Power-to-X for the future fuels supply
Techno economic evaluation and system analysis

Friedemann G. Albrecht, Simon Maier, Ralph-Uwe Dietrich,
Research Area Alternative Fuels
Institute of Engineering Thermodynamics
DLR e.V.

18. October 2017
Ferankfurt/Main
Agenda

1. Motivation Power-to-X
   - Need for GHG emission reduction
   - GHG emissions in Germany
   - Options to reduce GHG emissions

2. Power-to-X concepts
   - PtX-Options
   - Evaluation criteria of PtX-Concepts

   - Introduction to DLR methodology
   - Example: PtL – Jet fuel by Fischer-Tropsch

4. Summary and Outlook
Climate Change – Driver for Power-to-X?

No slow-down of carbon dioxide concentration rise to observe!

Source: https://www.co2.earth/daily-co2
Global agreement to mitigate climate change

Global long term targets

- COP21 targets:
  - Decarbonization of Society
  - Global average temperature increase below 1.5 °C

European mid term goals

- EU-targets until 2030\(^1,2\):
  - 40 % reduction of GHG (base year 1990)
  - 27 % increase of renewable energies in primary energy consumption
  - 10 % renewable energy in transport and 6.8 % advanced renewable fuels in fuel supply

---

\(^1\) European Council, “2030 Climate and Energy Policy Framework,” Brussels 2014

\(^2\) European Commission, “Proposal for a directive on the promotion of the use of energy from renewable sources (recast),” Brussels 2016
## CO₂ Emissions from Germany

<table>
<thead>
<tr>
<th>Energy Usage</th>
<th>CO₂ Emissions (Mt₂₀₁₅)</th>
<th>Energy Consumption (PJ₂₀₁₅)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard coal Power, Steel works</td>
<td>148.5</td>
<td>1,729</td>
</tr>
<tr>
<td>Lignite Power</td>
<td>171.6</td>
<td></td>
</tr>
<tr>
<td>Oil Transport</td>
<td>245.6</td>
<td></td>
</tr>
<tr>
<td>Heat (Industry, households)</td>
<td>150.7</td>
<td></td>
</tr>
</tbody>
</table>

### How to reduce Carbon Footprint?
- Wind, PV, biomass, nuclear
- e-Mobility, biofuels, PtX
Comparison of PtX concepts

Merit-Order of carbon reduction technologies

EU instrument to reduce GHG emissions: CO₂-certificates

Goal: CO₂ reduction @ minimized GHG-Abatement cost, either by reducing GHG footprint or costs!

Standardized and verified methodology for LCA and TEA required!
2. Power-to-X concepts – part of a new integrated energy system

Electricity market

Intermittent power generation
Baseload power generation

Sector coupling

Electrolysis (optional)
Electric Arc Furnace
Calcination
Grid stabilization measures
Reconversion into electricity

Electrolysis
$2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2 + \text{O}_2$
$\text{CO}_2 + \text{H}_2 \leftrightarrow \text{CO} + \text{H}_2\text{O}$

Chemicals

Heat carriers

Fuel/gas Synthesis

Industry
Residential

Application

Heat / heat carriers
Seasonal energy storage
Transport / Aviation

CO$_2$
Basic chemicals

DLR.de • Chart 7 • Dietrich et al. • Power-to-X for the future fuels supply • 18. October 2017
3. Process evaluation of Power-to-X – Methodology @ DLR

DLR-evaluation and optimization tool

Technical evaluation

Production Costs

CO₂-Footprint

Ecoconomic assessment

CO₂-Abatement costs

Ecological evaluation

Life cycle assessment (LCA)
Example: PtL – Jet fuel by Fischer-Tropsch

**Electrolyzer options:**
- Alkaline electrolyzer
- Polymer electrolyte membrane (PEM)
- High-temperature electrolysis (SOEC)

**Carbon Sources:**
- Power Plants
- Industry (Cement, Iron&Steel, Chemical, Petroleum industry)
- Biomass
- Air

ASTM 7566
max. 50 % drop-in
3. Process evaluation of Power-to-X – Methodology @ DLR

- Technical evaluation
- Life cycle assessment (LCA)
- Economic assessment
- Ecological evaluation

DLR-evaluation and optimization tool

PtX
TEA Methodology
- adapted from best-practice chem. eng. methodology
- Meets AACE class 3-4, Accuracy: +/- 30 %
- Year specific using annual CEPCI Index

Process simulation results

Plant and unit sizes

Capital costs
- Equipment costs
- Piping & installation
- Factory buildings
- Engineering services ...

Aspen Plus®

TEPET-ASPEN Link
- Automated interface for seamless integration
- Easy sensitivity studies for every parameter
- Learning curves, economy of scale, ...

Operational costs
- Raw materials
- Operating materials
- Maintenance
- Wages ...

Production costs
€/l, €/kg, €/MJ

Material and energy balance
Example: PtL – Boundary conditions dictate economic results

2016 investment costs:

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Cost (€/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEM-Electrolyzer (stack)</td>
<td>720</td>
</tr>
<tr>
<td>PEM-Electrolyzer (system)</td>
<td>1,350</td>
</tr>
<tr>
<td>Fischer-Tropsch</td>
<td>95,650</td>
</tr>
</tbody>
</table>

(TEPET) scale factor 1

2016 raw material & by-product market prices:

<table>
<thead>
<tr>
<th>Material</th>
<th>Price (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>83.7 MWh</td>
</tr>
<tr>
<td>CO₂</td>
<td>12.1 t</td>
</tr>
<tr>
<td>Oxygen (export)</td>
<td>23.7 t</td>
</tr>
<tr>
<td>Steam (export)</td>
<td>14.7 t</td>
</tr>
</tbody>
</table>

