The role of industrial biorefineries in a low-carbon economy

Summary and conclusions from the IEA Bioenergy/IEA IETS workshop

This publication provides the summary and conclusions for the joint IEA Bioenergy/IEA IETS workshop 'The role of industrial biorefineries in a low-carbon economy' held in conjunction with the meetings of the Executive Committees of IEA Bioenergy and IEA IETS in Gothenburg, Sweden on 6 May 2017.

IEA Bioenergy

iets

IEA Bioenergy: ExCo: 2017:07

The role of industrial biorefineries in a low-carbon economy

Summary and conclusions from the IEA Bioenergy/IEA IETS workshop

Published by IEA Bioenergy and IETS

EXECUTIVE SUMMARY

Luc Pelkmans, Technical Coordinator, IEA Bioenergy

Thore Berntsson, Chair IEA IETS

The workshop on 'The role of industrial biorefineries in a low-carbon economy' was organised by the IEA Bioenergy Technology Collaboration Programme (IEA Bioenergy) in close collaboration with the IEA Technology Collaboration Programme on Industrial Energy-related Technologies and Systems (IETS). It was held in Gothenburg on 16 May 2017 in conjunction with the Executive Committee meetings of both TCPs. The workshop consisted of four sessions: a plenary session on biorefinery developments, followed by an interactive workshop on strategic biorefinery developments, and a plenary session on how to overcome deployment barriers for biorefineries, followed by an interactive workshop on deployment barriers and actions.

Biorefinery developments and business opportunities

IEA scenario calculations have indicated an important role for biomass in reaching greenhouse gas reduction targets by 2050-2060. Biomass availability is not unlimited, so efficient use will be crucial and uptake of biorefineries at industrial level will be required to achieve this.

Current developments in biorefineries are building on the long standing success of several industries, such as starch processing and paper and pulp, as well as biotechnology and conventional and advanced biofuel processes. Investment needs are very significant and developments need to be profitable with a fair return on investment. Classical oil-based refineries have had more than 100 years to get to the scale and economics they are at today. The biorefinery sector needs to build up over the next few decades. This requires a significant effort from industry as well as the right regulatory environment. A major challenge is that decision makers – both at industry and policy level – require a good knowledge of the cost and environmental performance of emerging technologies and new value chains. The further technologies are from commercialisation stage, the higher the uncertainty in their performance.

Biorefineries are generally expected to play an important role in decarbonising the energy and transport sectors with bioenergy and biofuel products. On the other hand, national and regional economies would benefit the most from a production portfolio that favours high-added value products, like advanced materials, chemicals and food/feed ingredients. Industrial symbioses and increased integration with versatile production of added-value biobased products and bioenergy products can have the highest impact both for climate goals and economic growth.

The scale of biorefineries is a major challenge and it may be wise to build on existing infrastructure. Regional biorefineries linked to existing oil refineries, petrochemical clusters, chemical factories, pulp/saw mills and district heating systems would facilitate a smooth transition, building up step-by-step. It would enable very efficient conversion of biomass to renewable fuels, chemicals and materials at a scale that would make a difference, by taking advantage of investments and permits of existing infrastructures.

The workshop discussed promising concepts of biorefineries and business opportunities in different sectors:

- *Pulp and paper mills* – particularly in the boreal region – are at the heart of the forest bioeconomy. They are an ideal platform for the demonstration of the biorefinery concept because of their scale, existing infrastructure, proximity to biomass sources, and experience in biomass-handling logistics.
- *Chemical industries* can shift to biobased resources, e.g. sugars, focus on materials with specific functionalities (not only replacing fossil chemicals) and consider CO_2 and hydrogen as building blocks. The experience obtained from developing advanced biofuels can form an important stepping stone towards biochemicals.
- *Food and feed industries* already base their production on biobased feedstocks, and more can be done with residues and waste, or non-conventional crops (e.g. proteins from grass or insects). Some existing biofuel production plants already include food/feed as co-products, and they can also move more towards the production of higher value-added components.
- *Petroleum refineries* can be a basis to build regional biorefineries. Hydrogen, which is an important component in refinery processes, could be produced from biomass. Co-processing of biobased intermediates such as pyrolysis oil in petroleum refineries can be a very efficient way to build on existing infrastructure and attain a smooth transition.
- *Energy utilities* can integrate more with other industries, exchanging residues, heat and potentially CO_2. Flexibility in feedstocks (seasonal biomass & residues) and outputs (electricity, heat, biofuels) will be important to reduce investment risks. Where concentrated CO_2 is available, carbon capture and utilisation (CCU) can be considered.

Deployment barriers and recommendations

There is a clear motivation for policy to speed the transition towards the bioeconomy – grand challenges and the associated policy goals of climate change mitigation, energy security, the circular economy concept, rural regeneration, smart specialisation[1] and, paradoxically, reindustrialisation. The biorefinery sits at the heart of all these policy concerns.

Deploying biobased concepts involves four stages: (1) lab-scale development, (2) testing the technology in a pilot plant, (3) demonstration at commercial scale in a reference plant and (4) deployment at industrial scale. It takes time (sometimes decades) to go through the different development steps. Particularly the second and third stages are very cost-intensive, and require partnering with strategic investors, but also need government support. Demonstration support programmes enable the development of first-of-a-kind industrial biorefineries, prove conversion technologies at scale, validate techno-economic assessments, and gain investor confidence. Loan guarantees for commercial biorefinery projects can accelerate the deployment of such projects by helping to bridge the "Valley of Death". Traditional industries can be provided with systems engineering models and decision-making tools to evaluate the most promising biorefinery products/technologies to support the transition to integrated biorefineries. Companies can also aim at the production of specific biobased molecules with intrinsic advantages compared to their fossil counterparts.

The workshop discussed the main non-technical barriers and problems for industrial players to adopt and integrate biorefinery concepts, how to overcome the major barriers and concrete recommendations for research, industry and policy.

1 Regional innovation and R&D investments based on an identification of a region's strengths and comparative assets, so that the region can develop its own competitive advantages.

Policy:

Further development of the biorefinery sector requires stable, coherent, consistent and predictable policies, as well as a long-term vision to provide long-term perspectives for industry. High investment needs and profitability are some of the major barriers for bioenergy and biobased products. Governments can facilitate the deployment of biorefineries through subsidies for innovation and R&D, support for demonstration and first of a kind plants, government guarantees to reduce investment risks, providing decision tools to show business opportunities, as well as purchase mandates and/or tax credits and long term targets. Real external cost and CO_2 price mechanisms should be applied to fossil based products, and fossil subsidies should be removed.

Business/industry:

Involvement of industry sectors and stakeholders is crucial, aiming at long-term commitments of these sectors. The industry has a responsibility to act, but this is also a major opportunity for growth. Industry sectors can set up business-to-business approaches, as for instance the Carbon Pricing Leadership Coalition, applying an internal value to CO_2 for investment decisions, without waiting for government decisions on this. Common grounds for collaboration between sectors should be found, with long-term multi-party agreements (national and international) and new biorefinery business models. It is important to have cross-sector information sharing. This requires the involvement and transparent commitment of industry, academics and NGOs.

Research, education and communication:

The scientific community needs to communicate with industries, the public and policy makers, to create awareness of the benefits of the biobased economy, to promote success stories in biobased products and to showcase the benefits of cooperation to industry. Education in the circular economy and biobased economy should be developed, as well as a transparent knowledge base on the status and prospects of biobased products, thus making the value of biobased products clear to consumers. In terms of standardisation, common language can be developed, e.g. in terms of definitions, measurements, assessments and calculation methods for biofuels and biobased products. Multidisciplinary RD&D is needed, e.g. related to separation and purification, but also in multi-criteria decision making and system research. Technological innovation should be better managed, and international cooperation improved.

The PowerPoint presentations can be downloaded from the websites of IEA Bioenergy[2] and IEA IETS[3].

2 http://www.ieabioenergy.com/publications/ws22-the-role-of-industrial-biorefineries-in-a-low-carbon-economy

3 http://www.iea-industry.org/

WORKSHOP

Welcome speeches

Åsa Forsum of the Swedish Energy Agency welcomed the participants to Sweden. Sweden aims to be the first fossil free country in the world with a target to reach net zero greenhouse gas emissions by 2045. Sweden has long experience in well maintained certified forests, which can play an important role in the further development of biorefineries. International cooperation is considered crucial to accelerate research and technological developments.

Thore Berntsson, the chair of the IEA IETS, gave a short introduction to the IEA Technology Collaboration Programme (TCP) on Industrial Energy-related Technologies and Systems (IETS). It is the only TCP with a distinct focus on industries. Currently 10 countries are members in IETS. IETS Annex XI is dedicated to industry-based biorefineries, which is also the central theme of this workshop. He welcomed the cooperation with IEA Bioenergy in organising this workshop together.

Kees Kwant, the chair of IEA Bioenergy, briefly introduced the IEA Bioenergy Technology Collaboration Programme, which has 24 contracting parties. The work is organised in Tasks, of which one (Task 42) is dedicated to biorefining. He referred to the commitments made at the Paris Agreement towards a low-carbon economy. Scenario calculations have indicated an important role for biomass in reaching the Paris Agreement targets. A central question concerns how to produce the required biomass in a sustainable way, but also how to use it efficiently. Uptake of biorefineries at industrial level will be required to achieve this. The workshop will contribute to thoughts and ideas on steps that can be taken to realise such a transition.

Session 1: Biorefinery developments

This session was moderated by IEA IETS chair Thore Berntsson.

Future biorefinery concepts

Jussi Manninen, VTT Technical Research Centre of Finland

Future biorefinery concepts need to satisfy several, sometimes conflicting, expectations from society and investors. On the one hand, society is expecting biorefineries to play an important part in decarbonising the energy and transport sectors with bioenergy and biofuel products, which are large volume low added-value products. On the other hand, national and regional economies would benefit the most from a production portfolio that favours high-added value products, such as advanced materials and chemicals, although specialised high value products may have low volume markets. Investors need to recover their investment in a reasonable time, so they naturally favour concepts that satisfy clear market needs, and are economically (CAPEX and OPEX) competitive. Product markets and profitable production are key requisites for a sustainable bioeconomy. In the context of a circular economy, industrial symbioses and increased integration with versatile production of added-value biobased products and bioenergy products can have the highest impact both for climate goals and economic growth. This was illustrated in the presentation with scenario calculations for Finland.

For the boreal region, pulp mills are at the heart of the forest bioeconomy, with new products increasing in significance. Mills would produce a combination of materials and energy products. Fibres would increasingly be used for textiles and composite materials. Lignin would be directed more towards higher value products, while other residues and side streams would be turned into fuels and chemicals.

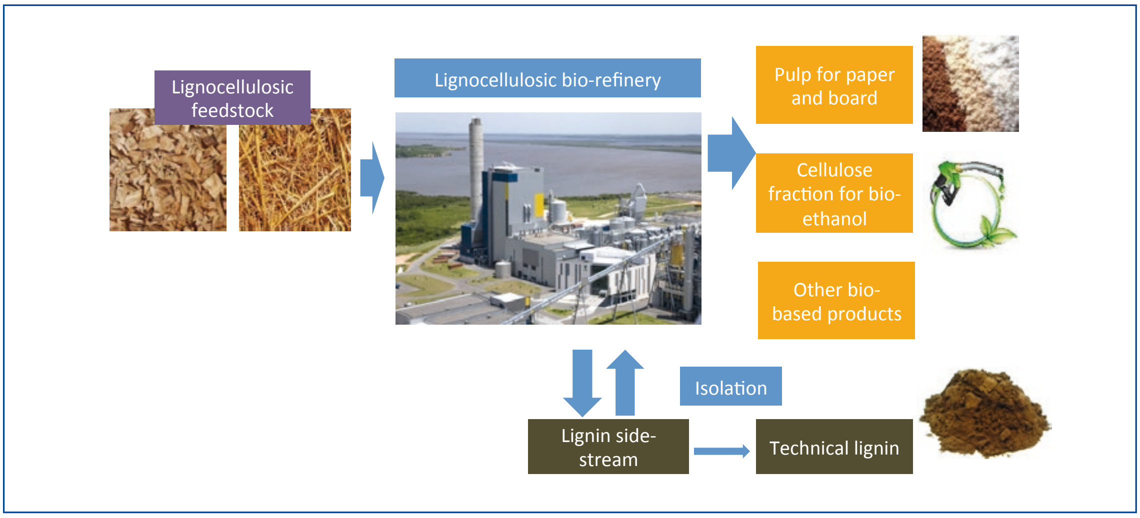

Figure 1: Scheme of a lignocellulosic biorefinery (source: VTT)

Current developments in advanced biofuels focus among others on:

- providing cheap sugars via *biotechnology*,
- reducing the economic scale of *gasification* processes to better fit the system, and
- improving the products of *pyrolysis* so that these can be either directly upgraded to transport fuel, or co-fed in existing petroleum refineries.

Such developments can be utilised at a later stage for the production of biochemicals, so that advanced biofuels form an important stepping stone towards biochemicals.

For the future, more efficient and selective extraction and production technologies will be needed, as well as widening the raw material options to include new, high yielding inputs such as algae and CO_2 as a source of carbon, with renewable electricity providing the hydrogen. Integration with the renewable electricity system can benefit both biorefineries and the electricity grid.

Key challenges for the economic and environmental evaluation of large biorefinery concepts

Andrea Ramirez, Delft University of Technology, the Netherlands

The deployment of (novel) biorefineries' concepts requires assessing the cost and environmental performance of emerging technologies and new value chains. This is inherently difficult. The further upstream a technology is from the commercial stage, the less certain is the understanding of its performance. Yet, the urgency of deploying cost-efficient solutions with low environmental impacts warrants that decision-makers are capable of deciding upon technology development paths with less than ideal information. Significant research efforts have already been made to develop methodologies that take those aspects into account, and provide information on the technology performance, economic viability and environmental soundness of biorefinery concepts.

The presentation made a distinction between screening studies and detailed studies. *Screening studies* generally use a multi-criteria approach and aim to identify significant differences between pathways/technologies. The high level of uncertainty is not necessarily a problem for this type of study. *Detailed studies* aim to assess the competitiveness and environmental impacts of specific routes, in comparison with petrochemical counterparts. Depending on the stage of development, the uncertainty may be problematic. Environmental impact analysis (LCA) and techno-economic analysis (TEA) use different system boundaries.

Some key challenges, particularly for detailed ex-ante studies are as follows:

- A *functional unit* is needed to make a meaningful comparison between systems. Biorefineries are by definition multi-output systems. Including novel products, or intermediate products (building blocks), the function of which is not comprehensively defined, is challenging.
- *Allocation* of the total system's environmental impacts to the different outputs is possible according to mass, volume, energy or market value. Some studies may choose the allocation that best fits confirmation of their hypothesis. The recommendation is to use several types of allocation methods and publish them all.
- *Displacement*: in the future, biobased products or fuels may not simply replace fossil products or fuels on a one-to-one basis, but may also compete with other (renewable) alternatives in the market place.
- *Scaling-up* should include not only process scale-up, but also system scaling, i.e. include effects of the introduction of the scaled up product in the market and the environmental impacts.
- *Time perspective*: Analysis takes place in a posited future scenario. When the process is at an early stage (lab, pilot), future conditions (both foreground and background) could also change.

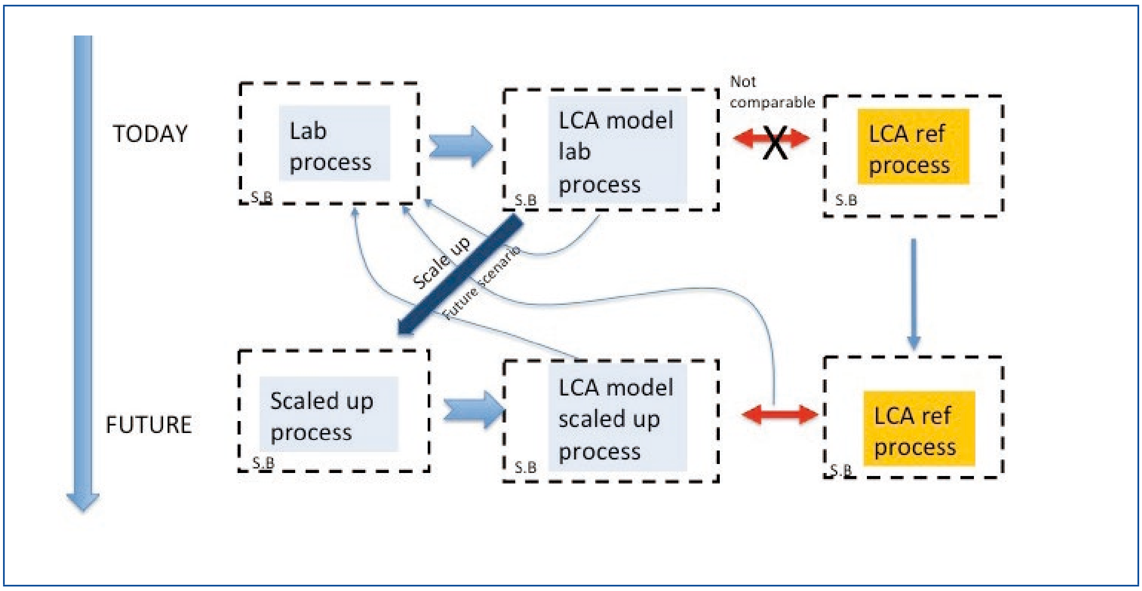

Figure 2: Time perspectives in the evaluation of biorefinery concepts (source: Villares et al. 2017)

Ex-ante assessment is interdisciplinary research, requiring transfer of knowledge and data across research fields. TEA, LCA and LCC (life cycle costing) are heavily dependent on data (e.g., energy, raw materials, operating conditions, life time, and costs). Large uncertainties are inherent in an ex-ante assessment: it requires assumptions, simplifications and sensitivity analysis. Complexity and uncertainty are reinforced by the unclear (or non-existant) socio-technical embedment of the technology. Comparative and iterative approaches are needed. Results of ex-ante assessments should not be considered as deterministic outcomes.

Infrastructure for biorefinery systems – a future scenario for oil refineries and the chemical industry

Henrik Thunman, Chalmers University of Technology, Sweden

Yearly consumption in oil refineries and the petrochemical cluster in West Sweden amounts to 274 TWh (23 million tonnes of crude oil). The biomass needed to replace that would amount to approximately 400 TWh, which is twice the annual forest growth in Sweden. Thus, the scale of biorefineries is a major challenge, as well as the level of investments.

GoBiGas is an example of a biorefinery, producing biomethane from woody biomass in Gothenburg, Sweden. Its scale is 20 MW and it includes a full petrochemical factory, including a gasification unit and a synthesis plant. For an actual commercial unit, the scale should be at least 10 times larger, i.e. in the order of 200-500 MW, which is equivalent to 80-200 tonnes/h wet biomass.

The presentation suggested the possibility to integrate an indirect gasifier with an existing CFB (circulating fluidised bed) boiler. Through the CFB, bed material heat can be provided to the gasifier. This configuration could achieve up to 87% chemical energy efficiency (considering the products going to the synthesis process). Integration with existing solid fuel boilers provides a cost effective shortcut for the implementation of gasification technology.

Moreover the gasification process provides an excellent opportunity to convert electricity into chemically bound energy. Hydrogen from electrolysis would be combined with CO_2 from the synthesis process. Depending on the end product, the potential ratio between electricity and biomass input could be 1.2-1.6. So this concept would require major input of (renewable) electricity.

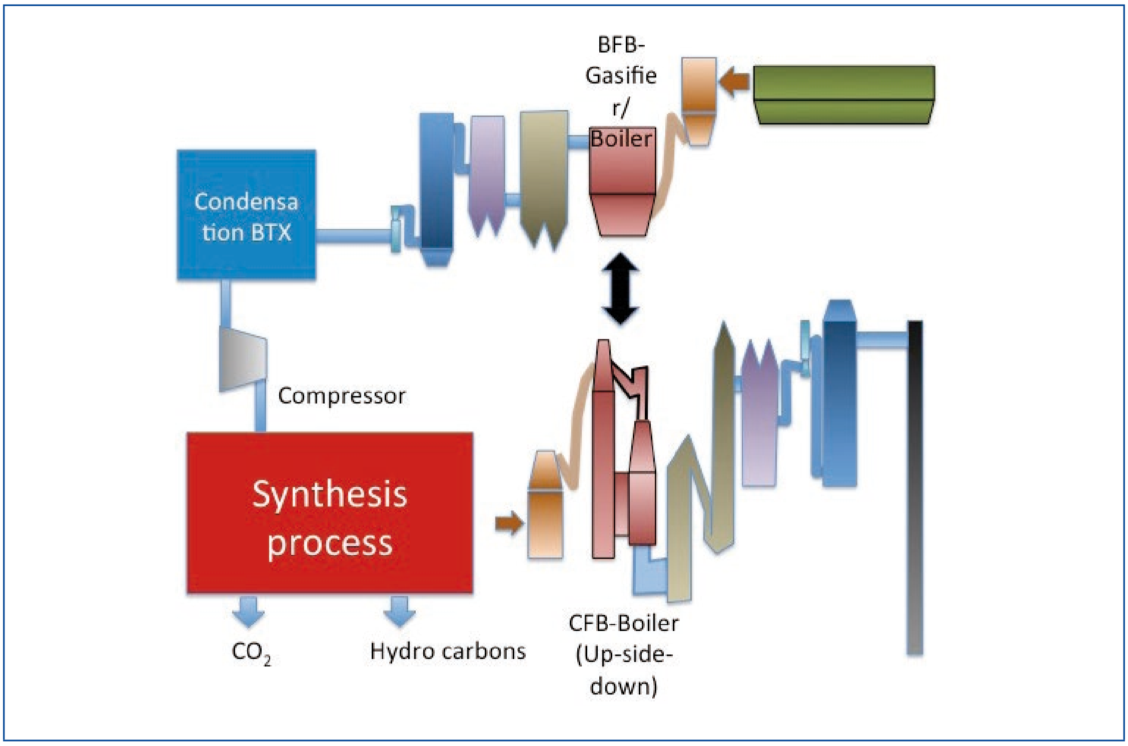

Figure 3: Gasification process provides an excellent opportunity to convert electricity chemically bound energy (source: Chalmers University of Technology)

Drying in the process would be crucial to handling excess heat. A stand-alone dryer consumes around 15% of the chemically bound energy; drying upstream of a biorefinery can only be viable if there is excess heat available. Therefore, the presentation suggested focusing on the logistics of wet biomass.

Finally, the presentation considered a regional approach in West Sweden. In addition to the three refineries and the petrochemical cluster, the region also has chemical factories, three pulp/saw mills and several district heating systems, all along a 350 km line. Connecting these industries in regional biorefineries and basing them on existing plants, would facilitate a smooth transition, building up step-by-step. It would enable very efficient conversion of biomass to renewable fuels, chemicals and materials at a scale that would make a difference, by taking advantage of investments and permits of existing infrastructures.

Industry view on worldwide biorefinery development

Johan van Doesum, DSM Bio-based Products & Services, The Netherlands

According to the IEA, the Paris climate deal will unlock $13.5 trillion of investments in energy efficiency and low carbon technologies by 2030. The industry has a responsibility to act, but this is also a major opportunity for growth.

The current developments in biorefineries are building on the long standing success of several industries, such as starch processing and paper and pulp as well as biotechnology. Integrated biorefineries based on agricultural crops provide multiple services.

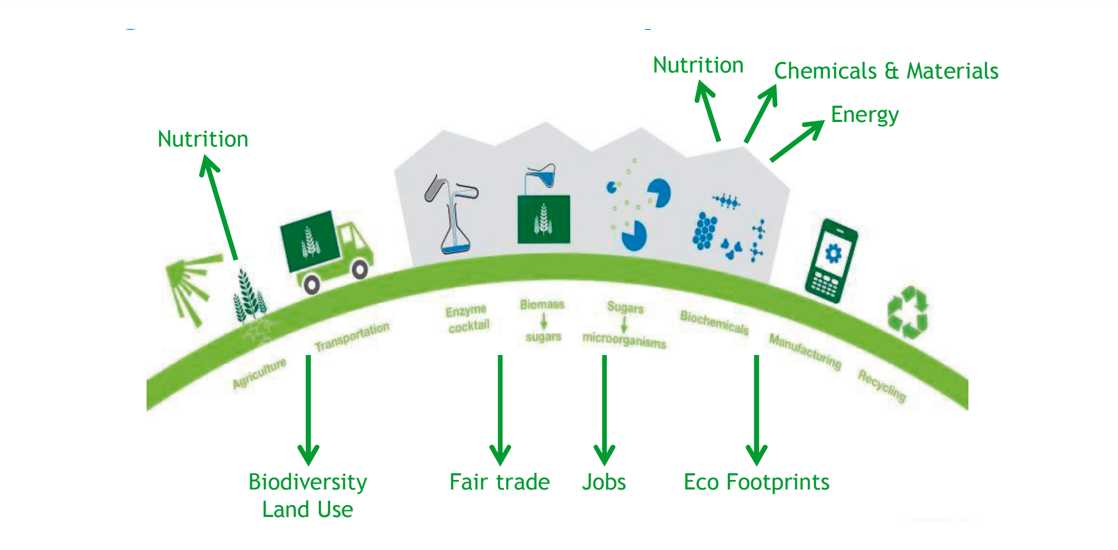

Figure 4: Schematic overview of the different functions of biorefineries (source: DSM)

It is a fact that 1st generation corn ethanol developments have sparked a lot of evolution. The basis is a rather low value product, but more products are now produced such as oils and fibres, and in future high value compounds can be made from yeast in addition to, or instead of ethanol. 2nd generation technologies in integrated biorefineries build further on this, producing sugars in multiple ways (leading to ethanol and other high value compounds), lignin and derivatives, oligomers of glucose, xylose, etc.

As knowledge and experience is needed in broad areas throughout the value chain, there is a need for establishing partnerships, including industry, local and national authorities and knowledge institutes.

Investment needs are very significant and developments need to be profitable with a fair return on investment. Classical oil-based refineries have had more than 100 years to get to the scale and economics they are at today. The biorefinery sector needs to build up over the next few decades. This requires a major effort from industry, as well as the right regulatory environment. Governments can play a role in stimulating development, i.e. through subsidies, grants and the removal of regulatory hurdles. Generally this happens at a local scale, with many different requirements, a lack of transparency and time consuming investigations and reporting. A global level playing field is needed. A carbon tax would be a good tool, but the current systems are broken because too many free emission allowances were allocated, leading to low carbon prices.

The *Carbon Pricing Leadership Coalition* is a voluntary partnership of national and sub-national governments, businesses, and civil society organisations that cooperate to advance the carbon pricing agenda by working with each other towards the long-term objective of a carbon price applied throughout the global economy. The goal is to have carbon prices expand up to a coverage of 50% of global GHG emissions, to increase price levels in order to ensure they are meaningful and to link carbon pricing systems across the world. One of the actions of DSM is to consider an internal carbon price of 50€/tonne CO_2 when reviewing large investment decisions or where significant capital expenditure is required.

Overall, a long term vision is crucial to creating transformative innovation. It is essential for success to have the right partners. A consistent government approach is needed to shape the business environment.

Session 2: interactive workshop on strategic biorefinery developments

This session was moderated by Erik op ten Berg, PioenConsult.

The previous session served as an inspiration for a brainstorming session on strategic biorefinery developments. After an introduction by the session moderator, the audience was split up into 9 break-out groups of approximately 7 to 9 people each, in order to discuss promising concepts of biorefineries and business opportunities in different sectors. Two groups discussed developments in the pulp and paper industry; two groups focused on developments of biorefineries in the chemical industry, two groups considered prospects in the food and feed industry, two groups discussed the role of biomass in petroleum refineries and one group considered energy utilities.

In an initial brainstorming, as many ideas as possible were collected for promising concepts of industrial biorefineries related to the focus of the subgroup. From this long list, a number were selected by the groups as the most promising concepts and business opportunities. Each group made a pitch of their results to the plenary session. The following shows a summary of the main suggestions by sector.

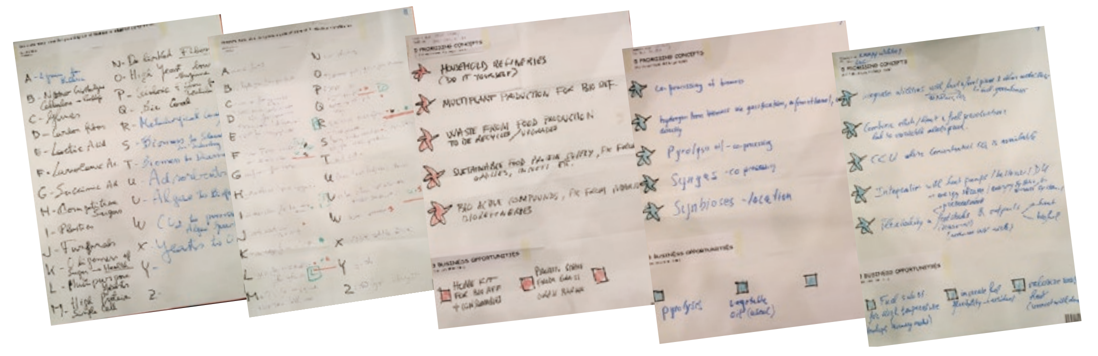

Figure 5: Examples of notes from the different brainstorm groups

Pulp and paper industry:

- use existing infrastructure as innovation platform
- self-energy sufficient mills, below-zero carbon pulp and paper mills
- resource use efficiency in pulp and paper industries, with residues going to energy
- cross-sectional clustering with intermediates and integration
- produce products on demand (flexibility)
- lignin separation and valorisation for high added value products
- black liquor gasification
- advanced biofuels (bunker fuels, aviation biofuels)
- ionic liquids, novel fibre products, textiles

Chemical industry:

- start from CO_2 and hydrogen as building blocks
- produce hydrogen from biomass
- nitrogen chemistry
- competitive sugars
- high temperature yeasts/low temperature enzymes
- biobased plastics, ethylene glycole
- medicines and pharmaceuticals (extractives)
- cellulose to higher fibre value, textiles
- resins and adhesives from lignin
- biofuels

Food and feed industry:

- home kit for biorefineries and consumables (do it yourself)
- system design to use multi-plants for biorefineries
- integrate brewing industry with low cost raw materials
- using food waste in the food/feed chain
- waste from food production to be recycled/upgraded
- health products from non-conventional crops
- bioactive compounds, e.g. in marine biorefineries
- sustainable food protein supply, e.g. grass, insects
- protein recovery (fish, meal, vegetable)
- protein shake from grass; grass rubber
- functional food from residues
- peat-free garden soil
- small regional-scale biorefineries
- proteins for industrial biobased products
- sustainable processing of biomass for food and non-food

Petroleum refineries:

- symbioses with other industries – co-location
- build on existing infrastructure for regional biorefineries
- produce hydrogen from biomass via gasification, or for methanol, or for direct use of hydrogen in further processes
- co-processing of biomass/pyrolysis oil/syngas/Fischer-Tropsch crude/used vegetable oils in petroleum refineries
- lignin based biofuels
- upgraded pyrolysis oil for maritime applications

Energy utilities:

- integrate energy utilities with food & feed production and other industries (including residue and CO_2 use)
- combine electricity, heat and fuel production; link to variable electricity production
- flexibility in feedstocks (seasonal) and outputs (heat/biofuel) to reduce investment risks
- CCU where concentrated CO_2 is available
- integration with heat pumps/batteries/ district heating => energy storage/energy systems for smart systems
- fuel substitution for high temperature applications to develop bioenergy markets
- increase fuel flexibility (to use residues as input)
- valorise waste heat (connect with demand)
- upstream separation of added-value biobased products from feedstocks before energy production

Session 3: How to overcome deployment barriers for biorefineries

This session was moderated by René van Ree, Wageningen Research, leader of IEA Bioenergy Task 42 Biorefining in a future BioEconomy.

Perspectives of industrial biorefineries in the global bioeconomy – role of the policy framework to support implementation

Jim Philp, OECD, France

Historically, the large transitions in energy and production have taken decades to accomplish. It is no surprise that the bioeconomy transition is also taking decades. However, there is a clear case for policy to speed the transition – grand challenges and the associated policy goals of climate change mitigation, energy security, the circular economy concept, rural regeneration, smart specialisation and, paradoxically, reindustrialisation. Moreover, whereas previous transitions could be achieved by "more from more", the bioeconomy transition may have to happen by "more from less" as resource depletion and emissions control continue to gain importance. The biorefinery sits at the heart of all these policy concerns representing large financial investments that continue to be high risk in a world currently dominated by relatively low oil prices and very high fossil fuel subsidies.

Various bioeconomy strategies have been published, but so far policies have not been sufficient. The following considerations were presented in the presentation:

- *Public procurement* can be very important. OECD governments spend around 13% of GDP on public procurement. An interesting example is the BioPreferred Program of USDA, with some 15,000 products in the catalogue.
- Biorefinery *logistics* need to be considered in an *integrated* way. A combination of rural and coastal biorefining, i.e. build biomass pre-treatment and concentration plants rurally and build integrated biorefineries near international ports and/or near waste CO_2 sources. The current chemical industry is truly integrated; 90% of feedstocks are provided via waterways.
- Advantages in terms of *job creation and environmental aspects* need to be communicated to the public.
- Flagship projects of lignocellulosic biorefineries are usually complex with many stakeholders involved. They are not easily bankable, so that *loan guarantees* can be very important. *Private-public partnerships* are central to address the lack of trust of investors.
- A biobased chemicals policy could *integrate biofuels and chemicals in the same programme.*
- An *explicit price of carbon* is the way to go.

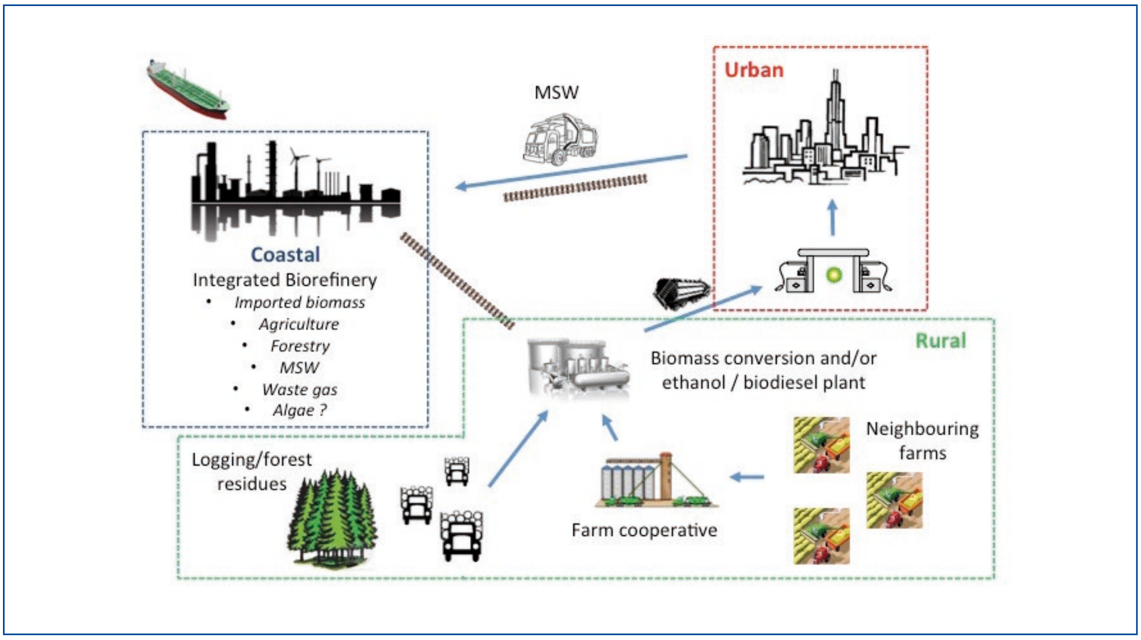

Figure 6: Integrated biorefinery logistics (source: OECD)

Biofuel driven biorefineries in the United States and non-technical deployment barriers

Jim Spaeth, U.S. DOE Bioenergy Technologies Office, United States

Several commercial advanced biofuel biorefineries are in the early stages of commissioning, start-up, shakedown and/or commercial production. However, large scale implementation of highly-efficient advanced biorefinery facilities is still a goal yet to be realised. This is caused by a variety of non-technical and technical barriers. Success depends on technology, finance and policy.

Since 2006, the Bioenergy Technologies Office (BETO) has supported a total of 42 pilot, demonstration and pioneer-scale facilities. These investments have allowed industry partners to enable the development of first-of-a-kind IBRs (industrial biorefineries), prove conversion technologies at scale, validate techno-economic assessments, and gain investor confidence.

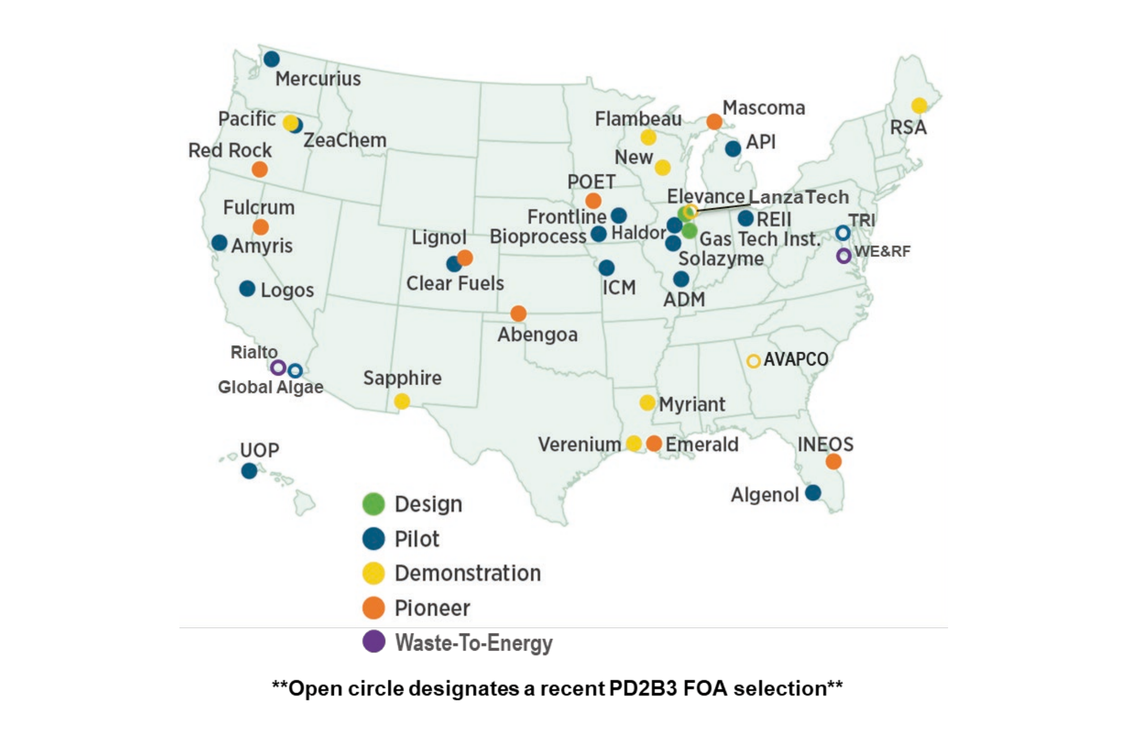

Figure 7: Distribution of IBR projects since 2006 (source: US DOE)

Technical challenges include feedstock collection, harvesting & storage (certain feedstocks are just harvested in six weeks' time); feedstock pre-processing; pre-treatment; conversion yields; bio/chemical catalyst selectivity and fouling; process integration; continuous throughput.

The following *non-technical barriers* were identified:

- closing contracts for feedstock supply, off-take agreements for the biofuels, EPC (Engineering, Procurement, and Construction) contracting;
- experience of doing business and project management;
- existence and experience of infrastructure for feedstock provision and biofuels distribution;
- quality requirements and codes and standards to be followed;
- public perception and acceptance of biofuels;
- environmental concerns;
- finance – strategic investors;
- unstable policy framework.

Industrial biorefineries can be extremely capital intensive and it takes time (sometimes decades) to go through the different development steps. Funding between each round, from pilot through demonstration to pioneer, is difficult to raise without government support. Not all funding can be debt; strategic investors are needed, as well as money being lent at reasonable interest rates. Federal loans guarantees for commercial biorefinery projects accelerate the deployment of such projects by helping to bridge the "Valley of Death".

Reference was also made to the conclusions of a US workshop on IBR optimisation in October 2016[4]. The aim of the workshop was to gather stakeholder inputs and opinions on IBR development and optimisation issues. Key findings from the participant breakout sessions covered topics of best practices, lessons learned, challenges, potential solutions, and resources needed to overcome current challenges.

Supporting the transformation of forest industry to biorefineries and bioeconomy

Eric Soucy, CanmetENERGY, Canada

Due to market shifts and an aging infrastructure, several Canadian pulp and paper mills have closed their doors or have downsized their production. The industry continues to face significant challenges, which cannot be addressed by simple retooling to increase the production or to improve the performance. Recent studies stated that long-term funding of research and development for biorefinery value-added products could give Canada a leading role and a first-mover advantage in the biorefinery market. Canada has a unique natural advantage in its extensive feedstock supply, a world-class forest sector innovation system based on strong collaboration and the benefit that the transformation could leverage on existing assets. It was found that the pulp and paper mills provide an ideal platform for the demonstration of the biorefinery concept because of their scale, existing infrastructure, proximity to biomass sources, and experience in biomass-handling logistics.

Over recent years, the Canadian Council of Forest Ministers (CCFM) has outlined a dedicated framework to promote the forest bioeconomy in Canada. Objectives of the forest biorefinery R&D program are to:

- develop updated biorefinery and bioenergy technology maps, as well as current and emerging market trends of bioenergy, biofuels, biochemicals, and biomaterials;
- develop systems engineering models and decision-making tools to evaluate the most promising biorefinery products/technologies that, when optimally integrated into an existing industrial site, will result in radically improved economic performance and environmental footprint;
- develop state-of-the-art retrofit and design solutions to enable the transformation of traditional forest markets through incremental implementation of biorefineries.

4 https://www.energy.gov/sites/prod/files/2017/02/f34/biorefinery_optimization_workshop_summary_report.pdf

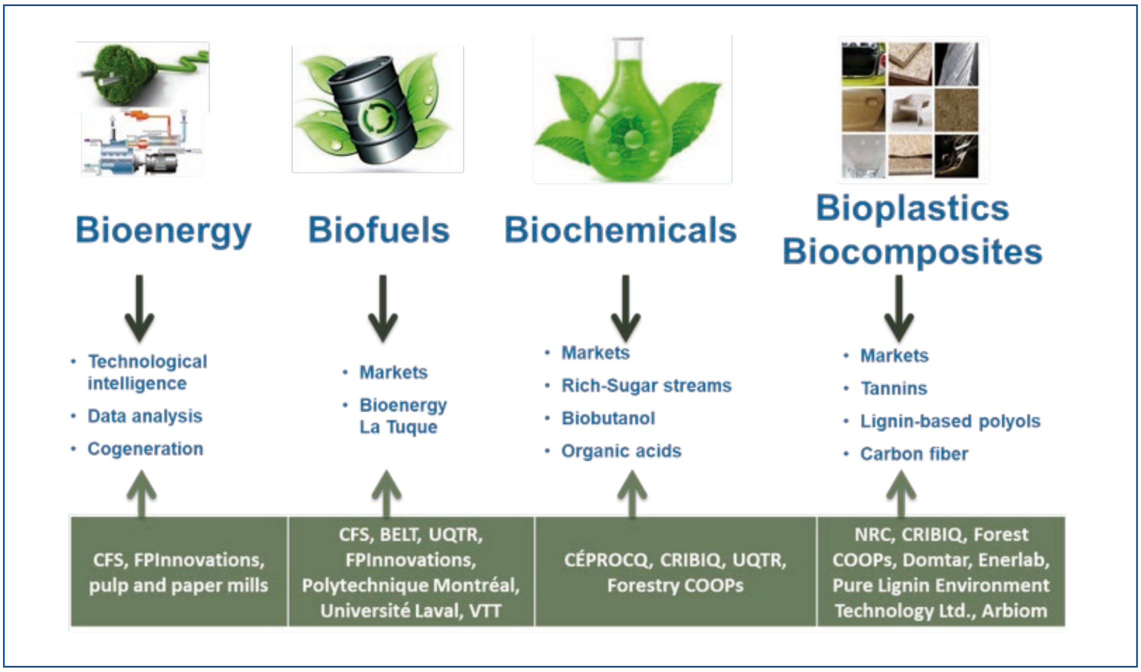

Figure 8: Biorefinery focus areas in Canada (source: Natural Resources Canada)

The presentation specifically highlighted the i-BIOREF tool, a biorefinery pre-feasibility analysis software, as a decision support system to support the transition of the forest industry to integrated biorefineries. The tool advises the forest industry on the following questions:

- How can a company succeed in identifying a strategy to enter the bioeconomy that is robust for future market scenarios, and at the same time, yields high margins?
- What are the benefits of integrating a biorefinery technology into an existing mill?
- In an integrated biorefinery, what are the impacts on the existing mill?
- Under what conditions does a biorefinery project become economically and environmentally viable?

