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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<tbody>
<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>
</tr>
<tr>
<td>Sugar-to-jet</td>
<td>SIP-SPK</td>
<td>Synthesized iso-paraffins (SIP) obtained via farnesene intermediate</td>
</tr>
<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

Energy crops

Cellulosic materials

(bio)chemical pretreatment

Fermentation

Dehydration

Oligomerization

Hydrogenation

Distillation

ATJ (C8-C16)

Feedstock opportunity

Municipal & Industrial waste streams

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

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)

Waste streams → Clean water → Biogas → Liquid biofuels
Anaerobic digestion: The classical view

Polymers
- carbohydrates, proteins, lipids

Monomers
- monosaccharides, amino acids, LCFA

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

Current focus
Different microbial groups degrade complex waste streams into biogas.

Hydrolysis

Acidogenesis

Acetogenesis

Methanogenesis

H₂

Acetate

CH₄ + CO₂
Anaerobic digestion: Butanol enrichment

Hydrolysis
- **Polymers**
  - carbohydrates, proteins, lipids

Acidogenesis
- **Monomers**
  - monosaccharides, amino acids, LCFA
- **Short-chain fatty acids**
  - propionate, butyrate, ...

Solventogenesis
- **C2-C5 alcohols**

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

- H$_2$+Butyrate $\rightarrow$ Acetate$+$H$_2$
- Acetate $\rightarrow$ CO$_2$+CH$_4$
- CO$_2$+H$_2$ $\rightarrow$ CH$_4$
- Anaerobic Butyrate Conversion
- Acetoclastic Methanogenesis
- 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

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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: