Life Cycle Assessment for Methanol Production from Industrial CO$_2$ sources and Direct Air Capture [Topic : 5]

Ankur Gaikwad
Fraunhofer UMSICHT
17.02.2023
Research Question

- Methanol carbon footprint considering
  - Different carbon capture technologies?
  - Different CO₂ concentration of gases on methanol footprint?
  - Imported / off-site green hydrogen

Industrial Sectors
- Lime & Cement
- Iron & Steel
- Municipal Waste Incineration

Carbon Capture Technologies
- Monoethanolamine
- Calcium looping
- Membrane

Chemicals Sector

Carbon Capture & Utilization (CCU)

STATUS QUO
SUSTAINABLE INDUSTRIES

ATMOSPHERE

Fossil Resources

Imported Resources like Natural Gas, Coal

Imported Resources like Natural Gas, Coal
Methodology
Framework of assumptions

- System boundaries
  - Water electrolysis by alkaline electrolyzer
  - Hydrogen transport by ship & pipe
  - Carbon capture unit
  - Methanol synthesis unit
  - Respective prechains excluding that of industrial flue gas
- Functional unit: 1 kg methanol
- Production Region: Germany
- Impact Assessment Methodology: Environmental Footprint 3.0 by European Commission’s Joint Research Centre
- LCA database: GaBi (thinkstep) Version 2022.2
- Two electricity supply scenarios
  - Germany national mix, 2020
  - Germany national mix, 2040
Methodology
LCA of different carbon capture technologies for methanol production

- Life cycle inventory for foreground system tabulated
- Direct CO₂ emissions from thermal energy provision fed to carbon capture unit, in addition to industrial flue gas
- Byproducts of carbon capture unit substitute respective materials & energy on 1:1 basis
- Hydrogen transport
  - Electrolyzers at offshore wind platform
  - Wind park -> Port: Ship (30 km)
  - Port -> CCU site: Pipe (300 km; recompression every 250 km from 30 to 100 bar)

<table>
<thead>
<tr>
<th>Process</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Capture Technologies</td>
<td></td>
</tr>
<tr>
<td>Monoethanolamine-based</td>
<td>[Meunier et al, 2019], [Li et al, 2022]</td>
</tr>
<tr>
<td>Calcium looping (CaL)</td>
<td>[Greco-Coppi et al, 2021]</td>
</tr>
<tr>
<td>Membrane</td>
<td>[Wu et al, 2021]</td>
</tr>
<tr>
<td>Direct Air Capture</td>
<td>[Keith et al, 2018]</td>
</tr>
<tr>
<td>Hydrogen Supply Chain</td>
<td></td>
</tr>
<tr>
<td>Alkaline electrolyzer</td>
<td>[Wulf et al, 2018a]</td>
</tr>
<tr>
<td>H₂ transport by pipe</td>
<td>[Wulf et al, 2018b]</td>
</tr>
<tr>
<td>CO₂-based Methanol Synthesis Unit</td>
<td>[Meunier et al, 2019]</td>
</tr>
</tbody>
</table>
Methodology
LCA for methanol from different industrial CO\textsubscript{2} sources

- [Li et al, 2022] simulated MEA capture systems for 11.5, 20, 28.6 mol-% CO\textsubscript{2}
- Parametric analysis enables coverage of all industrial CO\textsubscript{2} sources able to use MEA units
  - CO\textsubscript{2} content in industrial flue gases cover a range of 10-35 mol-% CO\textsubscript{2}
- Energy requirements for MEA carbon capture unit for parametric LCA through regression
  - Electricity: Linear
  - Thermal Energy: Logarithmic, due to non-linear trend of specific MEA regeneration energy w.r.t. flue gas’ changing CO\textsubscript{2} concentration [Xu et al, 2019]
Methanol production from industrial CO₂ sources

H₂ provision at CCU site

- On-site electricity consumption the main contributor to climate change
Methanol production from industrial CO₂ sources

H₂ provision by on-site electrolysers & imports equally

- Hydrogen produced at offshore wind park
- Transport to CCU site with pipeline
- For cleaner electricity mix, methanol becomes carbon-negative

![Diagram showing the climate change impact of methanol production from CO₂ sources.](image)
Methanol production from industrial CO₂ sources

Influence of H₂ imports
Methanol production from industrial CO₂ sources
Parametric Analysis for all possible industrial CO₂ sources (DE 2040 Electricity Mix)

- H₂ produced on-site
- ~15% reduction in carbon footprint due to change in CO₂ content of flue gas from 10 vol.-% to 35 vol.-%
- Energy demand variation, especially thermal energy demand for amine regeneration
Methanol production from atmospheric CO₂

- High-temperature process
  - Thermal energy provision by natural gas causes considerable emissions
- Choice of CO₂ footprint value affects footprint considerably
- CF reductions by 50% hydrogen imports, as well as cleaner electricity mix not enough to make DAC-Methanol competitive to methanol from industrial CO₂
Conclusion & Outlook

Conclusions

- Prioritizing industrial CO₂ sources can mitigate climate change more effectively than utilizing atmospheric CO₂.
- In most cases, methanol production by industrial CO₂ utilization fares better compared to conventional methanol production.

Outlook

- Pre-combustion carbon capture and utilization for different industrial CO₂ sources.
- Influence of choice of industrial CO₂ carbon footprint value on methanol’s carbon footprint.
- Subsequent influence on comparison with atmospheric CO₂-based methanol.
- Low-temperature capture process for CO₂ from air.
# Bibliography


Thank you for your attention!

M.Sc. Ankur Gaikwad
Sustainability Assessment Group
Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT
📞 +49 (0) 208 8598-1608
✉️ ankur.gaikwad@umsicht.fraunhofer.de