Life Cycle Assessment of different BtL-Fuel Pathways from Wood, Straw and Miscanthus

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Overview

- Biomass-to-liquid fuels can be produced in different process layouts
- BTL fuels reduce climate change effect compared to fossils
- Only some production pathways comply with Swiss biofuels directive
- The type of biomass and conversion efficiency are most important for the assessment
Classification of fuels: Marketing and brand names

- Sunfuel, Sundiesel: synthetic fuels from Choren process
- Ökodiesel, Biodiesel: mainly used for XME with biomass from different origin
- Naturgas: natural gas mixed with >10% biogas
- Kompogas: brand name of biogas plants
- 1st, 2nd, 3rd generation: unclear definition e.g. based on today market share, resource types or edibility or conversion processes

➢ Marketing and brand names do not help for a discussion on renewable fuels

Classifications of powertrain fuels

- Resources used
  - Non-renewable: crude oil, natural gas, coal, nuclear
  - Renewable: energy crops (edible, non-edible), algae, forest wood, biomass residues (e.g. straw), industrial residues (e.g. Black Liquor), sun, wind
- Conversion process technologies
  - mechanical, chemical reaction, thermal treatment, fermentation, anaerobic digestion, pyrolysis, gasification, Fischer-Tropsch synthesis, biotechnical
- Chemical classification of the product
  - methane, ethanol, methanol, dimethylether (DME), hydrogen, oils, methyl ester, liquids (petrol, diesel, BtL, GtL), ETBE, MTBE

➢ Fuels can only be classified by a combination of resource, process and product
➢ Biomass-to-liquid (BTL) fuels from black-liquor, miscanthus, wood and straw
Questions related to BTL production

- Which BTL production route is the one with the lowest environmental impacts?
- Improvement options of production routes, e.g. biomass inputs?
- Priorities for process development?
- Scenarios for technology development for BtL-production plants and influence on results?

System outline

Sometimes termed as well-to-tank
Key data biomass production

- Straw, short-rotation wood and miscanthus
- data given per kg dry substance (DS)

<table>
<thead>
<tr>
<th></th>
<th>bundles, short-rotation wood</th>
<th>bundles, short-rotation wood</th>
<th>miscanthus bales</th>
<th>miscanthus bales</th>
<th>wheat straw bales</th>
<th>wheat straw bales</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>starting point</td>
<td>scenario 1</td>
<td>starting point</td>
<td>scenario 1</td>
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<td>N-fertilizer</td>
<td>g/kg DS</td>
<td>5.2</td>
<td>6.3</td>
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<td>4.0</td>
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<td>Lime</td>
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<td>3.3</td>
<td>2.3</td>
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<td>12'630</td>
<td>14'970</td>
<td>20'504</td>
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<td>Yield, wheat grains</td>
<td>g DS/ha/a</td>
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<td>-</td>
<td>-</td>
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<td>Energy content of biomass</td>
<td>MJ/kg DS</td>
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<td>18.8</td>
<td>18.8</td>
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<tr>
<td>Losses during storage</td>
<td>%</td>
<td>7%</td>
<td>4%</td>
<td>6%</td>
<td>3%</td>
<td>6%</td>
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System boundaries conversion

- Solid biocarrier
- Gasification media
- Raw gas
- Gas cleaning
- Gas conditioning
- Fuel synthesis
- BTL-fuel
- Electricity
- Steam and heat
- Steam and power boiler
- Tail gas by-products
- Direct air emissions off-gas
- Air emissions allocated to electricity and heat energy
- Electricity delivered to grid
LCI and LCIA modelling principles

- No modelling of intermediate flows between conversion stages
- Emissions of power plant are allocated to heat and electricity based on exergy production
- No allocation of biomass input to by-products, like electricity
- No agreement on LCIA of pesticides and heavy metals in the project

General assumptions necessary

- Data provided are completed with general assumptions
- Emission profile of conversion based mainly on gas or wood power plants
- Waste and effluent composition available only from model calculation
- Catalyst use assessed based on literature
- All assumptions approved by process developers
### Characteristics of data

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>dEE-Dx</td>
<td>dEE-Dx</td>
<td>dEE-Dx</td>
<td>ICFB-Dx</td>
<td>BLEF-DME</td>
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<tr>
<td>Developer²</td>
<td>UET</td>
<td>CUTEC</td>
<td>FZK</td>
<td>TVE</td>
<td>CHEMREC</td>
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<td>Biomass type</td>
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<td>Amount and type¹</td>
<td>Amount and type¹</td>
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<td>Provided 🌐</td>
<td>Provided 🌐</td>
<td>Provided 🌐</td>
<td>Provided 🌐</td>
</tr>
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<td>H₂S, NH₃</td>
<td>CO₂, H₂S, NH₃</td>
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<td>Literature for gas firing¹</td>
<td>Literature for gas firing¹</td>
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<td>Amount of air emissions</td>
<td>Calculated with emission profile and CO₂ emissions</td>
<td>Calculated with emission profile and CO₂ emissions</td>
<td>Calculated with emission profile and CO₂ emissions</td>
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<tr>
<td>Retort type</td>
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<td>Only amount. Rough assumption on polluted media</td>
<td>Only amount. Rough assumption on polluted media</td>
<td>Only amount. Rough assumption on polluted media</td>
<td>Only amount. Rough assumption on polluted media</td>
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<td>Only amounts</td>
<td>Only amounts</td>
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<td>Standard/RENEW model for upgrading</td>
<td>Standard/RENEW model for upgrading</td>
<td>Standard/RENEW model for upgrading</td>
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<td>Products²</td>
<td>BTL-FT, electrolyte</td>
<td>FT new product, electrolyte</td>
<td>FT new product, electrolyte</td>
<td>FT new product, electrolyte</td>
<td>FT new product, electrolyte</td>
</tr>
<tr>
<td>Conversion rate (biomass to all liquids)</td>
<td>53%</td>
<td>57%</td>
<td>40%</td>
<td>38%</td>
<td>45%</td>
</tr>
<tr>
<td>Capacity biomass input (MW)</td>
<td>499</td>
<td>462</td>
<td>485</td>
<td>463</td>
<td>455</td>
</tr>
<tr>
<td>All liquid products (diesel, naphtha, DME)</td>
<td>22.5</td>
<td>22.3</td>
<td>16.6</td>
<td>15.0</td>
<td>17.5</td>
</tr>
</tbody>
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### Key data of modelling conversion in 2020

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Product</th>
<th>Code</th>
<th>Developer</th>
<th>energy</th>
<th>energy</th>
<th>conversion rate (biomass to all liquids)</th>
<th>capacity biomass input (MW)</th>
<th>all liquid products (diesel, naphtha, DME)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>BTL-FT</td>
<td>cEF-D</td>
<td>UET</td>
<td>53%</td>
<td>499</td>
<td>22.5</td>
<td>462</td>
<td>22.3</td>
</tr>
<tr>
<td>Straw</td>
<td>BTL-FT</td>
<td>cEF-D</td>
<td>UET</td>
<td>57%</td>
<td>462</td>
<td>22.3</td>
<td>485</td>
<td>16.6</td>
</tr>
<tr>
<td>Wood</td>
<td>BTL-FT</td>
<td>CFB-D</td>
<td>CUTEC</td>
<td>40%</td>
<td>485</td>
<td>16.6</td>
<td>463</td>
<td>15.0</td>
</tr>
<tr>
<td>Straw</td>
<td>BTL-FT</td>
<td>CFB-D</td>
<td>CUTEC</td>
<td>38%</td>
<td>463</td>
<td>15.0</td>
<td>455</td>
<td>17.5</td>
</tr>
<tr>
<td>Straw</td>
<td>BTL-FT</td>
<td>dEF-D</td>
<td>FZK</td>
<td>45%</td>
<td>455</td>
<td>17.5</td>
<td>52</td>
<td>1.1</td>
</tr>
<tr>
<td>Wood</td>
<td>BTL-DME</td>
<td>BLEF-DME</td>
<td>CHEMREC</td>
<td>69%</td>
<td>500</td>
<td>29.0</td>
<td>50</td>
<td>1.1</td>
</tr>
</tbody>
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²: Data from literature sources.
Discussion of results for BTL-fuel production

- CML characterisation
- Evaluation of product stages
- Comparison of biomass and conversion concepts
- Peer review according to ISO14040

Contribution of sub-processes (cEF-D, wood)

- 50% BTL-fuel synthesis, wood UET
- 30% Carbo-V-gasifier, wood UET
- 10% biomass storage and preparation, Wood UET
Observations

