Technology Collaboration Programme
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Developing business models for efficient use of biomass

Summary and conclusions from the IEA Bioenergy workshop, Tallinn (Estonia), 22 October 2019

This publication provides the summary and conclusions for the workshop 'Developing business models for efficient use of biomass' held in conjunction with the meeting of the Executive Committee of IEA Bioenergy in Tallinn, Estonia on 22 October 2019.

IEA Bioenergy

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January 2020

Front cover image: Estonian Cell AS Pulp Mill

Published by IEA Bioenergy

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EXECUTIVE SUMMARY

Luc Pelkmans, Technical Coordinator, IEA Bioenergy

The IEA Technology Collaboration Programme on Bioenergy (IEA Bioenergy) held its biannual workshop in Tallinn, Estonia on 22 October 2019 in conjunction with its Executive Committee meeting (ExCo84). The workshop on 'Developing business models for efficient use of biomass' was prepared in close collaboration with the Estonian Ministry of Economic Affairs and Communications. The workshop consisted of three sessions: (1) setting up biomass supply chains, (2) examples of developing biobased business models, and (3) CO_2 capture as part of future biomass business models. The workshop was concluded with a panel discussion on barriers for setting up biobased business models and recommendations to overcome those barriers. Around 80 participants attended the workshop.

Biomass and bioenergy may play a vital role in meeting the goals of the Paris Agreement to keep the increase in global average temperature to well below 2°C above pre-industrial levels. The role of negative emission technologies will increase, with bioenergy combined with carbon capture and storage (BECCS) being one of the most promising options. According to the International Energy Agency, modern bioenergy would have to increase by a factor 2 in the 2030 timeframe (compared to 2015), and a factor 4 by 2060[1]. So, there will be a need for further deployment at the global level, also implying that **economically viable and bankable business models need to be developed** in terms of setting up biomass supply chains, implementing efficient conversion processes and reaching end markets. Biorefining to produce different energy and material products (as is done in oil refineries) will be an important concept to get the most value from the available biomass, and CO_2 capture and storage (CCS) or utilization (CCU) will also become part of such business models.

Based on the experiences shared about developments and business cases in the workshop, a number of implementation barriers were identified, as well as recommendations to deal with these:

- The **mobilisation of biomass** resources is an important prerequisite in biobased business models. Feedstock cost, diversity, supply security, as well as sustainability governance are all key considerations in setting up successful business models. Integration throughout the value chain is a challenge for biobased industries and requires substantial efforts. Parties need to understand each other, and communication is a crucial issue.
- The concept of **bio-hubs** – providing feedstock collection, intermediate pre-treatment and storage – can be a promising tool to deal with the **interface between supply chains and markets** they serve. It is best to aim for a few commodity products, with well-defined quality criteria. These commodities can be part of **trading platforms**. The experience with a 'Biomass Exchange' trading platform in the Baltics has shown that such systems bring transparency and competition to markets and can reduce prices compared to more concentrated markets.
- The challenge and complexity of biobased systems should be recognized. To transition away from fossil resources, **massive developments will be needed in the biobased economy**, with high investment projects and long timelines. So, it is important to ensure good business models and the right investment conditions.

