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• Introduction on Biobased Chemicals
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• Technology push or market pull?
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• Dilemma: Drop-in versus novel building blocks
• Biobased Chemicals - SWOT analysis
• Conclusions
Task Framework – Biorefining

Definition IEA Bioenergy Task42

Sustainable processing of biomass into a portfolio of marketable biobased products (food and feed ingredients, chemicals, materials, fuels, energy, minerals, CO₂) and bioenergy (fuels, power, heat)
Setting the Scene
Biorefining in a Future Circular (Bio)Economy

Circular (Bio)Economy

Recycle resources
- nutrients
- water
- carbon

Recycle of materials
- bulk chemicals

Re-use of products

Array of Products Services

Use

waste

Re-think products & needs

Renewable Resources

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Task42 – Biorefining in a Future BioEconomy
Renewable Carbon

A Fossil-Free World

There are only three renewable carbon sources available in this world...

- Plant-Based Rediscover
- Air-Based Reroute
- Man-Made Repurpose

Glucose as Building Block

CO₂ Conversions

Chemical Recycling

...that enable a circular economy

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The Chemical Industry: A Key to Mitigating Climate Change

6 years until the carbon budget to limit global warming to 1.5 degrees is used (extrapolating current CO₂ emissions)

90% of the chemical products we use are derived from fossil carbon (this excludes fuels)

4x is the expected growth of the plastic market from 2014-2050

This represents 11% of global primary demand for oil and 8% for natural gas

Plastics are expected to make up 15% of carbon budget in 2050

1-2% of current plastics are made from renewable feedstock

1 Brief 2017, IPCC – Figures correspond to a 50% chance to limit global warming to 1.5 or 2 degrees; IEA, July 2018; Ellen McArthur
2 New plastics economy’, 2016
WTI (West Texas Intermediate) crude oil daily closing prices over the last 10 years
Global Prices of Key Food Commodities *(Source: World Bank, last observation is 2018Q3. Shaded areas denotes forecasts)*

US$ 100=2010

Grains

Oils and meals
Why producing Biobased Chemicals (in conjunction with Bioenergy) in a Biorefinery

• To supply the market with sustainable/renewable chemicals
• To improve the economics of bioenergy production
• To partly make use of existing industrial (energy) infrastructure potentially decreasing initial investments and shorten time-to-market
• To make scaling up easier (makes plant already commercial viable at smaller scales)
• Unique functionality
• Medium term CO₂ storage (depending on chemical)
• Reduction of non renewable energy usage (NREU) usage (both because of renewable product and less fossil fuel used in production
Current Market Size

Fossil based Chemicals:
>330 million tonnes

Main molecules:
  methanol, ethylene, propylene, butadiene, benzene, toluene and xylene

Biobased Chemicals & derived Materials:
90 million tonnes

Main molecules:
  Fermentation products (e.g. ethanol), fatty acids (derivatives)
Pull or Push?

- Governmental – Legislative push
  - Sustainability
  - Green House Gas savings / Non Renewable Energy Usage
  - Security of supply

- Technological push
  - Biochemical / Chemical
  - Concepts versus applicability

- Market pull
  - Brand owners
  - Consumers
The Biobased Transition has started, Companies look for Bio-Based Alternatives

“Apple believes that improving the environmental performance of our business starts with our products. The careful environmental management of our products includes controlling the types of materials used: plastics used in the display frame are made with 28% bio-based content”

“The best-known example of how we rethink our packaging is our breakthrough bio-based, low-carbon, Green Fibre Bottle. It continues to attract attention and spark discussion”

“Lego invests 1 billion DKK in R&D and implementation of new, sustainable, raw materials to manufacture LEGO elements as well as packaging materials; “This is a major step for the LEGO Group on our way towards achieving our 2030 ambition on sustainable materials”.

“We envision a transition from linear to circular business models and a world that demands closed-loop products...” “We are re-imagining waste streams as value streams...” “...and encourage broader adoption of renewables as part of our effort to control absolute emissions”

“The new Biolage R.A.W. haircare line was sustainably designed and developed, in response to consumers’ growing expectations in this area. Raw materials of natural origin are preferred, with percentages of natural ingredients between 70% and 100%”

“There are about 400 pounds of plastic on a typical car, our job is to find the right place for a green composite to help our impact on the planet”
Global production capacities of Bioplastics 2018 (by material type)

Total: 2.11 million tonnes

- PE: 9.5%
- PET: 25.6%
- PA: 11.6%
- PP: 0.0%
- PEF: 0.0%
- PTT: 9.2%
- Other (bio-based/non-biodegradable): 0.9%
- PBAT: 7.2%
- PBS: 4.6%
- PLA: 10.3%
- PHA: 1.4%
- Starch blends: 18.2%
- Other (biodegradable): 1.5%

Bio-based/non-biodegradable: 56.8%
Biodegradable: 43.2%

*Bio-based PP and PEF are currently in development and predicted to be available at commercial scale in 2023

Source: European Bioplastics, nova-Institute (2018)
Global Production Capacities of Bioplastics (2017 – 2023)

Source: European Bioplastics, nova-Institute (2018)

Bioenergy – Refining in a Future BioEconomy
Conversion technologies for biomass based on IEA Bioenergy Task 42 biorefinery classification system
Dominant Platforms

Syngas Platform
Biogas Platform
C6 sugar platform*
C6/C5 sugar platform
Plant-based Oil Platform*
Algae Oil Platform
Organic Solutions Platform
Lignin Platform
Pyrolysis Oil Platform

* Currently the dominant platforms for biobased chemicals
World primary energy demand and energy-related CO$_2$ emissions by scenario. Bubble size represents size of global economy.
Required policy actions, consumer behaviour change and technological progress identified by IEA Bioenergy Task 42

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Sustainable Development Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy</td>
<td>• High CO₂ price &gt; 100 $/t&lt;br&gt;• Fossil subsidies are gone&lt;br&gt;• Net CO₂ sequestration incentivised&lt;br&gt;• Circular economy is mandatory&lt;br&gt;• Sustainable forestry and agriculture is mandatory</td>
</tr>
<tr>
<td>Technology</td>
<td>High progress:&lt;br&gt;• In up- and downstream processes for bio-based feedstock&lt;br&gt;• Ethanol-to-chemicals&lt;br&gt;• Green H₂- production&lt;br&gt;• Widespread algae/ seaweed utilisation</td>
</tr>
<tr>
<td>Social acceptance</td>
<td>High acceptance of climate treat and for climate policy:&lt;br&gt;• Agreement on biomass sustainability and biodiversity&lt;br&gt;• Willingness to change behaviour&lt;br&gt;• Willingness to pay for climate-friendly products&lt;br&gt;• Open attitude to locations of facilities&lt;br&gt;• Less meat demand (resulting in high feedstock availability)</td>
</tr>
</tbody>
</table>
Consequences for the scenarios with respect to more sustainable biobased economy identified by IEA Bioenergy Task 42

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Sustainable Development Scenario</th>
</tr>
</thead>
</table>
| Prices and renewable energy share            | • High prices for GHG-intensive products  
• Share of electricity from renewable sources 100%, surplus electricity available               |
| Feedstock availability                       | • No restrictions (1\textsuperscript{st}, 2\textsuperscript{nd} and 3\textsuperscript{rd} generation are available) |
| Bio-based industries                         | • Biobased chemicals for all chemical products  
• Large scale lignocellulosic biomass utilisation  
• Extensive use of drop-in chemicals from biomass for existing industry  
• Biogenic CO\textsubscript{2}-conversion to chemicals digestion |

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Biobased Chemicals Table

- Gives an overview of the biobased chemicals status in two categories
  - High growth potential
  - In the pipeline (demonstration or pilot facility running)
- Organized from C1 (methanol, formic acid etc) to Cn (all molecules with more than 6 C atoms)
- Exhaustive list but certainly not complete
- Biobased Chemicals Field is very dynamic at the moment so probably already some new changes / additions needed
<table>
<thead>
<tr>
<th>Cn</th>
<th>Products with strong growth potential Company</th>
<th>Bio-Based Chemicals in the pipeline Chemical Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Methanol, BioMCN, Sodra, AkzoNobel/Enerkem</td>
<td>Formic acid / formiate, Avantium</td>
</tr>
<tr>
<td></td>
<td>Methane, Many</td>
<td>Formaldehyde, BASF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Syn gas, BioMCN</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO₂, Climeworks</td>
</tr>
<tr>
<td>2</td>
<td>Ethylene, Braskem</td>
<td>Ethyl acetate, Greenyug</td>
</tr>
<tr>
<td></td>
<td>Ethanol, Many</td>
<td>Glycolic acid, Metabolix Explorer</td>
</tr>
<tr>
<td></td>
<td>Ethylene glycol (MEG), India Glycols Ltd,</td>
<td>Acetic acid, Wacker, Godovari Biorefineries Ltd</td>
</tr>
<tr>
<td></td>
<td>HaldorTopsoe, UPM, Avantium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ethylene Oxide, Croda, Biokim</td>
<td></td>
</tr>
</tbody>
</table>
# Biobased Chemicals

