

- Average Carbon Footprint ~ 0.5 kg CO₂-eq./kWh

- Alternatively wind power

Data basis for the life cycle assessment

Process simulations

1. Process-technology model (PT)
   - precise modeling of the reactors links this model to a dynamic process simulation of the network

2. Co-Simulation (CS)
   - links sub models of several academic and industrial partners within the Carbon2Chem® project via the internet to a cross-industrial network simulation

3. Process-logistics model (PLM)
   - mixed-integer linear programming model that focuses on the precise simulation of the management and supply of energy and materials between units
Investigated scenarios
Main assumptions

- Basic assumptions for all simulation models
  - About 8.5 Mio. tons of steel mill gases (SMG) are directed to the Carbon2Chem® facilities and are avoided in the power plant of the integrated steel mill (BFG and COG)
  - No changes in the operation of the integrated steel mill

- Scenarios
  - Jumbo: 8.5 Mio. tons of SMG are directed to chemical production
  - Industrial: Only a small part of SMG is directed to chemical production, rest goes to power plant
  - COG max: The entire COG is used for chemical production
  - Watergas shift reaction (WGS): Additional reactor to shift CO to CO₂ and H₂ (higher yields vs. additional process unit)
Functional unit in the case of methanol production

- The functional unit refers to the steel production in Duisburg in 2016 and the investigated scenario
  - 8.4 Mio. t steel per year
  - 0.3 – 5.8 Mio. t methanol per year

- Reference: Average methanol production mix of Germany
  - Synthesis gas for methanol production is produced by steam reforming and partial combustion

Reference: Average methanol production mix of Germany
Further assumptions

- Emissions of the integrated steel mill are reduced by the use of steel mill gases
- Total CO₂ emissions of the integrated steel mill incl. prechains: approx. 17 Mio. t per year
- Avoided greenhouse gas emissions by utilization of SMG in Carbon2Chem® are calculated through 100 % conversion of SMG to CO₂
- Steam produced in new power plant covers the entire steam demand of the integrated steel mill
- Not considered processes
  - Waste water treatment
  - Gas purification for watergas shift reaction
  - Catalysts
  - Transport of hydrogen
Results for methanol jumbo scenarios (ESDP mix 2030)

Global warming impact

- Products
  - ~ 4.1 – 4.4 Mio. t methanol and 8.4 Mio. t steel
  - Jumbo scenario

- Different simulation tools lead to similar results

- Integrated production of steel and methanol shows higher GWI compared to stand-alone production

GWI = Global Warming Impact; ESDP = Energy System Development Plan
Results for methanol | Various scenarios (ESDP mix 2030) Global warming impact

- Products
  - ~ 0.3 - 5.8 Mio. t methanol and 8.4 Mio. t steel

- Industrial scenario
  - Less methanol and less H₂ demand

- COG max scenarios
  - No external H₂ demand (similar to reference)

- WGS scenarios slightly better
Results for methanol (Wind power)
Global warming impact

- Products
  ~ 0.3 - 5.8 Mio. t methanol and 8.4 Mio. t steel
- Power provided by wind
- Integrated production of steel and methanol shows smaller global warming impact compared to stand-alone production

![Graph showing GWI (kg CO2-Äq./FU) for different processes and scenarios.]

- GWI = Global Warming Impact
- NG = Natural Gas

Legend:
- 01 Steel production
- 01a External elec. steel
- 02 Methanol production
- 03 Electricity H2 + Compressors
- 04 Power plant
- 05 NG for power plant
- 06 Cooling
- 01 - Methanol
- 02 - Hot rolled coil

WGS Scenarios
Results for urea
Global warming impact

- **Products**
  - ~10 Mio. t urea and 8.4 Mio. t steel

- **Cooling** was not modelled due to lacking data

- **GWI of urea production** smaller than reference

- In the case of ESPD, electricity contributes to approx. 65% of the GWI

- **GWI of urea production with wind power** approx. 1/3 of GWI

GWI = Global Warming Impact

![Graph showing GWI for different processes and technologies](image)
Results for higher alcohols
Global warming impact

- Products
  - 3.3 Mio. t petrol and 8.4 Mio. t steel
- Total hydration of alkenes to higher alcohols
- GWI of integrated production approx. 2 times higher than reference (ESDP)
- Only approx. 1/2 of GWI with wind power

![GWI Chart]

GWI = Global Warming Impact
Results for polycarbonates and methanol
Global warming impact

- Products
  - Methanol 1.5 Mio. t
  - NaOH 0.1 Mio. t
  - Polycarbonates 0.3 Mio. t
  - 8.4 Mio. t steel
- ESDP mix: 8 % higher than reference
- Wind power: 21 % smaller GWI
Comparison of Break-Even-Points