1 IEA (2017). Technology Roadmap: Delivering Sustainable Bioenergy.

- Current commercial bioenergy initiatives had substantial **lead times**. Bioenergy technologies typically require more than a decade to mature. A key question is how to speed up these learning curves. Investors need to have clear medium to long term perspectives recognizing that first of a kind installations are inherently high risk and require substantial initial investment.
- **Risk abatement and risk sharing** will be crucial, e.g. through public funding at the initial phase (to bring technology to a certain point) and public investment funds/ loan guarantees at early market introduction. Cooperation and partnering between the private sector, public sector and academia can be key enablers. A positive opportunity is that current interest rates are low, and a lot of venture capital is looking for good investment opportunities.
- Considering market competitiveness and feedstock availability, technologies need to be developed that are capable of dealing with varieties of feedstocks (including lower quality). **Value creation** from the biomass should be maximized through a mix of technologies and end products (as is common practice in petroleum refineries), which means that energy production may not be the first target. Nevertheless, the high price competitiveness in chemical markets should be considered, while at the moment there are limited incentives for more environmentally friendly chemicals/products. Strong policy support may be key to early market creation considering the value proposition provided by biobased solutions.
- Many outside stakeholders question the sustainability of bioenergy, so verifiable and well-designed sustainability attributes need to be at the core of any project. To increase financial viability, projects should strive to have their **sustainability advantages reflected through market value or market access**.
- The biobased sector should explore and develop **CO_2 capture** opportunities to accomplish negative emissions. Bioenergy combined with carbon capture and storage (**BECCS)** is the most market ready negative emission technology today, with many development activities around the world. Some of the early lower cost carbon capture opportunities will be at biomass facilities. Carbon transport and storage technologies are also being developed – serving the fossil sector as well – which bioenergy can tap into.
- **Credits for negative CO_2 emissions** will be needed, which could be through taxation of CO_2 emissions. Alternatively, voluntary compensation systems could complement policies. In these systems, net-negative businesses – that store more CO_2 than they emit – can get extra revenues from CO_2 removal certificates.
- **Communication and engagement of the local community** is very important. **Shared benefits/ownership** can be a powerful way to deal with local resistance to new facilities. Public engagement and the development of mutual benefits is critical.
- A long term **stable policy framework** is a prerequisite for investments with a 15 to 20-year timeframe. The risk of policy reversals is a major deterrent. Investment decisions in relation to biofuels must consider the longer term where demand may shift from light duty vehicles more to heavy duty vehicles, marine transport and renewable jet fuels.

The PowerPoint presentations can be downloaded from IEA Bioenergy's website https://www.ieabioenergy.com/publications/ws25-developing-business-models-for-efficient-use-of-biomass/.

WORKSHOP

Welcome and introduction

Jim Spaeth, US Department of Energy, chair of IEA Bioenergy, welcomed all participants on behalf of IEA Bioenergy and thanked the Estonian Ministry of Economic Affairs and Communications for hosting the event. He gave a short introduction to the programme of the workshop and stressed that viable business cases are crucial for the deployment needed in the biobased economy.

Timo Tatar, Deputy Secretary General for Energy in the Estonian Ministry of Economic Affairs and Communications welcomed all participants to Estonia. Mr. Tatar gave an overview of the Estonian energy supply and the energy targets. The National Climate and Energy Plan is quite ambitious, aiming to bring carbon emissions down by 70% by 2030. Estonia has 50% forest cover; therefore, forestry residues have a crucial role. By 2030 Estonia intends to have 42% of renewable energy (now 30%) with two thirds of this coming from bioenergy, largely through combined heat and power (CHP) plants.

The IPCC sees an important role for bioenergy to achieve the 1.5°C target, which also requires a scale up of bioenergy combined with carbon capture and storage (BECSS) which is to have a key role in future.

In the case of bioenergy, public acceptance is very important and getting more challenging. Forests need to be managed sustainably, and efficient use of biomass in the bioeconomy is key. This is a challenge in Estonia as well as in other countries. Therefore, a study was launched on maximizing the added value and efficient use of biomass in the Estonian bioeconomy (*see presentation Liina Joller*).

Maximising added value and efficient use of raw materials in the bioeconomy and its sectors in Estonia

Liina Joller-Vahter, University of Tartu, Estonia

In early 2018, a project was started to explore the prospects of further developments of the bioeconomy in Estonia, aiming to give maximum value to the economy and to participating partners. Estonia is doing quite well in biomass production (forestry, agriculture), as well as in traditional processing technologies like sawmills or dairy companies. Forestry provides 15 million m^3 of wood annually, which is close to the maximum that they can get from domestic production. There are also imports from Russia. A high share of woody material is exported with insufficient value added. Advanced bioprocessing methods or advanced biomass production methods (e.g. bioreactors) are not widely used in Estonia and business innovation capacity is rather weak. The project explores how to get more value from the country's biomass resources, considering new value chain based business models, based on aquatic/marine resources, biofuels and bioenergy, food and feed production, and production of biomaterials, chemicals, pharmacy and plastic products. The project will also develop policy recommendations and instruments for supporting bioeconomy development in Estonia.

Session 1: Setting up biomass supply chains

This session was moderated by Mark Brown, University of the Sunshine Coast, Australia, leader of IEA Bioenergy Task 43.

SWOT of bio-hubs in deploying biobased supply chains

Ioannis Dimitriou, Swedish University of Agricultural Sciences

The term 'bio-hub' still requires a clear definition. In general, bio-hubs are biomass terminals directing material flows from the provider of the biomass to industries/end users. Terminals enable improved value by having more functions than just sorting and storing. Biomass can for example be debarked, crushed and compacted to suit end user requirements better; to further improve storage and transportation properties of the feedstock industrial pre-treatments like torrefaction or pyrolysis can be used to produce a tradable commodity. So far, value chains focused on connecting one type of biomass resource with one use. However, in future, types of biomass sources will expand, as well as different uses, making the picture much more complicated.

On 10 October 2019, IEA Bioenergy Task 43 and the Bio-East Initiative (a cooperation between East European Countries with a focus on agriculture, aquatic biomass and forestry) organized a workshop in Hungary on '*Bio-hubs as keys to successful biomass supply integration for bioenergy within the bioeconomy*'. The workshop included a consensus-based SWOT analysis with participants using a Q&A and polling platform (Slido). The group generated lists of potential strengths, weaknesses, threats and opportunities related to bio-hubs, compared to a conventional biomass supply. The importance of each SWOT was rated, and the group provided ideas to mitigate the most important weaknesses and threats, and actions to realize the opportunities, with a vote for each idea.

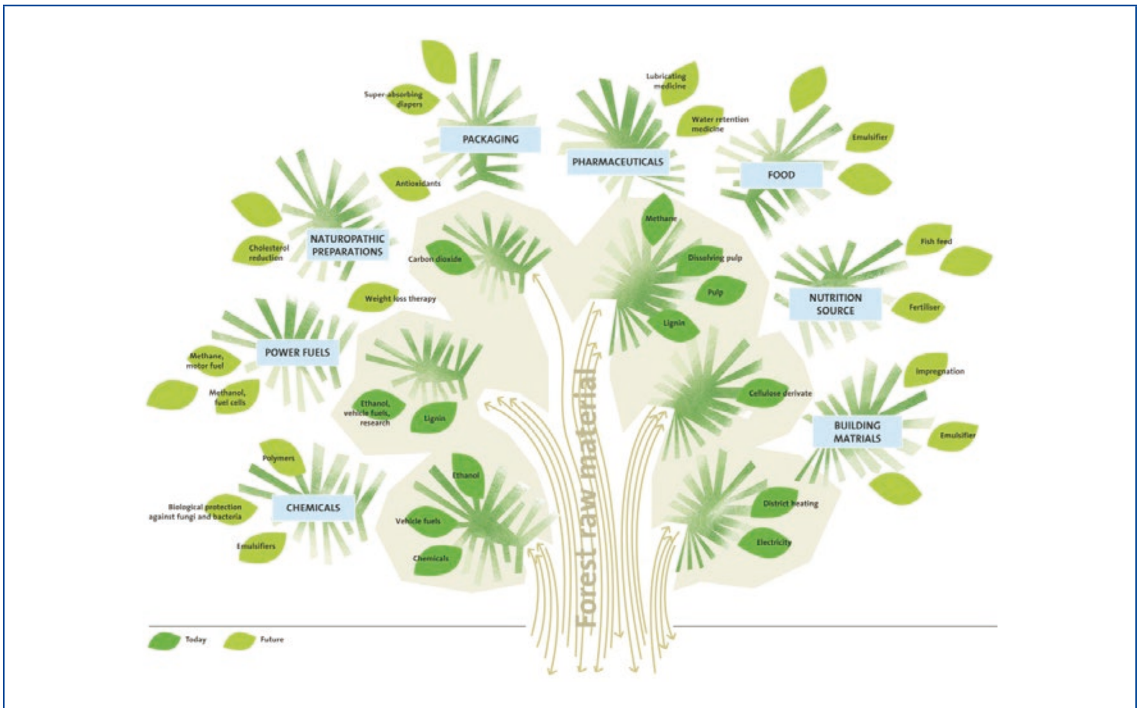

Figure 1: Possible products and processes from forest raw material; today and in the future (source: SP Processum)

The results of this process are still being processed, but some first outcomes were presented.

- *Strengths*: security of supply; possibility to handle biomass from multiple sources; flexible supply from a diverse set of feedstocks for flexible demand/different types of users
- *Weaknesses*: investment requirement (▶ joint investments, cooperative approach); infrastructure financing (▶ regional development policies/funds, use existing infrastructure).
- *Threats*: Large impact on all users in case of disruption in the hub (▶ risk plan, create several hubs); too much market influence if the hub becomes a single dominant buyer (▶ create competition); market versatility (▶ different end products, long term contracts, flexible design)
- *Opportunities*: develop new markets for farmers and forest owners (▶ inform producers, connect market demand with biomass production); value optimisation (▶ differencing commodities to high value-added products); improved certification schemes (▶ need well-designed standards)

The aim is to repeat this process with other expert groups and conduct a validation survey of the SWOT results across the IEA Bioenergy Task 43 network. The results will also guide future work of Task 43 related to bio-hubs.

The Biomass Exchange – virtual transmission grid in biomass markets

Vaidotas Jonutis, Baltpool, Lithuania

Lithuania consumes two times more heat energy than electricity, with an important role of district heating. Ten years ago, the first steps were taken to move from natural gas to biomass, with the main goal being security of supply. In the past ten years, the share of biomass in Lithuanian district heating increased from 18 to 69%; overall biomass consumption increased by 260% (from 144 ktoe to 523 ktoe).

It was a challenge to organise the market, which developed very fast. Initially the biomass market was implemented like a natural gas market, depending on a limited number of suppliers. By 2012, the market was unable to regulate itself, with non-transparent purchase practices, high barriers for new market participants, weak competition between suppliers and high market concentration (with a few dominating players), which resulted in high fuel prices.

At that time the Biomass Exchange was set up to increase transparency and competition in the biomass market. A main challenge was that biomass links to unlimited trading hubs, while natural gas only has 12 trading hubs in Europe and supply is guaranteed by Transmission System Operators (TSOs). The Biomass Exchange is a virtual transmission system, with every supplier being a single point. The large amount of trading hubs guarantees market liquidity. It is mainly about wood chips, and transport distances are up to 100 km.

Figure 2 below shows how the Biomass Exchange changed the biomass market in Lithuania.

Additional services of the platform include amongst others an auction system making it easier to conclude contracts; a back office system aiding the execution of contracts (biomass quality reporting, delivery scheduling, invoicing, waybills); urgent market messages to provide higher transparency of the market; and integration of independent laboratories in quality establishment.

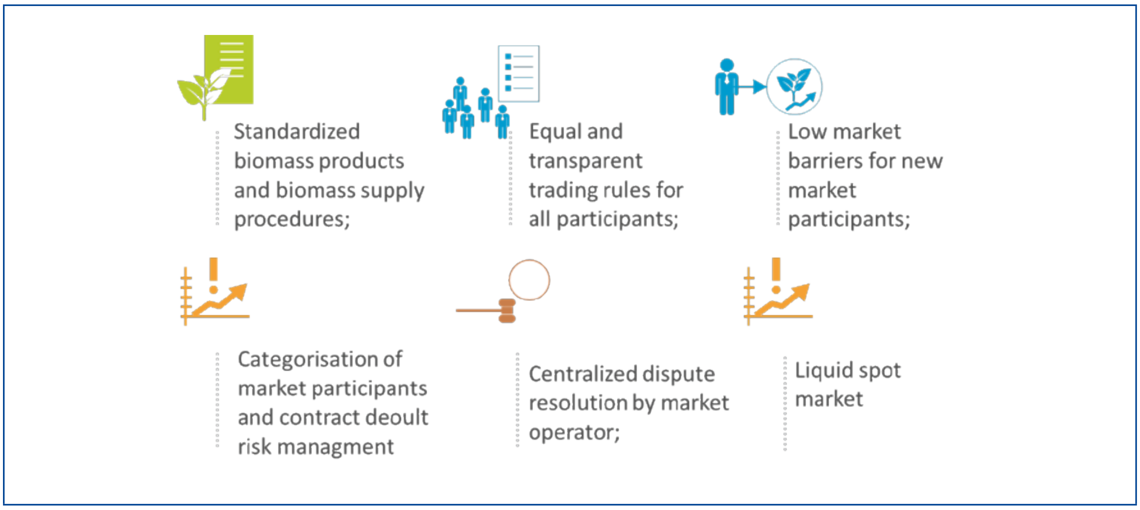

Figure 2: How the Biomass Exchange changed the market (source: Baltpool)

Baltpool has become the central biomass business organisation platform in Lithuania, and has meanwhile expanded to Latvia (2017), Estonia (2018), Denmark (2018), Sweden (2019) and Finland (2019) (Poland is also foreseen in 2019). In 2018, more than 5,000 transactions were executed with 71 buyers and 130 sellers, and around four million tonnes was traded (some also from Russia). The market is much less concentrated, with the biggest player representing 14% of the market – in 2012 the biggest player represented 42% – and biomass prices decreased up to 40% compared to 2012.

Enabling a Regional Bioeconomy: Australian case study for developing biomass supply chains

Mark Brown, University of the Sunshine Coast, Australia

The Australian case study presented looks at valorising biomass residues from pine plantations on the east coast of Australia (south-east Queensland). The project is driven by the interest of private companies: a large softwood owner, an MDF producer, and a pellet producer. The fact that the material is currently not being used was key to the project. The increased biomass demand is based on pure economics: site preparation savings for next generation planting, stabilizing long term electricity costs, and expanding the supply chain for pellet production. The case study consists of four parts: (1) biomass assessment; (2) operational considerations (harvesting, site preparation, economics); (3) supply chains options; and (4) optimal supply chains.

The project investigates biomass residues from two harvesting systems: cut to length (CTL) harvesting, where residues are left in the field; and whole tree harvesting (WT), where residues are left on the roadside. WT currently represents 75% of operations on site. The project concluded that there are viable amounts of recoverable biomass, estimated at 10 to 20 green tonnes per hectare, with Whole Tree Harvesting sites most favourable for extraction. Extraction of biomass residues would have a positive impact on the costs for preparing the next plantation, but a negative impact on soil nutrients. By leaving behind the fine branches and needles (containing 50% of tree nutrients), they only have to churn up the site for replanting.

For supply chains options, more than 40 alternative scenarios were developed, looking at machinery to remove/pick up the raw material, processing and transport. Fourteen more likely options were modelled. The remaining options were in field processing; roadside processing with arranged piles (truck mounted or roadside track-mounted grinder or chipper); and central processing at compartment (grinder or chipper). Several assumptions need to be further refined from the landowner perspective, based on regional and market constraints. The next steps in the project will involve strategic field trials and refining the model assumptions.

