Life-Cycle Assessment for Carbon Dioxide Utilization
Lessons learned from and for LCA

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Method of choice: Life Cycle Assessment (LCA)

Lessons learned for LCA of CCU

CO₂ source → CO₂ transport → CO₂ conversion

Disposal → Recycling → Use phase

Lessons learned from LCA of CCU

**CO₂-based polymers: Project “Dream Production”**

1. **Scrubbing and supply of CO₂**
   - **VORWEG GEHEN**

2. **Process development and conversion of CO₂**
   - **Bayer Technology Services**

3. **Production and testing of polyurethanes with CO₂**
   - **Bayer MaterialScience**

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**Fundamental research**

**CQT Catalytic Center**

**RWTH AACHEN UNIVERSITY**

**Life Cycle Assessment**

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**Life-Cycle Assessment for Carbon Dioxide Utilization**
CO₂-based polymers: Project “Dream Production“

Life Cycle Assessment

von der Assen, Bardow, Green Chem., 2014, 16, 3272
Dream Production: Life-cycle assessment


CO₂-based polyol (20 mass-% CO₂)

Conventional polyol

- CO₂ capture

- Substitution of raw materials

1 kg CO₂ as feedstock can avoid
3 kg of CO₂ emissions

Lessons learned from LCA of CCU

- CO₂ utilization can save GHG emissions
  - By replacing energy-intensive fossil-based feedstock
CO₂ hydrogenation to C1-chemicals

CO\textsubscript{2} hydrogenation to C1-chemicals


- Formic acid
- Formaldehyde
- Methanol
- Methane

Formic acid $\rightarrow$ Formaldehyde $\rightarrow$ Methanol $\rightarrow$ Methane

Carbon monoxide
**Impact of complexity on climate change mitigation potential**


CO₂ utilization can reduce complexity

⇒ Reduction of GHG emissions

- CH₄
- CO
- HCOOH

Life-Cycle Assessment for Carbon Dioxide Utilization
Lessons learned from LCA of CCU

• CO₂ utilization can save GHG emissions
  • By replacing energy-intensive fossil-based feedstock
  • By leading to more efficient process routes
**Efficiency = climate change mitigation per hydrogen used**


Here: Maximum potential

Assumption: „Free hydrogen“ from green electricity

<table>
<thead>
<tr>
<th>Compound</th>
<th>GW reduction (CO₂-eq/kg H₂ used)</th>
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<tbody>
<tr>
<td>CH₄</td>
<td>1</td>
</tr>
<tr>
<td>CO</td>
<td>1</td>
</tr>
<tr>
<td>HCOOH</td>
<td>1</td>
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</tbody>
</table>
„Green“ electricity for CO₂-based fuels

Electricity global warming impact in g CO₂,e / kWh
Fuel global warming impact in g CO₂,e / MJ

- Methane (LCA: Sternberg et al., Process: Müller et al.)
- Methane (LCA: Sternberg et al., Process: Saint Jean et al.)
- GTL-type fuel (LCA: Giesen et al., Process: Giesen et al.)
- Jet fuel (LCA: Falter et al., Process: Shell GTL-plant)
- DME (LCA: Schakel et al., Process: Schakel et al.)
- DMM, oxidative route (LCA: Deutz et al., Process: Bongartz et al.)
- DMM, reductive route (LCA: Deutz et al., Process: -)
- Fossil diesel

„Green“ electricity for CO₂-based fuels

- Benefits requires very green electricity but not 100% renewables
- Regional potential already today

Given 1 MWh of surplus electricity, which energy storage system brings the greatest environmental benefit?

Power to What?

Power to What?


Life-Cycle Assessment for Carbon Dioxide Utilization
Power to What?

- Winner: Efficient routes replacing inefficient processes
- Power-to-Chemicals and Power-to-Fuels not as energy storage but because we need chemicals and want fuels

Lessons learned from LCA of CCU

- CO₂ utilization can save GHG emissions
  - By replacing energy-intensive fossil-based feedstock
  - By leading to more efficient process routes
  - By producing fuels using renewable energy (if available)

- CO₂ utilization can be useful beyond climate change
**CO$_2$-based OME1 as diesel blend: NOx & soot trade-off**

CO$_2$-based OME1 as diesel blend: NOx & soot trade-off

OME1 strongly reduces both NOx and soot emissions

Lessons learned from LCA of CCU

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- CO₂ utilization can be useful beyond climate change
  - Need to understand the service (functional unit) provided by CCU

Lessons learned for LCA of CCU
Carbon footprint of CO₂-based methanol

- Huge differences in LCA literature on CCU

Carbon footprint of CO$_2$-based methanol: Harmonized inputs

- Need for harmonized LCA data
- LCA focus currently on background system, not on CO$_2$ conversion technology

Life Cycle Assessment (LCA) : Cradle-to-Gate comparison

- CCU is „Carbon-reducing“
- Often in literature: „(Net) Carbon-negative“
**CO₂–emissions: The full life cycle**

- **Best case: CO₂ in = CO₂ out**
- **Goal: CO₂ neutral!**
- **Potential climate benefit of temporary storage**
- **Or: Link with permanent storage (e.g. mineralization CCUS)**
Lessons learned from LCA of CCU

- CO₂ utilization can save GHG emissions
  - By replacing energy-intensive fossil-based feedstock
  - By leading to more efficient process routes
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- CO₂ utilization can be useful beyond climate change
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Lessons learned for LCA of CCU

- Harmonized LCA for CCU
- Early stage LCA
- Account for temporary storage (but effect for LCA will be small!)
- Clarify terminology for climate change mitigation
Vielen Dank
für Ihre Aufmerksamkeit

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