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>
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<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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<td>FT-SPK/A</td>
<td>FT-SPK with increased aromatic content</td>
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<td>Oil-to-jet</td>
<td>HEFA-SPK</td>
<td>SPK from hydro-processed esters and fatty acids (HEFA)</td>
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<td>Sugar-to-jet</td>
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<td>Synthesized iso-paraffins (SIP) obtained via farnesene intermediate</td>
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<tr>
<td>Alcohol-to-jet</td>
<td>ATJ-SPK</td>
<td>SPK from C2-C5 alcohols</td>
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FOCUS

The alcohol-to-jet pathway

1. Energy crops
2. Cellulosic materials
3. Municipal & Industrial waste streams
4. (bio)chemical pretreatment
5. Fermentation
6. Dehydration
7. Oligomerization
8. Hydrogenation
9. Distillation
10. ATJ (C8-C16)

Feedstock opportunity

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

Opportunities:
- Non-competition with food production
- Cheap feedstock
- Closing the circular economy gap
- Energy recovery
Butanol from waste – How?

- Anaerobic mixed microbial cultures
- Non-standard conditions (pH 5, increased pH$_2$)

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

Hydrolysis

Polymers
- carbohydrates, proteins, lipids

Monomers
- monosaccharides, amino acids, LCFA

Vendor classes
- monomers, fatty acids
  - propionate, butyrate, ...

Acidogenesis

Acetogenesis

Methanogenesis

Current focus

Different microbial groups degrade complex waste streams into biogas.

H₂, Acetate

CH₄ + CO₂
Anaerobic digestion: Butanol enrichment

**Polymers**
carbohydrates, proteins, lipids

**Monomers**
monosaccharides, amino acids, LCFA

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

**C2-C5 alcohols**

New focus
Operate at pH 5 and high pH$_2$ to promote alcohol formation.

\[ \text{Butanol} \]

\[ \text{H}_2 + \text{Acetate} \rightarrow \text{Butyrate} \]

\[ \text{Butyrate} \rightarrow \text{Acetate} + \text{H}_2 \]

\[ \text{Acetate} \rightarrow \text{CO}_2 + \text{CH}_4 \]

\[ \text{CO}_2 + \text{H}_2 \rightarrow \text{CH}_4 \]

\[ \text{Acetoclastic Methanogenesis} \]

\[ \text{Anoerobic Butyrate Conversion} \]

\[ \text{Hydrogenotrophic Methanogenesis} \]
Thermodynamic system design

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

Butanol formation
$\text{Butyrate}^- + H^+ + 2H_2 \rightarrow \text{Butanol} + H_2O$

Diagram showing the thermodynamic conditions for butanol formation, with $\Delta G^1 < 0$ at lower pH and $\Delta G^1 > 0$ at higher pH.
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: