Exergetic analysis of renewable Fischer-Tropsch fuels production from biomass, CO2 and electricity

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ELCAS-5
09-11.07.2017, Nisyros, Greece
IATA Technology Roadmap

Main goals:
1. Improvement of fuel efficiency about 1.5% p.a. until 2020
2. Carbon-neutral growth from 2020
3. Potential CO₂ emissions reductions by 2050

Expected demand of ≈ 50 - 60 Mt kerosene equivalent

- Forecasted CO₂ emissions without reduction measures

European aviation jet fuel consumption in 2010: ca. 56.5 Mt[1]

Planned Measures:
- Improvement of technologies, operations and airport
- CO₂-certificates and other economic measures
- Radical technology transitions and alternative fuels

Applied methodology for fuel evaluation

**Technical evaluation – focus on:**
- Production pathways
- Resource and energy intensity
- Fuel efficiency (≈ exergy efficiency)
- Technical fuel potential

**Ecological evaluation – focus on:**
- CO₂-footprint of produced fuels
- CO₂-abatement costs

**Economic evaluation – focus on:**
- Production costs (CAPEX, OPEX, NPC)
- Sensitivity analysis
- Identification of cost reduction potentials (exergoeconomic evaluation)
Applied methodology for fuel evaluation

Ecological evaluation – focus on:
- CO₂-footprint of produced fuels
- CO₂-abatement costs
Methodology – exergy analysis

- Includes all important equipment such as pumps/HEX/Reactors
- Physical exergy $E_x^{Ph}$ available in Aspen Plus for every material stream
- Direct link between Aspen and TEPET
- Calculation of chemical exergy $E_x^{Ch}$
- Automated exergy analysis
- (planned) exergoeconomic optimization
Multiple options for FT-fuels from biomass, power and CO₂

FT-fuel from Biomass – Biomass-to-Liquid (BtL)

FT – Reaction:

\[ 2n \, H_2 + CO \xrightarrow{\text{Catalyst}} -(CH_2)_n + H_2O \]
Multiple options for FT-fuels from biomass, power and CO$_2$

FT-fuel from Power and CO$_2$ – Power-to-Liquid (PtL)
Multiple options for FT-fuels from biomass, power and CO$_2$

FT-fuel from Power and Biomass – Power&Biomass-to-Liquid (PBtL)
Multiple options for FT-fuels from biomass, power and CO₂

FT-fuel from Power and Biomass – Power&Biomass-to-Liquid (PBtL)

\[
\begin{align*}
\dot{E}_{P,1} & = \sum_{i=1}^{j} \dot{E}_{F,i} - \sum_{i=1}^{k} \dot{E}_{P,i} - \sum_{i=1}^{l} \dot{E}_{L,1} \\
\dot{E}_{P,1} & = \sum_{j=1}^{i} \dot{E}_{F,j} - \sum_{i=1}^{l} \dot{E}_{L,1} \\
\dot{E}_L & = \sum_{j=1}^{i} \dot{E}_{L,1} \\
\varepsilon & = \frac{\dot{E}_P}{\dot{E}_F} \\
\gamma_D & = \frac{\dot{E}_D}{\dot{E}_F} \\
\gamma_L & = \frac{\dot{E}_L}{\dot{E}_F}
\end{align*}
\]
Exergy flows - Biomass-to-Liquid

Exergy input:
100 MW (Biomass)

Largest exergy destruction during gasification

Legend
- Fuel [MW]
- Power [MW]
- Steam [MW]
- Heat [MW]
- E_des [MW]
- E_loss [MW]
Exergy flows - Biomass-to-Liquid

\[
\gamma_{D,sys} = \frac{\dot{E}_{D,section}}{\sum \dot{E}_D}, \quad \gamma_{D,sys} = \frac{\dot{E}_{D,section}}{\sum \dot{E}_D}
\]

- Exergy - transf.
- Exergy - Fuel
- Exergy - Power
- Exergy - Steam
- Exergy - loss
- Exergy - dest.
Detailed exergy analysis of gasification section

Water quench responsible for:
- **87 %** of exergy destruction within gasification section
- **35 %** of total exergy destruction within system

Promising alternatives:
- Hot gas cleaning
- Change of gasifier technology
Exergy flows –PBtL

Exergy input:
37.1 MW (Biomass)
63 MW (Power)

Largest exergy destruction during electrolysis

Legend
- Fuel [MW]
- Power [MW]
- Steam [MW]
- Heat [MW]
- Exergy loss [MW]
- Exergy destruction [MW]

Exergy loss: 0.7 MW
Exergy destruction: 17.1 MW

Central processes:
1. **Electrolysis**
   - Hydrogen: 44.3 MW
   - Power: 63 MW
   - E_loss: 0.7 MW
   - E_des: 17.1 MW
   - Power generation & balance of plant

2. **FT-Synthesis**
   - Syngas: 130.7 MW
   - E_loss: 0.4 MW
   - E_des: 3.9 MW

3. **Separation & Upgrading**
   - FT-Product: 635.6 MW
   - Heat: 6 MW
   - E_des: 3.7 MW
   - Internal recycle: 514.6 MW
   - Fuel: 53.1 MW
   - E_loss: 1.2 MW
   - E_des: 2.1 MW
   - Power: 3 MW
   - Steam: 3.8 MW
   - Heat: 0.5 MW

Other processes:
1. **Pyrolysis**
   - Biomass: 37.1 MW
   - Slurry: 32.1 MW
   - Pyrolysis gas: 2.3 MW
   - E_loss: 1.4 MW
   - E_des: 1.3 MW

2. **Gasification**
   - Raw gas: 27.8 MW
   - Oxygen & water: 0.4 MW
   - Oxygen: 0.9 MW
   - Power: 0.5 MW
   - E_des: 2.3 MW
   - E_loss: 0.4 MW
   - E_des: 4.1 MW
   - E_loss: 1.1 MW

3. **Rabits**
   - rWGS
   - Oxygen: 0.9 MW
   - E_loss: 1.1 MW
   - E_des: 4.1 MW

**External recycle:** 64.6 MW
**Internal recycle:** 514.6 MW
**Fuel:** 53.1 MW

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Result of exergy analysis

<table>
<thead>
<tr>
<th>Model</th>
<th>Fuel</th>
<th>Power</th>
<th>Steam</th>
<th>Loss</th>
<th>Dest.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BtL</td>
<td>37.8%</td>
<td></td>
<td></td>
<td>9.0%</td>
<td>14.2%</td>
</tr>
<tr>
<td>PtL</td>
<td>35.9%</td>
<td></td>
<td></td>
<td>3.4%</td>
<td>1.6%</td>
</tr>
<tr>
<td>PBtL</td>
<td>34.9%</td>
<td></td>
<td></td>
<td>5.2%</td>
<td>3.8%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>$\varepsilon_{\text{fuel}}$</th>
<th>$\varepsilon_{\text{total}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BtL</td>
<td>37.8%</td>
<td>63.5%</td>
</tr>
<tr>
<td>PtL</td>
<td>53.7%</td>
<td>61.2%</td>
</tr>
<tr>
<td>PBtL</td>
<td>53.1%</td>
<td>60.4%</td>
</tr>
</tbody>
</table>

Source of highest exergy destruction:
- BtL: gasification
- PtL: electrolysis
- PBtL: electrolysis
Conclusion

• High demand of alternative fuels in order to fulfill CO\textsubscript{2}-reduction targets -> especially with regard to the aviation sector

• DLR has developed a methodology to evaluate fuel production pathways

• Results of the presented case study:
  
  ➢ Exergy efficiency of fuel production in the range of 37- 54 %
  
  ➢ Most exergy destruction occurs during syngas production -> Technology shift may increase system efficiency significantly

  Promising options: BtL- Hot gas cleaning

  PtL- High temperature electrolysis (SOEC)
Outlook

• Applying fuel evaluation methodology on other renewable fuel production concepts
  • Butanol
  • Methanol-to-Gasoline
  • HEFA
  • Solar-Fuels
  • etc.

• Economic optimization (Exergoeconomic analysis/optimization)

• Lifecycle assessment
  • CO₂-footprint
  • CO₂-abatement cost

• Application of exergy and exergoeconomic analysis on other thermo-chemical processes
  • DLR-Project IsEN (Isentropic energy storage)
Other options for „green“ aviation?
Gossamer Albatross?

Crossing of the English Channel between Folkestone and Cap Gris-Nez by Bryan Allen on 12. June 1979
• Distance: 35.8 km
• Travel time: 2:49 hours

This corresponds to:
Flight from Stuttgart (STR)
➢ Kos (KGS): 1.970 km
Calculated flight time: 155 hours (6.5 days)

Source: https://de.wikipedia.org/wiki/Gossamer_Albatross
THANK YOU FOR YOUR ATTENTION!

German Aerospace Center (DLR)
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Research Area: Alternative Fuels

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http://www.dlr.de/tt/en
Example: Process simulation Flowsheet (PtL)