Butanol for sustainable aviation

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Outline

Introduction
– Alternative jet fuel pathways
– Alcohol-to-jet

Opportunities for butanol
– Butanol from waste
– The GreenLogic project

Methods and results
– Continuous enrichment studies
– Thermodynamic system design
– Modelling of full-scale reactors

Conclusions

Outlook
Alternative jet fuel pathways

- There are five ASTM D7566 certified pathways for synthetic paraffinic kerosene (SPK) production

<table>
<thead>
<tr>
<th>Type</th>
<th>Pathway</th>
<th>Description</th>
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<tr>
<td>Gas-to-jet</td>
<td>FT-SPK</td>
<td>SPK from syngas via Fischer-Tropsch (FT)</td>
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<tr>
<td></td>
<td>FT-SPK/A</td>
<td>FT-SPK with increased aromatic content</td>
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<tr>
<td>Oil-to-jet</td>
<td>HEFA-SPK</td>
<td>SPK from hydro-processed esters and fatty acids (HEFA)</td>
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<tr>
<td>Sugar-to-jet</td>
<td>SIP-SPK</td>
<td>Synthesized iso-paraffins (SIP) obtained via farnesene intermediate</td>
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<tr>
<td><strong>Alcohol-to-jet</strong></td>
<td>ATJ-SPK</td>
<td>SPK from C2-C5 alcohols</td>
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</tbody>
</table>

**FOCUS**

The alcohol-to-jet pathway

Energy crops
Cellulosic materials
Municipal & Industrial waste streams

Alcohols

Fermentation
(bio)chemical pretreatment

Dehydration
Oligomerization
Hydrogenation
Distillation

ATJ (C8-C16)

Opportunities

- ASTM D7566-18 permits blending iso-butanol and ethanol derived SPK with conventional jet fuels of up to 50%
- Sourcing C2-C5 alcohols from waste
Butanol from waste – How?

- Anaerobic mixed microbial cultures
- Non-standard conditions (pH 5, increased pH₂)

The GreenLogic project

- Production of **C2-C5 alcohols** from industrial and municipal waste streams
- Upgrading waste water treatment plants (WWTP) into water **resource recovery** facilities (WRRF)
Anaerobic digestion: The classical view

Polymers
carbohydrates, proteins, lipids

Monomers
monosaccharides, amino acids, LCFA

Short-chain fatty acids
propionate, butyrate, ...

H₂

Acetate

CH₄ + CO₂

Hydrolysis

Acidogenesis

Acetogenesis

Methanogenesis

Current focus

Different microbial groups degrade complex waste streams into biogas.
Anaerobic digestion: Butanol enrichment

Polymers
- carbohydrates, proteins, lipids

Monomers
- monosaccharides, amino acids, LCFA

Short-chain fatty acids
- propionate, butyrate, ...

C2-C5 alcohols

Hydrolysis

Acidogenesis

Solventogenesis

New focus

Operate at pH 5 and high pH₂ to promote alcohol formation.

H₂ + Butyrate ➔ Acetate + H₂

Acetate ➔ CO₂ + CH₄

Acetoclastic Methanogenesis

Butanol

CO₂ + H₂ ➔ CH₄

Hydrogenotrophic Methanogenesis
Thermodynamic system design

- Unlocking butanol formation
- Increase $H_2$, decrease pH (see arrow)

Butanol formation
Butyrate$^- + H^+ + 2H_2 \rightarrow$ Butanol + H$_2$O

\[ \Delta G^1 < 0 \]
\[ \Delta G^1 = 0 \]
\[ \Delta G^1 > 0 \]
Modelling of full-scale anaerobic digesters

- From biogas towards butanol formation

Confidential information on this slide has been removed.
Conclusions

- **Butanol production** from waste under non-standard conditions

- **Mixed culture biotechnology** as a solution for cheap feedstock conversion into ATJ-SPK

- ATJ-SPK approval for C3-C5 alcohols expected in the **mid-term**; ethanol and iso-butanol are certified already
Outlook

- **Techno-economic analysis** of upstream (H₂ and butyrate sources) and downstream processing

- **Enrichment of new biocatalysts** for butanol formation (microorganisms, enzymes)

- Municipal and industrial waste streams as **cheap and sustainable feedstock** for jet fuel production
Thank you for your attention!

Project partners: