Technical and Economical Evaluation of
Biomass-to-Liquid (BtL)
Power-to-Liquid (PtL)
Power & Biomass-to-Liquid (PBtL) Processes

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DLR – Research Group for Alternative Fuels

Open Workshop:
Energy System Integration of Bio-Based Fuels

Trondheim, NO
13th September 2018
Outline

1. Introduction and Motivation
2. Technical evaluation
3. Economical evaluation
4. Results
5. Summary & Outlook
1. Brief introduction: DLR – German Aerospace Center

- 8,200 Employees (Feb. 2018)
- 40 institutes at 20 sites (+ offices in Brussels, Paris, Tokyo, Washington)
- Total budget 925 Mio.€ (2016)
- 6 research areas
1. Motivation for alternative fuels – Rising CO$_2$ levels

- 1 ppm CO$_2$ $\approx$ 8 Gt CO$_2$
- CO$_2$ absorbs thermal radiation - rising CO$_2$ levels $\rightarrow$ more heat is trapped in atmosphere

Aug. '18 – 406.99 ppm

CO$_2$ conc. (ppm)

Thousands years ago

CO$_2$ conc. (ppm)

Year

CO$_2$ – Data obtained from www.co2.earth
1. Demand for transportation & mobility is rising

- With rising prosperity comes rising demand in mobility and transportation
- Example: Increasing Air traffic

<table>
<thead>
<tr>
<th>Year</th>
<th>Europe (Billion passenger km / per year)</th>
<th>North-America (Billion passenger km / per year)</th>
<th>China (Billion passenger km / per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>760</td>
<td>1030</td>
<td>510</td>
</tr>
<tr>
<td></td>
<td>1210</td>
<td>2880</td>
<td>370</td>
</tr>
<tr>
<td>2000</td>
<td>440</td>
<td>860</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>750</td>
<td>2720</td>
<td>60</td>
</tr>
</tbody>
</table>

1. IATA Technology Roadmap - Reduction of CO$_2$ emissions in the air traffic sector

- Not every transport sector can be electrified (yet)
- Renewable generated fuels are a solution to decarbonize transport sectors like air traffic

Source: iata.org
Outline

1. Introduction and Motivation
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2. Technical evaluation - Production processes

- ASPEN Plus is used for the technical evaluation
- What are the options for alternative fuels

C - Source:
- Biomass
- CO₂
- Biogas
- ...

C - Utilization:
- rWGS
- Gasification
- DryRef
- ...

H₂ - Source:
- PEM
- AEL
- WGS
- ...

Synthesis step:
- FT-Reaction
- MtG Process
- Fermentation
- ...

Product:
- Gasoline
- Diesel
- FT - Product
- ...

BtL Process
PBtL Process
PtL Process
2. The BtL – PBtL – PtL Processes

- Synthesis commercially available
- Secunda CTL (Sasol): 160,000 bpd (ca. 7 Mio.t/a)
- Pearl GTL (Qatar Petroleum + Shell): 140,000 bpd (ca. 6 Mio.t/a) – since 2011

\[ 2 \text{H}_2 + \text{CO} \rightarrow \text{H}_2\text{O} + -(\text{CH}_2) - \]
2. Process simulation – Key results for BtL Process

- H\textsubscript{2}/CO ratio for FT-Synthesis ≈ 2
  \[2 \text{H}_2 + \text{CO} \rightarrow \text{H}_2\text{O} + -(\text{CH}_2)\]

- WGS reaction is H\textsubscript{2} source
  \[\text{H}_2\text{O} + \text{CO} \rightleftharpoons \text{H}_2 + \text{CO}_2\]

<table>
<thead>
<tr>
<th>Stream [t/h]</th>
<th>BtL Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>22</td>
</tr>
</tbody>
</table>

\(r = 50 \text{ km}\)
2. Carbon flow diagram – BtL Process

75 % of biomass carbon lost as CO₂
2. Process simulation – Key results for BtL Process