From innovation to reality: Realising industrial transformation towards the circular economy.

Ed de Jong, Avantium, The Netherlands

The circular economy is the general framework for industrial transformation. As acknowledged by the Ellen MacArthur Foundation, the circular economy is not only about material recycling, but also about using renewable carbon, in the form of biomass or CO_2. Glucose is a central building block for many biobased chemicals and polymers, but pure glucose is not so easy to find.

Deploying biobased chemistry involves four stages: (1) lab-scale development, (2) testing the technology in a pilot plant, (3) demonstration at commercial scale in a reference plant and (4) deployment at industrial scale. Particularly the second and third stages are very cost-intensive in terms of CAPEX and OPEX, and require partnering.

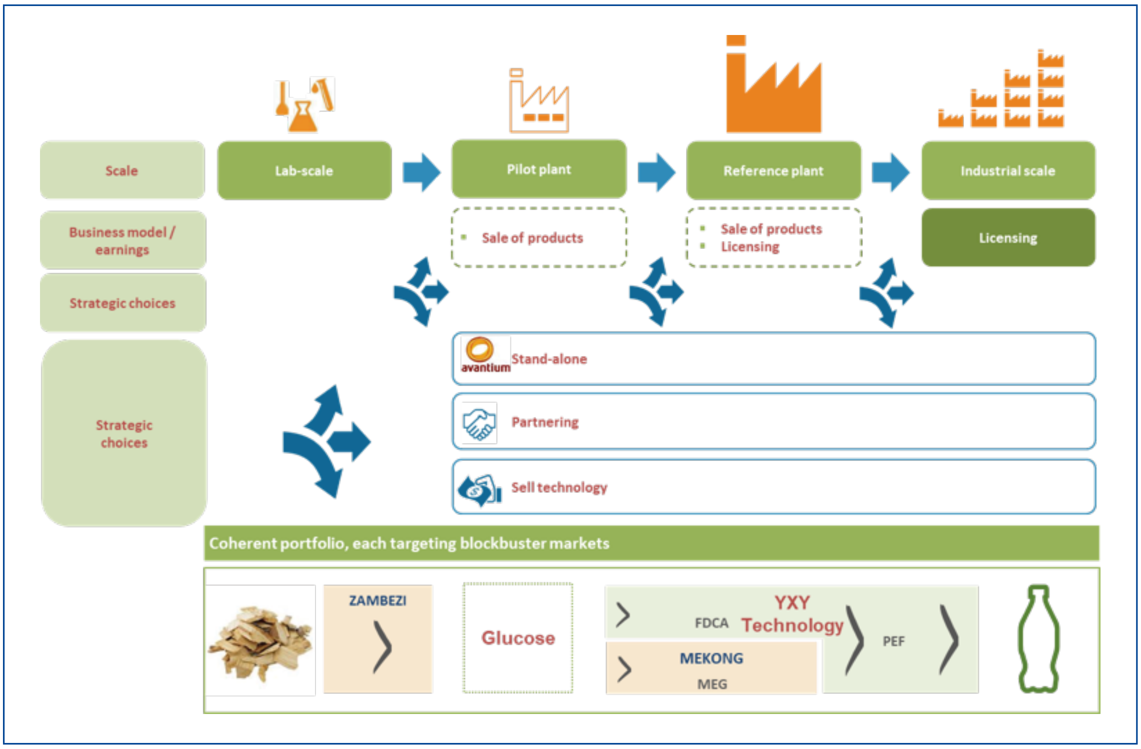

Figure 9: Strategic choices to deploy renewable chemistry projects (source: Avantium)

The presentation showed the stages and further plans of Avantium for lignocellulose pretreatment (ZAMBEZI), producing bio-MEG (Mono Ethylene Glycole, Mekong technology), producing FDCA (Furan Di-Carboxylic Acid) and combining FDCA with MEG to make a biobased polymer PEF (PolyEthylene Furanoate). The commercial launch of FDCA and PEF (with production capacity up to 50 ktonnes/year) is planned for the short term in a joint venture between Avantium and BASF.

Compared to conventional plastics, PEF is characterised by improved barrier properties for gases such as carbon dioxide and oxygen. This can lead to longer shelf life for packaged products. Due to its higher mechanical strength, thinner PEF packaging can be produced, leading to a lower amount of packaging material being necessary. Therefore, PEF is particularly suitable for the production of certain food and beverage packaging, for example films and plastic bottles. After use, PEF can be recycled.

Electrochemical CO_2 reduction (VOLTA) was also highlighted as an option to produce chemicals. Replacing existing processes is not easy: using H_2/O_2 for reduction/oxidation is often more economical. Moreover margins on bulk processes are low, so that everything needs to be optimised.

A combination of skills is required to design new electrochemical processes: organic chemistry, electrochemistry, catalysis, electrochemical engineering, process design and process economics.

The main opportunities are in regimes that are not accessible to conventional catalysis or chemistries: *targeting specific molecules, where the number of process steps can be reduced and where the amount of waste can be diminished.* Some intermediate products could be interesting, such as oxalic acid.

Session 4: interactive workshop on deployment barriers and actions

This session was moderated by Erik op ten Berg, PioenConsult.

The audience was split up into the same 9 break-out groups of approximately 7 to 9 people each, in order to discuss the main non-technical barriers and problems for industrial players in adopting and integrating biorefinery concepts, how the major barriers could be overcome and what concrete recommendations could be made for research and industry, and for policy support. Each group presented their recommendations to the plenary session.

Figure 10: Examples of notes from the different brainstorm groups

The main identified **barriers** are:

Social: • image/acceptance/public perception on sustainability of biomass • lack of knowledge related to opportunities of the biobased economy • food habits, throw-away society • resistance to change for new products	**Technological:** • technology readiness; need further developments in separation and purification (e.g. proteins) and harvesting • technical knowledge gaps and too many choices; complexity and rapid innovations • lack of qualified staff • product quality (certification needs), health & safety
Economic: • uncertainty about profitability; large investments with high risk level • lack of new biorefinery business models along the whole value chain • difficult access to capital and financing, even for viable projects; shortening timing of business cycle: investors need faster guaranteed return of investment • relatively high cost of biomass • knowledge and risk perception	**Markets:** • need for sector cooperation, but conservative industries (both in traditional biobased and in energy) • opposition of existing infrastructure and stakeholders • competition from other markets with mature technologies, including oil derivatives • strength/lobby power of the fossil industry and existing subsidies for fossil products • competition for sustainable feedstocks • fragmented and volatile markets; lack of market development, e.g. for lignin products
Policy: • unstable policies & policy uncertainty • lack of long term vision and policy consistency • uncertainty about sustainability requirements, risk of revisiting decisions • legislation related to waste & feedstocks (incl. definition of waste), food safety and GMOs • local definitions for a global problem (carbon, renewables)	

In relation to the identified barriers, the following main recommendations were presented for different actors and sectors: policy makers, business, as well as research, education and communication.