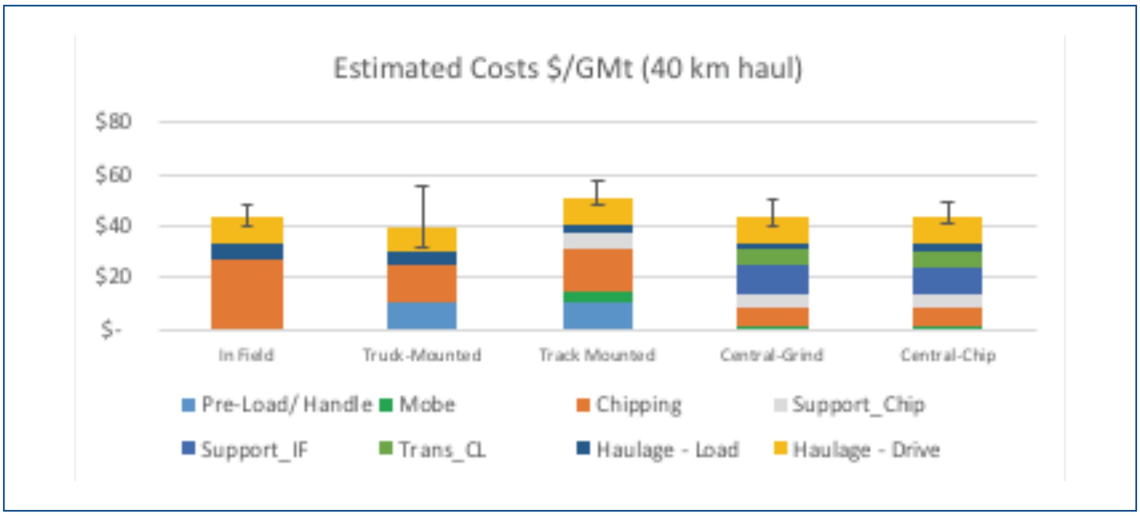

Figure 3: Estimated costs for different supply chain options (source: USC)

Session conclusions

Matthew Clancy, Sustainable Energy Authority of Ireland, provided a synopsis of the presentations in this session and put forward some questions to the presenters in relation to sustainability considerations and stakeholder involvement. Additional questions were posed by the audience. The presenters made the following clarifications:

- *Sustainability*: The presented systems mainly rely on (FSC or PEFC) certified forests and/or existing forest regulations. Certificates can quite easily be connected to virtual trading systems.
- *Energy focus of the Biomass ExChange system*: The presented Biomass ExChange system is currently focused on energy, but this doesn't prevent other applications in future.
- *Cross-border trade in the Biomass Exchange*: the Baltic states are connected as one trading zone. Overseas connections are more complicated. The model of FOB (Freight On Board) is currently explored for ports.
- *Can extra return for biomass residues lead to expansion of plantations?* Only 2-3% of total return for plantation owners come through these residues, so it won't drive massive decisions. It may help in keeping current forestry systems in place and avoiding conversion to other land uses.

Session 2: Examples of developing biobased business models

This session was moderated by Kees Kwant, Netherlands Enterprise Agency (RvO.nl)

Turning wood into high purity lignin and wood sugars to industrialize innovative biomaterials and bioproducts – status of SWEETWOODS Flagship Project

Peep Pitk, Graanul Biotech, Estonia

Graanul Invest is Europe's largest pellet producer, with 11 pellet factories, and an annual production capacity of 2.2 Million tonnes per year. They are also involved in forest management. Graanul participates in the Sustainable Biomass Partnership (SBP), providing the same basis of comparison on sustainability for customers.

Graanul aims to start the next steps beyond bioenergy. Their strategic target is to become the leading European biochemical/biomaterials producer from woody material, aiming to convert more than 90% of wood input to useful products, with the remaining available for energy. Mr. Pitk presented the project SWEETWOODS, a European flagship project. With this project, they are establishing a first-of-a-kind wood fractionation demonstration plant in Estonia, using hardwood biomass as raw input material. The aim is to demonstrate on an industrial scale how novel pre-treatment technology in combination with innovative enzymatic solutions will provide a liquid fraction of mixed sugars and a solid fraction of high-quality lignin. The process would be wood species agnostic, with zero waste and minimal water and chemicals use. The demonstration plant is expected to be operational in 2021.