- H₂/CO ratio for FT-Synthesis ≈ 2
  \[2 \text{H}_2 + \text{CO} \rightarrow \text{H}_2\text{O} + -(\text{CH}_2)-\]

- WGS reaction is H₂ source
  \[\text{H}_2\text{O} + \text{CO} \rightleftharpoons \text{H}_2 + \text{CO}_2\]
  - Deactivated carbon (CO₂) can’t be reutilized
  - Lack of H₂ leads to low C-conversion
  - PBtL Process with additional H₂ source and rWGS Reactor

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<tr>
<td>Biomass</td>
<td>22</td>
</tr>
<tr>
<td>Liquid product</td>
<td>2.93</td>
</tr>
<tr>
<td>C - Conversion</td>
<td>25%</td>
</tr>
</tbody>
</table>
## 2. Process simulation – Key results

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<tr>
<th>Stream [t/h]</th>
<th>BtL Process</th>
<th>PBtL Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>( \text{H}_2 )</td>
<td>-</td>
<td>3.57</td>
</tr>
<tr>
<td>Liquid Product</td>
<td>2.93</td>
<td>11.04</td>
</tr>
<tr>
<td>( \text{C} ) - Conversion</td>
<td>25%</td>
<td>97.7%</td>
</tr>
<tr>
<td>Xtl Efficiency</td>
<td>36.3%</td>
<td>51.4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stream [t/h]</th>
<th>PtL – small</th>
<th>PtL - large</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{CO}_2 )</td>
<td>9.05</td>
<td>34.20</td>
</tr>
<tr>
<td>( \text{H}_2 )</td>
<td>1.48</td>
<td>5.77</td>
</tr>
<tr>
<td>Total</td>
<td>2.93</td>
<td>11.05</td>
</tr>
<tr>
<td>( \text{C} ) - Conversion</td>
<td>98%</td>
<td>98%</td>
</tr>
<tr>
<td>Xtl Efficiency</td>
<td>50.6%</td>
<td>50.6%</td>
</tr>
</tbody>
</table>

\[
\eta_{\text{xTL}} = \frac{m_{\text{Prod}} \cdot LHV_{\text{Prod}}}{m_{\text{Biomass}} \cdot LHV_{\text{Biomass}} + P_{\text{El}}}
\]
Outline

1. Introduction and Motivation
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3. Economical evaluation

AACE Recommended Practice Class III + IV  Accuracy of cost estimation ±30%

- Equipment Dimensions
- Results of process simulation
- Mass / Energy Streams
- Aspen Plus®
- CAPEX
  - Buildings
  - Equipment costs
  - Piping & installation
  - Engineering
- Spec. Production costs
  - €/l - €/kg - €/MJ
- Resources
- Utilities
- Maintenance
- Salaries

TEPET
Techno economical process evaluation tool
3. Determination of costs

**CAPEX**
- Standard EQP (Heat exchanger, pumps...)
- Special EQP has to be obtained from literature, project partners
- Remaining costs can be divided into groups and estimated with factor method
  - Installation, Buildings...

**OPEX**
- Available market prices for commodities
- Remaining costs can be divided into groups and estimated with factor method
  - Maintenance, Salary,...

\[
C_i = C_0 \cdot \left( \frac{S_i}{S_0} \right)^f \cdot \frac{Index_{Jahr_i}}{Index_{Jahr_0}}
\]
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5. Summary & Outlook
4. Scenarios the techno economical evaluation

**Investment Costs**

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEM-Elektrolyser (stack)</td>
<td>720/kW</td>
</tr>
<tr>
<td>PEM-Elektrolyser (system)</td>
<td>1,350/kW</td>
</tr>
<tr>
<td>Gasifier</td>
<td>103,650/€/(kg_slurry/h)</td>
</tr>
<tr>
<td>Fischer-Tropsch Reactor</td>
<td>17,44 Mio./€/(kmol_feed/s)</td>
</tr>
</tbody>
</table>