<table>
<thead>
<tr>
<th>Cn</th>
<th>Products with strong growth potential</th>
<th>Bio-Based Chemicals in the pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>Company</td>
<td>Chemical</td>
</tr>
<tr>
<td>3</td>
<td>Lactic acid (many)</td>
<td>Corbion, NatureWorks, Anhui, Galactic, Henan Jindan</td>
</tr>
<tr>
<td></td>
<td>Propane</td>
<td>Neste</td>
</tr>
<tr>
<td></td>
<td>Glycerol</td>
<td>Many</td>
</tr>
<tr>
<td></td>
<td>Epichlorohydrin (many)</td>
<td>Yihai Kerry Group, Jiangsu Yangnong, Advance Biochemical Thailand</td>
</tr>
<tr>
<td></td>
<td>1,3-Propanediol</td>
<td>DuPont/Tate&amp;Lyle, Metabolic Explorer</td>
</tr>
<tr>
<td></td>
<td>Ethyl lactate</td>
<td>Vertec BioSolvents</td>
</tr>
<tr>
<td></td>
<td>Propylene Glycol (1,2-Propanediol)</td>
<td>ADM, Oleon, BASF, UPM</td>
</tr>
<tr>
<td></td>
<td>Acetone</td>
<td>Green Biologics</td>
</tr>
<tr>
<td>Cn</td>
<td>Products with strong growth potential Chemical</td>
<td>Products with strong growth potential Company</td>
</tr>
<tr>
<td>----</td>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>4</td>
<td>n-Butanol</td>
<td>Cathay Industrial Bio, Green Biologics, <em>Celtic Renewables</em></td>
</tr>
<tr>
<td></td>
<td>iso-Butanol</td>
<td>Butamax, Gevo</td>
</tr>
<tr>
<td></td>
<td>Succinic acid</td>
<td>Reverdia, <em>Myriant</em>, Succinity</td>
</tr>
<tr>
<td></td>
<td>1,4-Butanediol</td>
<td>Genomatica, Novamont, GBL</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Furfural</td>
<td>Many</td>
</tr>
<tr>
<td></td>
<td>Xylitol</td>
<td>a.o. Danisco/Lenzing, Fortress</td>
</tr>
<tr>
<td></td>
<td>Glutamic acid</td>
<td>a.o. Global Biotech, Meihua, Fufeng, Jubua</td>
</tr>
<tr>
<td>Cn</td>
<td>Products with strong growth potential Chemical</td>
<td>Company</td>
</tr>
<tr>
<td>----</td>
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</tr>
<tr>
<td>6</td>
<td>Sorbitol</td>
<td>a.o. Roquette, ADM</td>
</tr>
<tr>
<td></td>
<td>Isosorbide</td>
<td>Roquette</td>
</tr>
<tr>
<td></td>
<td>Aniline</td>
<td>Covestro</td>
</tr>
<tr>
<td></td>
<td>Citric acid</td>
<td>a.o. Cargill, DSM, BBCA, Ensign, TTCA, RZBC</td>
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<td></td>
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<tr>
<td>n</td>
<td>PHA</td>
<td>Telles, Meridian plastics</td>
</tr>
<tr>
<td></td>
<td>Dicarboxylic acids</td>
<td>Cathay Biotech, Evonik</td>
</tr>
<tr>
<td></td>
<td>Fatty Acid derivatives</td>
<td>Croda, Elevance</td>
</tr>
</tbody>
</table>
Product Commercialization

Key Criteria

Market assessment

Market fundamentals (local, regional, global)
Feedstock availability & price
Utilities (steam, gas, electricity etc) availability & price
Product profitability
Competitive nature of market
Need for partnerships
Downstream development opportunities

Technology assessment

Commercial experience
Bankability
Necessary capital investment
Process complexity
Access to technology
Environmental considerations
## Drop-in versus New Functionality

<table>
<thead>
<tr>
<th>Bio-based chemical</th>
<th>Reference Petrochemical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>Acetic acid</td>
</tr>
<tr>
<td>Adipic acid</td>
<td>Adipic acid</td>
</tr>
<tr>
<td>n-Butanol</td>
<td>n-Butanol</td>
</tr>
<tr>
<td>Ethylene</td>
<td>Ethylene</td>
</tr>
<tr>
<td>Bio-MEG</td>
<td>MEG (mono-Ethyleneglycol)</td>
</tr>
<tr>
<td>Ethyl lactate</td>
<td>Ethyl acetate</td>
</tr>
<tr>
<td>FDCA</td>
<td>Terephthalic acid</td>
</tr>
<tr>
<td>PHA</td>
<td>HDPE</td>
</tr>
<tr>
<td>PLA</td>
<td>PET and PS</td>
</tr>
<tr>
<td>Succinic acid</td>
<td>Maleic anhydride</td>
</tr>
</tbody>
</table>
## Drop-in versus Unique Functionality

