SYSTEM INTEGRATION – THE CENTER PIECE OF CARBON2CHEM®

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Carbon2Chem Objectives & Challenges
System Integration
Carbon2Chem Assessment
Conclusions and final Remarks
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Carbon2Chem Objectives & Challenges

System Integration

Carbon2Chem Assessment

Conclusions and final Remarks
The approach of Carbon2Chem is to create cross-industrial network by using CO₂ emissions

- Reduction of CO₂ emissions in steel production
- Development of a new raw material source for chemical production through the holistic use of C-sources
- Creation of cross-industry value chains
- Increase of energy efficiency by building a cross-industry network
- Making energy consumption more flexible and thus providing control energy to achieve the energy transition
- Use and integration of volatile and fluctuating renewable energy
- Production of chemical products with a higher added value than electricity or heat (e.g. methanol, ammonia etc.)
- Transfer of the results to other applications with an effect on energy system transformation
The approach of Carbon2Chem is to create cross-industrial network by using CO₂ emissions.
The cross-industrial network has a significant share in the economy

- Steel
  - Sales: 40 Mrd.€
  - Employees: 100,000
  - Depreciation of fixed assets: 20-25 Years

- Energy
  - Sales: 561 Mrd.€
  - Employees: 235,000
  - Depreciation of fixed assets: 25 Years

- Chemicals
  - Sales: 200 Mrd.€
  - Employees: 464,000
  - Depreciation of fixed assets: 20 Years

GDP Germany: 3.400 Mrd.€ in 2019
Digitize: Total simulation Carbon2Chem

[2] Real-world data from steel mill thyssenkrupp Duisburg
Challenges

**System Dynamics**
- Dynamic process gases (composition, amount)
- Volatile renewable energy

**Green Hydrogen**
- Electrolysis (dynamic, capacity)
- Renewable energy

**Gas Treatment**
- Amount of gases
- Minor components

**Synthesis**
- Stability / durability
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Carbon2Chem Objectives

System Integration

Carbon2Chem Assessment

Conclusions and final Remarks
Options in Steel Production

- **Conventional blast furnace with liquid product (2000°C)**
  - $\text{Fe}_2\text{O}_3$ → CO/CO$_2$ → $C_nH_m$
  - $\text{C}$ → Fe/C

- **Direct reduction with natural gas (methane), solid reaction (1000°C)**
  - $\text{Fe}_2\text{O}_3$ → H$_2$O → H$_2$ (state of the art)
  - $\text{CH}_4$ → Fe → CO$_2$
  - Synthetic methane: P2G (Power2Gas): El. Energy + 2H$_2$O → 2H$_2$ + O$_2$
  - $4\text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$

- **Hydrogen as reducing agent, solid reaction (1000°C?)**
  - $\text{Fe}_2\text{O}_3$ → H$_2$O → $\text{H}_2$ (in RTD phase)
  - $\text{C}$ → CO$_2$ → Fe
Conventional Processes
Reference System

Ore → Coal → Natural Gas → Conventional Blast Furnace → Raw Steel → Steel Production → Power Plant → Steel → Power

16.4 Mt/a CO₂

40% → Process Gas → 60%

50 TWh/a (Hu) → Natural Gas → Chemical Production → Fertilizer → Synfuel → 5.5 Mt/a MeOH

Oil

12.5 Mt/a CO₂

Carbon 2 Chem®
Cross-industrial Network

Ore
Coal
Natural Gas

Conventional Blast Furnace

Raw Steel
Process Gas

Steel Production
20 – 40%
60 – 80%

Gas Treatment / Gas Cleaning

Electrolysis

Hydrogen

Syn Gas

Chemical Production

CO₂

Steel

CO₂

Methanol

Wind
Solar

??? TWh

Water

??? Mt

20 – 40%
60 – 80%

??? Mt

??? Mt

??? Mt

20 – 40%
60 – 80%

20 – 40%
60 – 80%

20 – 40%
60 – 80%

20 – 40%
60 – 80%
Integrated System
Basis for Simulation
Different integration schemes: Results for methanol production