- Urea production leads to the highest Break-Even-Point (BEP)
  - GHG savings can be achieved today
- Methanol & polycarbonate production associated with higher BEP as methanol alone
- Higher alcohol production related to a BEP of about 0.1 kg CO₂-eq./kWh

Comparison of Break-Even-Points

<table>
<thead>
<tr>
<th>GWI = Global Warming Impact</th>
<th>Methanol &amp; PC-PT</th>
<th>Higher alcohols</th>
<th>Methanol and PC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break-Even-Points (kg CO₂-eq./kWh)</td>
<td>Methanol</td>
<td>Urea</td>
<td>Methanol</td>
</tr>
<tr>
<td>Methanol</td>
<td>Urea</td>
<td>Methanol</td>
<td></td>
</tr>
<tr>
<td>Methanol PT Jumbo</td>
<td>Methanol PT Industrial</td>
<td>Methanol PT COG max</td>
<td>Methanol PT WGS Jumbo</td>
</tr>
</tbody>
</table>
Absolute GHG savings using wind power

- Wind power
- Urea shows highest savings
- Methanol: Jumbo scenarios show much higher savings than industrial or COG scenarios
- Higher alcohols also lead to considerable savings
- Combination of PC and methanol can lead to higher GHG savings than methanol alone
The integrated production of steel and chemicals allows GHG reductions compared to stand-alone production.

The global warming impact mainly depends on two drivers:

1. Power demand for hydrogen production
   - Lowest hydrogen demand is needed for urea production, highest for higher alcohols

2. The product yields
   - Urea production scenario has the highest product yield (mass balance) followed by methanol and higher alcohols
The break-even-point is a suitable indicator to show at which carbon intensity of power generation the integrated production of steel and chemicals becomes beneficial.

- Depending on the target product and the production conditions, the BEP lies between approximately 0.2 and 0.5 kg CO₂-eq./kWh.
- In 2019, the carbon intensity of the German power production was about 0.5 kg CO₂-eq./kWh [Umweltbundesamt-2020].
- For urea, already today GHG savings can be achieved.

In the case of using wind power all scenarios lead to GHG savings:
- Total GHG emissions can be reduced by 5 to 25 Mio. t CO₂ per year (one site).
LCA Publications in Carbon2Chem®

Environmental impacts of CO₂-based chemical production: A systematic literature review and meta-analysis

M.A. Nils Thonemann
Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Gutersloh, Germany

Location Planning for the Production of CO₂-Based Chemicals Using the Example of Olefin Production

Nils Thonemann*, Sebastian Steßel, Daniel Maga, Boris Dresen, Markus Hiebel, Björn Hunstock, GÖRGE DEERBERG, Eckard Weidner

Life Cycle Assessment of Steel Mill Gas-Based Methanol Production within the Carbon2Chem® Project

Nils Thonemann* and Daniel Maga

Integration of Results from the Energy System Development Plan into Life Cycle Assessment

Nils Thonemann*, Daniel Maga, and Cornelia Petermann

DOI: 10.1002/ece.26800017

DOI: 10.1002/ece.26800051

DOI: 10.1002/ece.26800025

Consequential life cycle assessment of carbon capture and utilization technologies within the chemical industry:

Nils Thonemann* and Massimo Fitzer

Supporting information available online.

Handling of Multi-Functionality in Life Cycle Assessments for Steel Mill Gas Based Chemical Production

Nils Thonemann*, Daniel Maga, and Cornelia Petermann

DOI: 10.1002/ece.26800025
Outlook on Carbon2Chem® Phase 2

- Analysis of promising configurations
  - Also considering technical and economical limitations

- Analysis of further impact categories and trade-offs

- Consideration of further CO₂ sources
  - Cement plant, municipal waste incineration

- Comparison of CCU to direct reduction process for steel production

- Dynamic LCA-Model
  - Integration of LCA data into simulation tools to support decision making and plant control
  - Higher resolution of environmental footprint of CCU based chemical production
  - Identification of optimal solutions from an environmental point of view
MANY THANKS FOR YOUR ATTENTION

Looking forward to a good cooperation!

Present information on Life Cycle Assessment are available here:

KONTAKT
Fraunhofer UMSICHT
Osterfelder Straße 3
46047 Oberhausen
Germany
E-Mail: info@umsicht.fraunhofer.de
Internet: http://www.umsicht.fraunhofer.de

Dr.-Ing. Markus Hiebel
Head of Department Sustainability and Participation
Sustainability Officer
+49 (0) 208 8598-1181
markus.hiebel@umsicht.fraunhofer.de

Dr.-Ing. Nils Thonemann
Sustainability and Participation
Sustainability Assessment
+49 (0) 208-8598-1536
nils.thonemann@umsicht.fraunhofer.de

Dr.-Ing. Daniel Maga
Sustainability and Participation
Group Manager Sustainability Assessment
+49 (0) 208-8598-1191
daniel.magal@umsicht.fraunhofer.de
Thank you for your attention!