<table>
<thead>
<tr>
<th></th>
<th>Drop-in</th>
<th>Unique molecule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market acceptance</td>
<td>↑↑</td>
<td>↓↓</td>
</tr>
<tr>
<td>Speed of introduction</td>
<td>↑↑</td>
<td>↓↓</td>
</tr>
<tr>
<td>Fit with existing infrastructure</td>
<td>↑↑ ↔</td>
<td>↔ ↓</td>
</tr>
<tr>
<td>Oil/Feedstock price sensitivity</td>
<td>↑↑↑↑</td>
<td>↑</td>
</tr>
<tr>
<td>Sustainability</td>
<td>↑ ↔ ↓</td>
<td>↑↑↑ ↔</td>
</tr>
<tr>
<td>Unique market space</td>
<td>↓↓↓↓</td>
<td>↑↑↑↑</td>
</tr>
<tr>
<td>Scalability</td>
<td>↑↑↑</td>
<td>↑ ↔ ↓</td>
</tr>
<tr>
<td>Legislation (e.a. REACH)</td>
<td>↑↑↑</td>
<td>↑↑↑↓↓↓</td>
</tr>
</tbody>
</table>

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Task42 – Biorefining in a Future BioEconomy
Global ethanol production in million gallons in 2017

- United States: 15,800
- Brazil: 7,060
- European Union: 1,415
- China: 875
- Canada: 450
- Thailand: 395
- Argentina: 310
- India: 280
- Rest of world: 465

Production in million gallons
Biobased Chemicals - Strengths (SWOT analysis)

- Adding value to the use of biomass
- Maximising biomass conversion efficiency minimising raw material requirements
- Production of a spectrum of bio-based products (food, feed, materials, chemicals) and bioenergy (fuels, power and/or heat) feeding entire bioeconomy
- Strong knowledge infrastructure available to tackle technical and non-technical issues
- Biorefinery is not new, it builds on agriculture, food and forestry industries
Biobased Chemicals – Weaknesses (SWOT analysis)

- Broad undefined and unclassified area
- Involvement of stakeholders for different market sectors (agriculture, forestry, energy, chemical) over full biomass value chain necessary
- Most promising biorefinery processes / concepts not clear
- Most promising biomass value chains, including current/future market volumes/prices, not clear
- Studying and concept development instead of real market implementation
- Variability of quality and energy density of biomass
- Drop-in chemicals face difficult market penetration due to low oil prices
Biobased Chemicals - Opportunities

- Biorefineries can make a significant contribution to sustainable development
- Challenging national and global policy goals, international focus on sustainable use of biomass for the production of bioenergy
- International consensus on the fact that biomass availability is limited meaning that raw materials should be used as efficiently as possible
- International development of a portfolio of biorefinery concepts, including technical processes
- Strengthening of the economic position of various market sectors (e.g. agriculture, forestry, chemical and energy)
- Strong demand from brand owners for biobased chemicals
- Increased production of plant-based proteins for food and feed
Biobased Chemicals - Threats

- Economic change and volatility in fossil fuel prices
- Fast implementation of other renewable energy technologies feeding the market requests
- Bio-based products and bioenergy are assessed to a higher standard than traditional products (no level playing field)
- Availability and contractibility of raw materials (e.g. climate change, policies, logistics)
- (High) investment capital for pilot and demo initiatives difficult to find, and undepreciated existing industrial infrastructure
- Changing governmental policies
- Questioning of food/feed/fuels (indirect land use competition) and sustainability of biomass production
- Goals of end users often focused on single product
Conclusions

- Biobased Chemicals are essential to come to a circular economy
- Biochemical production is currently slowly expanding
- Only in a few cases products are market competitive without subsidies at current oil prices
- Currently more traction for new functionality molecules than for drop-in molecules
- Multiple actions in the biobased chemicals space are needed to achieve the Sustainable Development Scenario

Dissemination

- Pdf version available on IEA Bioenergy Task 42 website (http://task42.ieabioenergy.com/publications/bio-based-chemicals-a-2020-update/)
- Feedback: Ed de Jong (ed.dejong@avantium.com)