**Costs for Resources and by-products**

<table>
<thead>
<tr>
<th>Resource</th>
<th>Cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>99,6/MWh</td>
</tr>
<tr>
<td>Biomass</td>
<td>80,1/t</td>
</tr>
<tr>
<td>Oxygen (export)</td>
<td>24,3/t</td>
</tr>
<tr>
<td>Steam (export)</td>
<td>19,8/t</td>
</tr>
</tbody>
</table>

**Further conditions**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference year</td>
<td>2017</td>
</tr>
<tr>
<td>Annual full load hours</td>
<td>8,260 h/a</td>
</tr>
<tr>
<td>Operating time of plant</td>
<td>30 years</td>
</tr>
<tr>
<td>Interest rate</td>
<td>7%</td>
</tr>
</tbody>
</table>

4. Result: Cost comparison of BtL / PBtL / PtL - process

**Biomass-to-Liquid (BtL)**
- FCI: ca. 411 Mio. €
- Production costs: ca. 2.36 €/l
- Production capacity: ca. 24.2 kt/a
- CAPEX: 46.5%

**Power& Biomass-to-Liquid (PBtL)**
- FCI: ca. 781 Mio. €
- Production costs: ca. 2.23 €/l
- Production capacity: ca. 91.2 kt/a
- CAPEX: 24.7%

**Power-to-Liquid (PtL) - Large**
- FCI: ca. 696 Mio. €
- Production costs: ca. 2.64 €/l
- Production capacity: ca. 91.2 kt/a
- CAPEX: 18.6%
4. Sensitivity analysis

- TEPET is capable of performing sensitivity analyzes
- Specific production cost for different varying process parameters.

**Example**
- Influence of electricity price
- Influence of production capacity „economy of scale“
Outline

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5. Summary

• Tool for the technical and economical evaluations are available
• Open and transparent cost estimation method
• Opportunities for development can be shown and outlined
  o Technological perspective: e.g.: Yield curves, efficiencies etc.
  o Economical perspektive: e.g.: Influence of electricity price, economy of scale etc.

➢“Bottlenecks” and their influence can be identified and → e.g. carbon flow-diagram
1 - EU – ABC-Salt Project
www.abc-salt.eu – EU No. 764089

- Liquefaction of biomass in a molten salt environment with subsequent middle distillate production by the process steps:
  - Biomass liquefaction
  - Hydro-pyrolysis
  - Hydro-deoxygenation

- Process development from TRL 2 up to 4

- Prototype manufacture with a biomass feed of 100 g/h and a hydrocarbon yield of 35 wt.%

- Diesel net production costs < 0.80 €/l
2 - EU – ComSyn Project

www.comsynproject.eu – EU No. 727476

- Compact Gasification and Synthesis process for Transport Fuels

DFB PILOT @ VTT

- Hot gas filtration
- Partial flow to synthesis
- Gas cleaning
- Catalytic Reforming
- Fischer-Tropsch Microreactor

DFB Gasifier

Filter → Reformer → Gas cleaning → Fischer-Tropsch Synthesis → Product Upgrading
Flexible generation of heat, power and transport fuels

Catalytic Tar Reforming
- New and robust catalyst, developed by Johnson Matthey results in cheap operating expenditures with low investment costs
- CO content can be increased via CO$_2$ recycling
Thank you for your attention

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http://www.dlr.de/tt/en
Energy system integration

What does the energy system of the future look like?

- Sector coupling → Breaking the boundaries of heat, electricity and fuel market
- Taking the influence of production process into account? Rising demand increases the price?
- Estimating the available amount of a given resource? e.g.: Biomass, CO₂, Electricity
  - Minimum energy required for gas purification
  - CO₂ with DAC: $1.08 \text{ GJ}_e/t$ \[1\] $\rightarrow$ 0.3 MW / t CO₂/h