Sourcing of feedstock for biopolymers

Haldor Topsøe MOSAIK™ Technology
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Haldor Topsoe is a world leader in catalysis and surface science. We are committed to helping our customers achieve optimal performance.

We enable our customers to get the most out of their processes and products, using the least possible energy and resources, in the most responsible way.
Catalysis and surface science have a vital role to play

- Chemical processes are used in the production of countless everyday objects, including food, fuel, electronics, and medicine.
- Almost all chemical processes utilize catalysts, and more than 90% of all industrial products are made using catalysis in some way.
- In a catalytic process, catalysts promote the chemical reaction without being consumed by the process themselves.
- When a catalyst catalyzes a chemical process, the chemical reaction happens faster, using much less energy while also avoiding the production of unwanted byproducts.

Catalyst surface magnified to the micrometer scale in one of our electron microscopes.
The Future of Food and Farming – for a flexible, fair and sustainable Common Agricultural Policy

Brussels, 29 November 2017

Simpler rules and a more flexible approach will ensure the Common Agricultural Policy (CAP) delivers real results in supporting farmers and leads the sustainable development of EU agriculture.
Market Pull for Bio-Based Polymers

Ethylene glycol is an existing large volume chemical used for PET bottles and fabrics (polyester).

New products with new functionalities that are difficult to obtain from fossil sources.

NESTE & IKEA take leadership in bio-based home furniture

NESTE and IKEA join forces to industrialize and lead the trend of renewable bio-based materials for home furnishing plastic products.

PepsiCo Develops World’s First 100 Percent Plant-Based, Renewably ...

PepsiCo has developed a new PET bottle that is 100% plant-based. The bottle is made from sugarcane-based raw materials and is fully recyclable.

Coke and Pepsi foresee a biobased PET future for bottles ...

Coca-Cola and PepsiCo both foresee a future where biobased PET bottles will be common.
Can biomass replace oil?
In some cases, biomass can not only replace oil – it can be a better option.

• Biomass offers a lot of “chemical functions” that can be reused or slightly altered.

• The global production of bio-based polymers is expected to more than triple from 5.7 million tons in 2014 to approximately 17 million tons in 2020.

• Although the market share for bio-based polymers will remain small (4%) compared to oil-based polymers for years to come, the anticipated growth rates are far higher.
# Predicted EU bio-based production and private investment in 2025

<table>
<thead>
<tr>
<th>Product category</th>
<th>CAGR (%)</th>
<th>Bio-based production in 2025 (kt/a)</th>
<th>Total private investment (EUR million/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform chemicals</td>
<td>10</td>
<td>353</td>
<td>128</td>
</tr>
<tr>
<td>Solvents</td>
<td>1</td>
<td>80</td>
<td>16</td>
</tr>
<tr>
<td>Polymers for plastics</td>
<td>4</td>
<td>353</td>
<td>144</td>
</tr>
<tr>
<td>Paints, coatings, inks &amp; dyes</td>
<td>2</td>
<td>1,151</td>
<td>437</td>
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<tr>
<td>Surfactants</td>
<td>4</td>
<td>1,974</td>
<td>805</td>
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<tr>
<td>Cosmetics and personal care products</td>
<td>3</td>
<td>687</td>
<td>349</td>
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<tr>
<td>Adhesives</td>
<td>10</td>
<td>462</td>
<td>195</td>
</tr>
<tr>
<td>Lubricants</td>
<td>1</td>
<td>254</td>
<td>63</td>
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<tr>
<td>Plasticisers</td>
<td>3</td>
<td>83</td>
<td>52</td>
</tr>
<tr>
<td>Man-made fibres</td>
<td>3</td>
<td>738</td>
<td>494</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>6,134</td>
<td>2,683</td>
</tr>
</tbody>
</table>

Source: Insights into the European market for bio-based chemicals, 2019
The shift from fossil-based to bio-based chemicals has moved closer

- Haldor Topsoe’s MOSAIK™ technology produces chemicals from biomass at a cost that competes with that of traditional oil-based chemicals.

- Cost often put an end to the desire of lawmakers, industry, and consumers to replace oil with sustainable raw materials, such as biomass. However, new technology can change that.

- Haldor Topsoe researchers have devised a novel process that produces several chemicals from biomass – at an attractive cost that can compete directly with similar oil-based chemicals.
MOSAIK™ is a New Platform for Oxygenated Chemicals from Biomass

Oxygen retained in the C1-C3 is a competitive advantage compared to e.g. gasification

Sugar conversion pilot

Sugars

C1-C3 oxygenates

Glyoxal, 2 $bn/y
Pure glycolaldehyde
Ethylene glycol, 20-25 $bn/y
Glycolic acid
Ethanol amine, 3 $bn/y
Methionine hydroxy analogue, 3-4 $bn/y
Methyl vinyl glycolate
Product composition
C1-C3 oxygenate products

- Process is highly selective towards C1-C3 with 85% of carbon in useful compounds
Overview of competing technologies for producing bio chemicals compared to MOSAIK™

**Fermentation**
- Suited for small scale chemicals production (acids) and large scale for simple alcohols.
- High TRL.
- Many different products accessible.
- Often expensive product purification, leading to high production costs.
- Important chemicals: ethanol, butanol, isobutanol, lactic acid, succinic acid, itaconic acid.

**Catalysis**
- Potentially suitable for large-scale chemicals production.
- Only few useful products directly accessible.
- Low TRL.
- May lead to more intensive processing than fermentation, thereby lowering production costs.
- Important chemicals: sorbitol, gluconic acid, furfural, mixed glycols, (furan dicarboxylic acid, ethylene glycol, lactic acid)

**Gasification**
- Suited for large scale chemicals production.
- Existing chemical infrastructure can be used.
- High TRL.
- Not cost competitive with conventional routes.
- Important chemicals: methanol, methane, hydrogen, ammonia, formaldehyde.

**Pyrolysis**
- Enable direct conversion of raw biomass to a liquid product.
- Low-Medium TRL.
- Low cost method of processing the biomass.
- Very complex product spectrum in the bio-oil makes it unsuitable as a chemicals feedstock.
- Important chemicals: methanol, methane, hydrogen, ammonia, formaldehyde.

**Sugar cracking**
- Developed infrastructure for feedstock.
- High yields C1-C3 with few by-products.
- Enables economically feasible production of existing chemicals with large markets and production of new chemicals with promising applications.
- Product stable and thus easy to store and transport.
- Need to increase TRL.

**MOSAIK™**
Partnerships

• In 2017 Topsøe and Braskem made a partnership to commercialize ethylene glycol production from Topsøe MOSAIK™ technology, based on sugar as bio feedstock

• Ethylene glycol is a platform chemical for PET plastics

• Innovation Fund Denmark also invested in the development of the MOSAIK™ technology platform in 2017
Timeline for demonstration & commercialization of Bioglycols with Braskem

- '18: Finish construction of the demo plant in Denmark
- '19: Demo plant start-up & operation
- '20: Validation of technical parameters and Bio-MEG validation with clients
- '21: Commercialization
- '23+:
MOSAIK™ Technology Readiness Level (TRL)

After this demo scale
Conclusions

• The market for biobased platform chemicals is expected to grow in the next 5 years

• Our objective is to commercialize the MOSAIK™ technology which is a platform for a number of chemicals

• A full scale plant can be up running +2023 for producing a platform chemical for PET plastic