- Most important are impacts from biomass production
- Direct gaseous emissions are relevant for summer smog
- Comparison within process stages is difficult

Comparisons

- cEF-D lowest impacts mainly because of conversion efficiency
- No clear ranking of all processes if CML indicators are used
- ICFB-D has highest impacts in all categories because of low conversion efficiency to fuel (but by-product electricity)
- No clear recommendation comparing wood and straw and only one conversion process using miscanthus (ICFB-D)
General improvement options for conversion process

• Improve agricultural biomass production
• Increase of the fuel yield
• Reduce direct emissions (CH₄, NMVOC, NOₓ, particles) with off-gases and from the power plant
• Recycling of nutrients in slag and ashes

Life cycle assessment of using BTL (full life cycle)

• What are the environmental impacts of using BTL-fuels compared to fossil diesel?
• Importance of fuel combustion for total environmental impacts?
• GWP reduction potential
• Comparison of BTL with today biofuels?
• Yields per hectare compared to present situation?
• → Follow-up study commissioned by Swiss authorities in the framework of “Ökobilanz von Energieprodukten”
How much better are renewable fuels?

- Easy question without an easy answer ...

Exclusion of certain stages

The following assessment includes the full life cycle
The whole picture: overall env. impact

- GWP reduction between 28% and 69% → lower than what has been assumed so far

- Big differences between the production routes of the same biomass type
Comparison of renewable fuels

- No clear advantage nor disadvantage of BTL compared to other agrofuels
- Type of biomass resource is most important for each type of fuel

Mileage per hectare

- Mileage per hectare is a key indicator for evaluating the sustainability and efficiency of different biofuel production methods.
- Different crops and feedstocks show varying mileages per hectare, indicating the need for site-specific assessments.
- Methane and ethanol are compared against other competing fuels in terms of their energy density and environmental impact.

GWP, UBP, and Eco-indicator 99 are used to compare the greenhouse gas emissions, environmental impact, and energy efficiency of different biofuels.
Main observations for BtL

- Low emissions of GHG during combustion outweigh the higher impacts of fuel production for GWP
- Reduction potential for GWP and non-renewable energy is about 30% to 70% if the full life cycle is taken into account
- Other environmental impacts of BTL-fuel from agricultural biomass are higher than using fossil fuels
- Comparison with present agrofuels and evaluation of fuel yields show no generally better performance
- Type of biomass and conversion efficiency are important
- Criteria for Swiss tax exemption might be fulfilled by some production pathways

Thank you for your attention!

Publications:
- LCA of Biomass-To-Liquid fuel production (www.esu-services.ch/renew.htm)
- LCA of Biomass-To-Liquid fuel use (www.esu-services.ch/btl)

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Annexe
LCA of BTL-production

Dr. Niels Jungbluth
ESU-services Ltd., Uster, Switzerland

Intermediate Storage
Key assumptions

<table>
<thead>
<tr>
<th>Name</th>
<th>Unit</th>
<th>Location</th>
<th>Infrastructure</th>
<th>Process</th>
<th>Miscanthus-bales, scenario 1, at intermediate storage</th>
<th>Miscanthus-bales, scenario 1, at intermediate storage</th>
<th>Miscanthus-bales, scenario 1, at intermediate storage</th>
<th>Miscanthus-bales, scenario 1, at intermediate storage</th>
<th>Miscanthus-bales, scenario 1, at intermediate storage</th>
<th>Miscanthus-bales, scenario 1, at intermediate storage</th>
<th>Miscanthus-bales, scenario 1, at intermediate storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass losses during storage</td>
<td>%</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
</tr>
<tr>
<td>Water content of biomass</td>
<td>%</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
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<tr>
<td>Share of closed storage</td>
<td>%</td>
<td>RER</td>
<td>RER</td>
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<td>RER</td>
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<tr>
<td>Carbon content</td>
<td>%</td>
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<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
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<td>RER</td>
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<td>Lower heating value</td>
<td>MJ</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
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<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
<td>RER</td>
</tr>
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</table>
### Interpretation for biomass production

- **Main factors are fertilizer and diesel use and emissions due to use of fertilizers**
- **Small variations in scenarios**
- **General uncertainty in agricultural data is higher than the differences between scenarios**
- **Straw has lower impacts due to economic allocation, wood has higher or about the same impacts as miscanthus except for eutrophication**
Analysis of individual pollutants, i.e. Photochemical Oxidation