Other economic assumptions:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base year</td>
<td>2016</td>
</tr>
<tr>
<td>Plant lifetime</td>
<td>30 years</td>
</tr>
<tr>
<td>Operating hours</td>
<td>8,260 h/a</td>
</tr>
<tr>
<td>Interest rate</td>
<td>5%</td>
</tr>
</tbody>
</table>

[6] Own calculations based on natural gas price from Eurostat database
Example: PtL – Jet fuel production via Power-to-Liquid
Plant capacity: 107 kt/a (1 % of German jet fuel consumption) – Base year: 2016

Power-to-Liquid (PtL)
- Investment: 755 mio. €
- Production costs: 2.26 €/l
- CAPEX: 17 %

65% Electricity

Cheap renewable electricity required in order to make PtX competitive!
Example: PtL – Jet fuel production sensitivity analysis
Plant capacity: 107 kt/a (1 % of German jet fuel consumption) – Base year: 2016

Power-to-Liquid (PtL) – NPC = 2.26 €/l
Example: PtL – Jet fuel production sensitivity analysis
Plant capacity: 107 kt/a (1 % of German jet fuel consumption) – Base year: 2016

Reducing number of full-load hours based on EEX price signals

Presented base case!

Optimum?
Prices of 2016 are not going to last – only year specific costs are comparable.

NPC change with Year of Investment

Capital cost for PEM systems

Presented base case!

3. Process evaluation of Power-to-X – Methodology @ DLR

- Technical evaluation
- Economic assessment
- Ecological evaluation
- Life cycle assessment (LCA)

DLR-evaluation and optimization tool
Example: PtL – GHG-Footprint Calculation

Carbon footprint of used raw materials and energy sources defines carbon footprint of product!

Footprint of products: Fuel/heat/H₂ etc.

Plant efficiency

System integration

PtX - Concept

Accounting for by-products

Plant emissions

Power footprint

Carbon dioxide footprint

CO₂ – Abatement costs \[
\frac{€}{t_{CO₂}} = \frac{\text{Difference in fuel/heat/H₂ costs}}{CO₂ – emission reduction}
\]
Example: PtL – GHG-Footprint boundary Conditions

![Power, Carbon dioxide, Oxygen]

<table>
<thead>
<tr>
<th>Functional unit</th>
<th>([\text{kg}_{\text{CO2eq}}/\text{MWh}]^a)</th>
<th>([\text{kg}_{\text{CO2eq}}/\text{t}]^b)</th>
<th>([\text{kg}_{\text{CO2eq}}/\text{t}]^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low boundary</td>
<td>10</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Average</td>
<td>272.5</td>
<td>77.5</td>
<td>250</td>
</tr>
<tr>
<td>High boundary</td>
<td>535</td>
<td>150</td>
<td>400</td>
</tr>
</tbody>
</table>

\(^a\) Low boundary value for pure wind electricity taken from [1]. High value corresponds to the actual CO₂-footprint of the German electricity sector [2].

\(^b\) Based on own calculations. The carbon footprint represents emissions arising from sequestration of CO₂ from flue gas. Flue gas from cement industry and coal fired power plants were investigated. The probably fossil nature of the flue gas was not taken into account. Low/high value: energy demand of CO₂-sequestration from cement plant/ coal fired power plant is covered with wind energy/German electricity mix.

\(^c\) Taken from ProBas databank [1]. Low/high value due to different electricity sources.

---

Example: PtL – From CO₂-Footprint to CO₂-Abatement costs

**CO₂-Abatement costs:**

**Case1 – Current State:**
- Price of fossil kerosene: ca. 0.5 €/l
- Grid Power price: 83.7 €/MWh
- Plant capacity: 107 kt/a

**Case2 – Pressure on Fossil Fuels:**
- Price of fossil kerosene: ca. 1 €/l
- Renewable Power price: 30 €/MWh
- Plant capacity: 1,000 kt/a

**CO₂-Abatement costs € / tCO₂**

<table>
<thead>
<tr>
<th>Case</th>
<th>PtL-Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>650</td>
</tr>
<tr>
<td>2</td>
<td>92.3</td>
</tr>
</tbody>
</table>

Current Price of CO₂-European Emission Allowances:
ca. 5 - 8 €/tCO₂

PtL-concepts viable when using renewable power only!
4. Summary & Outlook

• **PtX is required to meet the aviation contribution (and more) for the German climate protection targets**

• Volatile renewable power sources have large (theoretical) potential in Germany

• Coping with fluctuating power input is key challenge for the PtX concept

• Viability of PtX concepts highly depends on GHG footprint and GHG abatement costs

• Evaluating PtX concepts requires standardization and common agreement on the methodology

• Transparent and open published DLR methodology for cost estimation and GHG-footprint calculation offers a starting point for future unified technology assessment

• **PtX R&D, Demo, Market Introduction into sustainable aviation need to start NOW**
Outlook – PTL demonstration for sustainable Aviation

Techno-economic assessment

DILO

CO₂ → Gas cleaning → Reverse water-gas-shift reactor → Fischer-Tropsch synthesis → Product separation → Refinery

O₂ → Electrolysis → H₂ → Internal Recycle → H₂ → Product separation → Syncrude

Tail gas processing → Tail gas → External Recycle

Power & H₂O → Fuel usage

DILO
THANK YOU FOR YOUR ATTENTION!

German Aerospace Center (DLR)
Institute of Engineering Thermodynamics, Stuttgart
Research Area Alternative Fuels

ralph-uwe.dietrich@dlr.de
http://www.dlr.de/tt/en