Global warming impact

- Products
  - ~ 0.3 - 5.8 Mt/a methanol and 8.4 Mt/a steel
- Power provided by wind
- Integrated production of steel and methanol shows smaller global warming impact compared to stand-alone production
- Results are strongly dependent on integration scheme

GWI = Global Warming Impact
WGS = Water Gas Shift
NG = Natural Gas

Further information by Dr. Daniel Maga
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Comparison of CO₂ Emissions
Reference: Steel (1 Mto) + Methanol (0,53 Mto)

Source: Wich-Konrad, Lüke, Deerberg; Chemie Ingenieur Technik; 2020; Assessment of Industrial Greenhouse Gas Reduction Strategies Within Consistent System Boundaries
Energy demand

Conventional

CCU

Source: Wich-Konrad, Lüke, Deerberg; Chemie Ingenieur Technik; 2020; Assessment of Industrial Greenhouse Gas Reduction Strategies Within Consistent System Boundaries
Energy Demand
CCU, CDA: Mainly Green Power for Hydrogen Production

Source: Wich-Konrad, Lüke, Deerberg; Chemie Ingenieur Technik; 2020; Assessment of Industrial Greenhouse Gas Reduction Strategies Within Consistent System Boundaries
Economy - all cost on Methanol !! – Sensitivity

- Without German REA-reallocation charge, grid share in costs, tax
- Without German REA-reallocation charge, grid share
- Without German REA-reallocation charge

Graph showing the relationship between Price of Electricity [€/MWh] and costs and profits for different scenarios:
- MeOH Costs [€/t MeOH]
- Profit (Fall 30€/t CO₂) [€/t MeOH]
- Profit (Fall 60€/t CO₂) [€/t MeOH]
- Profit (Fall 90€/t CO₂) [€/t MeOH]
Conclusions so far

- Depending on Process Integration CO₂-Reduction up to approx. 50% is possible
  - Without general Changes in the Steel Production
- Essential: Renewable Energy - Green Hydrogen
- Dynamics can be controlled
  - flexible and adaptive processes
- Costs are in reachable range, if green Hydrogen is excepted from shared costs

- Transfer of Carbon2Chem Approach to other Industries is to be considered
  - Other Steel production Sites
  - Cement Production
  - Waste Incineration
  - Combination with Direct Reducing Steel making Process (CDA)
CCU & CDA in combination leads to climate-neutral steel

- 2019 – 2022
  H2 in the blast furnace

- 2018
  The world first

- 2020 onwards
  Industrialization

- 2024 onwards
  The milestone

- 2026 onwards
  The scale-up

- 2030 onwards
  Climate-neutrality

- 2050 onwards
  Large-scale production

- 2025 onwards
  Climate-neutrality

- 2026 onwards
  The melting unit

- 2024 onwards
  The melting unit

- 2019 – 2022
  H2 in the blast furnace
CCU & CDA: Combination with Direct Reducing Steel making Process

Conventional Blast Furnace

Raw Steel

Steel Production

Gas Treatment / Gas Cleaning

DRI

0 ... 100%

Process Gases

100 ... 0%

Electrolysis

Hydrogen

PV

Wind

Water

Natural Gas

Ore

Coal

Natural Gas

Ore

PV

Wind

Natural Gas

Ore

Steel

CO₂

CO₂

Fertilizer

Fuels

Chemicals

0 ... 100%

40 – 20%

60 – 80%

??? Mt

??? Mt

??? Mt

100 ... 0%

60 – 80%

??? Mt

40 – 20%

??? TWh

24

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Final Remarks: Pathways for Reduction of CO₂ Emission

MtoCO₂/a

Pathway 1

Annual emissions without change

Pathway 2

Reduction of emitted CO₂

Important: Minimize area under the curve!
Final Remarks: Pathways for Reduction of CO₂ Emission

Pathway 1

- Dynamics of Transformation is important
- Act fast – Implement existing Solutions now
- Optimize by further Implementation of new more efficient Technologies when they are ready

Pathway 2

MtoCO₂/a

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<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2050</th>
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<tr>
<td>Emissions (MtoCO₂)</td>
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Many thanks for your attention

Further information: 
https://www.umsicht.fraunhofer.de/carbon-cycle

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