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

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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

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

Expected demand of ≈ 50 - 60 Mt kerosene equivalent


Source: iata.org
Applied methodology for fuel evaluation

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

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

**Ecological evaluation – focus on:**
- CO₂-footprint of produced fuels
- CO₂-abatement costs
Applied methodology for fuel evaluation

**Ecological evaluation – focus on:**
- CO$_2$-footprint of produced fuels
- CO$_2$-abatement costs
Methodology – exergy analysis

- Direct link between Aspen and TEPET
- Calculation of chemical exergy $E_{x}^{Ch}$
- Automated exergy analysis
- (planned) exergoeconomic optimization

- Includes all important equipment such as pumps/HEX/Reactors
- Physical exergy $E_{x}^{Ph}$ available in Aspen Plus for every material stream
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 CO₂

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

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

\[
\begin{align*}
\dot{E}_{F,1} & \rightarrow \sum_{i=1}^{j} \dot{E}_{F,i} - \sum_{i=1}^{k} \dot{E}_{P,i} - \sum_{i=1}^{l} \dot{E}_{L,i} \\
\vdots \\
\sum_{i=1}^{j} \dot{E}_{F,i} & \rightarrow \sum_{l} \dot{E}_{L,i} \\
\sum_{l} \dot{E}_{L,i} & \rightarrow \dot{E}_{P,1} \\
\vdots \\
\sum_{l} \dot{E}_{L,i} & \rightarrow \dot{E}_{P,k}
\end{align*}
\]

\[
\begin{align*}
\varepsilon & = \frac{\sum \dot{E}_{P}}{\sum \dot{E}_{F}} \\
\gamma_D & = \frac{\dot{E}_{D}}{\sum \dot{E}_{F}} \\
\gamma_L & = \frac{\dot{E}_{L}}{\sum \dot{E}_{F}}
\end{align*}
\]
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 input:
100 MW (Biomass)
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

Diagram:
- Slurry at T=43°C, P=30 bar enters the gasifier at T=1200°C, P=30 bar.
- Water quench at T=25°C, P=1 bar is used to cool the gas.
- Raw gas at T=120°C, P=30 bar is produced.
- Waste water at T=170°C, P=30 bar is discharged.
- Entrained-flow gasifier and water quench are highlighted in the diagram.
Exergy flows – PBtL

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

Legend
- Fuel [MW]
- Power [MW]
- Steam [MW]
- Heat [MW]
- E_des [MW]
- E_loss [MW]

Largest exergy destruction during electrolysis

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Result of exergy analysis

### Model Comparison

<table>
<thead>
<tr>
<th>Model</th>
<th>BtL</th>
<th>PtL</th>
<th>PBtL</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varepsilon_{\text{fuel}} )</td>
<td>37.8 %</td>
<td>53.7 %</td>
<td>53.1 %</td>
</tr>
<tr>
<td>( \varepsilon_{\text{total}} )</td>
<td>63.5 %</td>
<td>61.2 %</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 CO₂-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!

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Example: Process simulation Flowsheet (PtL)