Recommendations for policy makers:

- Further development of the biorefinery sector requires *stable, coherent, consistent and predictable policies*. Policy coordination is needed between agriculture, food & feed, forestry, energy, environment, economy, spatial planning and development, and financing.
- Governments can coordinate the elaboration of a *long term vision* with concrete actions and long term perspectives for industry. Evolution towards this vision should be *tracked and monitored*.
- Global IPCC work should be strengthened, and steps should be taken towards global policy support for biobased developments.
- Climate actions should consider the *role of agriculture*, moving the sector from a CO_2 source to a CO_2 sink. The sector should be rewarded for that, considering agriculture as an integrated supplier of feedstock and a service for carbon storage. To reduce competition for sustainable feedstocks it will be necessary to support a trend towards less meat consumption, as well as to build capacities to sustainably raise food yields on farms and yields from forests[5].
- Cost and profitability are some of the major barriers for bioenergy and biobased products. It is important that *real external cost and CO_2 price mechanisms* are applied for fossil based products, and fossil subsidies should be removed.
- Other measures to support deployment of biorefineries include:
  - providing government guarantees to reduce investment risks;
  - subsidies for innovation and R&D towards resource efficient biorefining;
  - support for demonstration and first-of-a-kind plants to bridge the valley of death; cost-sharing funding for early to late technology readiness level (TRL);
  - encouraging innovation deployment through purchase mandates, long term binding targets for renewable products, tax credits for biobased products, RIN systems, etc.
  - permitting to require recycling and use of renewables (circular economy).
  - To avoid sustainability risks, *sustainability criteria* should be a basis for funding. These should be aligned at international level, avoiding different approaches in individual countries.
  - *Cooperation between different sectors* will be essential and governments can facilitate such cooperation.

5 This topic was treated in a previous IEA Bioenergy workshop, see http://www.ieabioenergy.com/publications/ws20-mobilising-sustainable-bioenergy-supply-chains-opportunities-for-agriculture/

Recommendations for business:

- Involvement of industry sectors and stakeholders is crucial. *Long term commitments* of these sectors are needed. Fossil based industries should be encouraged to go for a transition towards renewable and biobased resources.
- Industry sectors can set up *business-to-business approaches*, as for instance the Carbon Pricing Leadership Coalition (see presentation of DSM). They can apply an internal value of CO_2 for investment decisions, without waiting for government decisions on this.
- Industry can take advantage of *green credentials*.
- Common grounds for collaboration between sectors should be found. Long-term *multi-party agreements* (national and international) and *new biorefinery business models* can be set up.
- Cross-sector *information* should be *shared*. This requires involvement and transparent commitment of industry, academics and NGOs.

Recommendations for research/ education/communication:

- In terms of *communication*, the *scientific community* needs to raise its voice, and increase its profile (versus lobby groups). It should communicate with industries, the public and policy makers, create awareness of the benefits of the biobased economy, showcase the benefits of cooperation to industry and promote success stories in biobased products.
- *Education* on the circular economy/ biobased economy should be developed, as well as solid scientific *data and a transparent knowledge base* on the benefits and status of biobased products to communicate to and educate markets, the public and politicians, thus making the value of biobased products clear to consumers.
- There should be a *good balance between academic and industrial research*. Multidisciplinary RD&D is needed, e.g. related to separation and purification, but also in multi-criteria decision making and system research. Technological innovation should be better managed, and international cooperation improved.
- There should be *continuous verification of the progress* in R&D, certification and standards implementation. In terms of standardisation, common language can be developed, e.g. in terms of definitions, measurements, assessments and calculation methods for biofuels/biobased products.

Conclusions

IEA scenario calculations have indicated an important role for biomass in reaching GHG reduction targets by 2050-2060. Efficient use of the available biomass will be crucial and the uptake of biorefineries at industrial level will be required to achieve this. The circular economy is the general framework for industrial transformation, which is not only about material recycling, but also about using renewable carbon, in the form of biomass or CO_2. Industrial symbioses and increased integration with versatile production of added-value biobased products and bioenergy products can have the highest impact both for climate goals and economic growth. Current developments in biorefineries are building on the long standing success of several industries, such as sugar and starch processing and paper and pulp, as well as biotechnology and developments in conventional and advanced biofuels.

Investment needs for biorefineries can be very significant and developments need to be profitable with a fair return on investment. Classical oil-based refineries have had more than 100 years to get to the scale and economics they are at today. The biorefinery sector needs to build up over the next few decades. This requires a significant effort from industry, as well as the right regulatory environment. It takes time (sometimes decades) to go through the different development steps, including lab-scale development, testing in a pilot plant, demonstrating in a reference plant, and deployment at industrial scale. Particularly the stages of pilot and demonstration are very cost-intensive and require partnering. Funding between each round, from pilot through demonstration to pioneer, is difficult to raise without government support. Governments can facilitate the deployment of biorefineries through subsidies for innovation and R&D, support for demonstration and first-of-a-kind plants, government guarantees to reduce investment risks, providing decision tools to show opportunities, but also purchase mandates and/or tax incentives and long-term targets. Real external cost and CO_2 price mechanisms should be applied for fossil based products and fossil subsidies should be removed.

Involvement and cooperation between industry sectors and stakeholders is crucial. It is essential for success to have the right partners. Connecting industries through regional biorefineries and basing them on existing plants can facilitate a smoother transition, building up step-by-step. It would enable very efficient conversion of biomass to renewable fuels, chemicals and materials at a scale that would make a difference, by taking advantage of the investments and permits of existing infrastructures. Combining and optimising biomass conversion and use for food and non-food applications could even further increase the impact of global sustainable biomass use. Next to a consistent government approach, clear and transparent industry commitments are also needed to shape the business environment. Industry can for instance apply an internal value of CO_2 for investment decisions, without waiting for government decisions on this. Multidisciplinary research is also a crucial factor. As knowledge and experience is needed in broad areas throughout the value chain, it requires a combination of skills, so that there is a need for establishing partnerships, including industry, local and national authorities and knowledge institutes.

Communication and education will be crucial pillars. While information needs to be shared between sectors, the scientific community should communicate with industries, the public and policy makers, and create awareness of the benefits of the biobased economy, promote success stories in biobased products and showcase the benefits of cooperation to industry.

Education on the circular economy and biobased economy should be developed, as well as a transparent knowledge base on the status and prospects of biobased products, thus making the value of biobased products clear to consumers. In terms of standardisation, common language can be developed, e.g. in terms of definitions, measurements, assessments and calculation methods for biofuels/biobased products.

Acknowledgements

The plenary workshop sessions were moderated by Thore Berntsson and René van Ree. Erik op ten Berg moderated the interactive parts of the workshop. Other people facilitating the break-out groups and/or being members of the organising committee are Kees Kwant, Isabel Cabrita, Horst Steinmüller, Luc Pelkmans, Ed de Jong, Clemente Pedro Nunes, Bert Annevelink and Per-Åke Franck. The contributions of these and also the invited speakers are gratefully acknowledged. A special thanks goes to the Swedish Energy Agency for hosting the event, as well as Göran Berndes and Thore Berntsson of Chalmers University for taking care of all practical issues before and during the workshop.

Luc Pelkmans, the Technical Coordinator of IEA Bioenergy, prepared the draft text with input from the different speakers and facilitators. Pearse Buckley, the IEA Bioenergy Secretary, facilitated the editorial process and arranged the final design and production.

IEA Bioenergy

iets

Further Information

IEA Bioenergy Website
www.ieabioenergy.com

IETS website:
www.iea-industry.org