Scenarios

- Starting point scenario provides a good basis for comparison of different conversion concepts
- Scenario 1 shows what would be possible if fuel yield should be maximized at a certain place. Hydrogen produced with wind power is used to maximize the fuel production
## Key data scenario 1

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Product</th>
<th>Code</th>
<th>Developer</th>
<th>conversion rate (biomass to all liquids)</th>
<th>capacity biomass input (MW)</th>
<th>external electricity, including H2 production</th>
<th>hydrogen input conversion</th>
<th>all liquid products (diesel, naphtha, DME)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>BTL-FT</td>
<td>cEF-D</td>
<td>UET</td>
<td>108%</td>
<td>499</td>
<td>489</td>
<td>0.24</td>
<td>45.6</td>
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<tr>
<td>Wood</td>
<td>BTL-FT</td>
<td>CFB-D</td>
<td>CUTECH</td>
<td>57%</td>
<td>485</td>
<td>135</td>
<td>0.13</td>
<td>23.4</td>
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<tr>
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<td>cEF-D</td>
<td>CUTECH</td>
<td>56%</td>
<td>464</td>
<td>149</td>
<td>0.13</td>
<td>21.9</td>
</tr>
<tr>
<td>Straw</td>
<td>BTL-FT</td>
<td>cEF-D</td>
<td>FZK</td>
<td>91%</td>
<td>455</td>
<td>515</td>
<td>0.34</td>
<td>34.9</td>
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<td>Wood</td>
<td>BTL-FT</td>
<td>ICFB-D</td>
<td>TUV</td>
<td>55%</td>
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<td>-</td>
<td>-</td>
<td>24.1</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>BTL-FT</td>
<td>ICFB-D</td>
<td>TUV</td>
<td>57%</td>
<td>498</td>
<td>-</td>
<td>-</td>
<td>24.0</td>
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</table>

## Well to tank comparison

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Miscanthus</th>
<th>Straw</th>
<th>Straw</th>
<th>Straw</th>
<th>Straw</th>
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<td>Wood</td>
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<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

- **Cumulative energy demand (MJ):**
  - TPA: 250%
  - CO2: 250%
  - C2H4: 250%
  - C2H6: 250%
  - CH4: 250%
- **Abiotic depletion (kg Sb eq):**
  - TPA: 24%
  - CO2: 24%
  - C2H4: 24%
  - C2H6: 24%
  - CH4: 24%
- **Acidification (kg SO2 eq):**
  - TPA: 24%
  - CO2: 24%
  - C2H4: 24%
  - C2H6: 24%
  - CH4: 24%
- **Oxidation (kg PO4 eq):**
  - TPA: 24%
  - CO2: 24%
  - C2H4: 24%
  - C2H6: 24%
  - CH4: 24%
- **Water use (m3):**
  - TPA: 24%
  - CO2: 24%
  - C2H4: 24%
  - C2H6: 24%
  - CH4: 24%

### Category indicator

- **Min Max**
- **Carbon footprint**
- **Aquatic ecotoxicity**
- **Terrestrial ecotoxicity**

- **Best efficiency gives lowest results, but also some differences depending on biomass and specific impacts**
Well to tank comparison
Scenario 1

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Miscanthus</th>
<th>Straw</th>
<th>Straw</th>
<th>Wood</th>
<th>Wood</th>
<th>Wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>BTL-FT</td>
<td>BTL-FT</td>
<td>BTL-FT</td>
<td>BTL-FT</td>
<td>BTL-FT</td>
<td>BTL-FT</td>
</tr>
<tr>
<td>Code</td>
<td>IFb-FT</td>
<td>CFB-D</td>
<td>CFB-D</td>
<td>dEF-D</td>
<td>CFB-D</td>
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Category indicator

<table>
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<tr>
<th>Cumulative energy demand</th>
<th>LjEq</th>
<th>LjCO2</th>
<th>LjCH4</th>
<th>LjSO2</th>
<th>LjPO4</th>
<th>LjSb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>TÜV</td>
<td>CUTEC</td>
<td>FZK</td>
<td>CUTEC</td>
<td>TÜV</td>
<td>LIET</td>
</tr>
</tbody>
</table>

Company

<table>
<thead>
<tr>
<th>Abiotic depletion</th>
<th>Global warming (GWP100)</th>
<th>Photochemical oxidation, non-b</th>
<th>Acidification</th>
<th>Eutrophication</th>
<th>Water use</th>
<th>Land competition</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg Sb eq</td>
<td>107%</td>
<td>203%</td>
<td>164%</td>
<td>257%</td>
<td>134%</td>
<td>100%</td>
</tr>
<tr>
<td>kg CO2 eq</td>
<td>123%</td>
<td>265%</td>
<td>138%</td>
<td>254%</td>
<td>151%</td>
<td>100%</td>
</tr>
<tr>
<td>kg CH4</td>
<td>141%</td>
<td>240%</td>
<td>178%</td>
<td>223%</td>
<td>156%</td>
<td>100%</td>
</tr>
<tr>
<td>kg SO2 eq</td>
<td>128%</td>
<td>166%</td>
<td>122%</td>
<td>209%</td>
<td>175%</td>
<td>100%</td>
</tr>
<tr>
<td>kg PO4 --- eq</td>
<td>156%</td>
<td>209%</td>
<td>100%</td>
<td>234%</td>
<td>209%</td>
<td>100%</td>
</tr>
<tr>
<td>m3</td>
<td>873%</td>
<td>164%</td>
<td>100%</td>
<td>332%</td>
<td>137%</td>
<td>100%</td>
</tr>
<tr>
<td>m2a</td>
<td>20%</td>
<td>148%</td>
<td>100%</td>
<td>416%</td>
<td>622%</td>
<td>300%</td>
</tr>
</tbody>
</table>

| Lowest impacts   | 100% | 168% |
| Lowest impacts   | 116% | 150% |
| Lowest impacts   | 151% | 250% |

Interpretation, Scenario 1

- Only preferable if electricity supplied by wind power, but in this case high demand for capacity and supply security or flexibility
- Higher impacts in case of external hydrogen production with European electricity mix
- No clear ranking because of different advantages and disadvantages

Page 35

Page 36
Change of results
Starting point -> Sc1, European electricity mix

Change of results
Starting point -> Sc1, wind electricity

Cumulative energy demand, abiotic depletion, global warming (GWP100), photochemical oxidation, non-b acidification, eutrophication, water use, land occupation.
Uncertainties
Straw, FZK against Wood, UET

Fuel yields

fuel yield (tonnes oil equivalent per hectare)
Share capital goods
(starting point, MJ fuel)

- Share up to 40%
- Exclusion would give wrong picture
- Article published in the Int. J. LCA that gives further details and recommendations

Limitations of the study

- Pesticides, heavy metals and impacts of land occupation for biomass production not considered in the assessment
- No agreement on reliability of assessment methodologies of toxicity impacts

Concawe compared to RENEW results (fuel production)

Figure 4.6.2-3  WTT GHG balance of syn-diesel pathways (including fossil CO₂ content of final fuels)

Range RENEW 27-65
Differences with Concawe study

- Higher nitrogen input in RENEW study (5-6 vs. 2.5 g N/kg DS) ↗ ca. +50% N2O
- Direct emissions (CH4 and N2O) lower because no data for conversion in Concawe study ↗ ca. +10-20% in RENEW
- No infrastructure in Concawe study ↗ +10-20%
- Credits for electricity production with biomass power plant - mainly relevant for TUV

Peer Review
LCA of BTL-fuel production

- Peer review according to ISO14040 in general quite positive:
  - Requirements are fulfilled
  - Data structure and results are exemplary
- Main critics are
  - No impact assessment for toxicological effects
  - No full cradle-to-grave LCA
  - No comparison to fossil fuel
- Reports have been finalized and published on the RENEW homepage together with full review comment
Questions to be answered

- Using BTL reduces the GWP by X% compared to fossil fuel
- Using a specific amount (e.g. 1 MJ or 1 kg) of BTL reduces the GWP by Y kg (or another appropriate unit) compared to fossil fuel

Calculations of potential reduction
And again: How much better are biofuels?

- If we want an answer like „the use of biofuel has ???% lower GWP than fossil fuels“ than we have to include the all parts of the life cycle, e.g. for transports also cars and streets
- Neglecting certain parts of the life cycle, even if the same for both options, will bias the results
- System boundaries must be stated correctly if comparing reduction figures, e.g. well-to-wheel should include the wheel
- See [www.esu-services.ch/btl/](http://www.esu-services.ch/btl/) for background paper

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BTL from short-rotation wood (IFEU study)