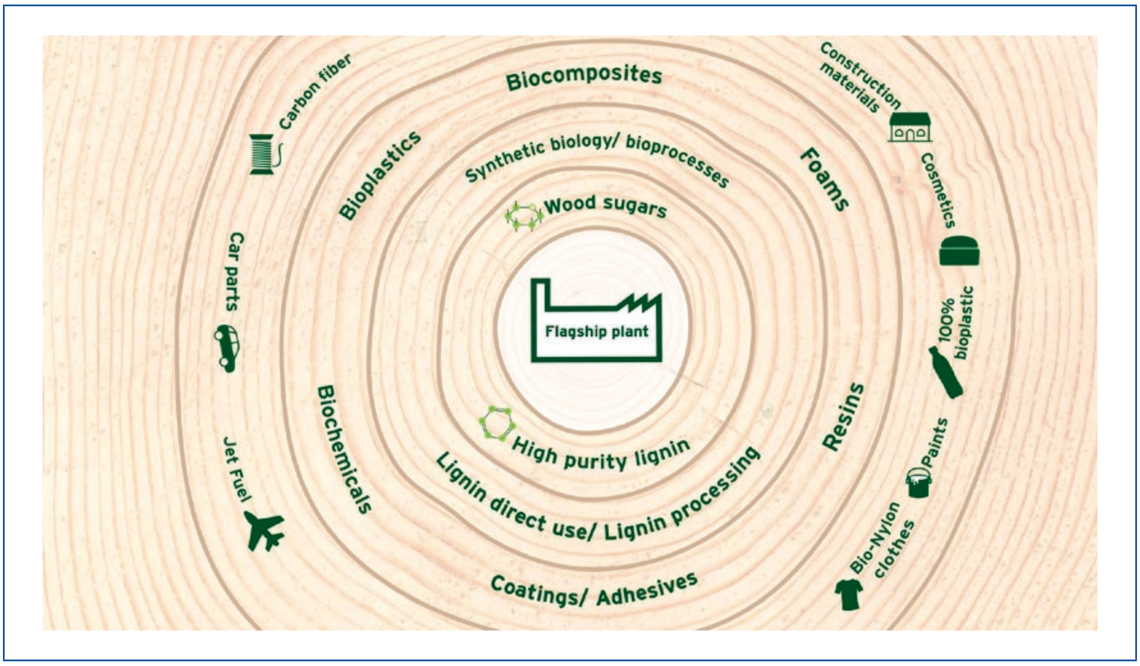

Figure 4: Range of products that can be produced from the wood sugars and lignin (source: Graanul)

Building a business case with pyrolysis of woody biomass

Mark Richters, BTG Bioliquids BV, the Netherlands

Mr. Richters gave some background on BTG Bioliquids, which was established by BTG in 2007; BTG is a spin-off of Twente University, working on fast pyrolysis since 1987. BTG Bioliquids is a technology provider, committed to the commercial deployment of fast pyrolysis technology. In fact, 2019 was the first year that they have had technology sales, which is more than 30 years after BTG was established.

Their first commercial scale plant (Empyro) is in operation since 2015, producing 20 million litres of pyrolysis oil per year from wood residues. Overall, the plant reaches a conversion efficiency of 85% (based on energy content of the biomass input), with 65% of the energy contained in the incoming biomass ending up in the bio-oil. A stable oil off-take is key. The current end user uses the bio-oil for process heat. Steam as by-product is sold to a chemical industry located beside the plant.

There are now new projects contracted in Finland and Sweden, of a similar size as the Empyro plant. These will all be located close to the biomass source (sawmill). In Sweden, the oil will be used in a petroleum refinery, which represents a new step. In future, BTG Bioliquids will further broaden the applications of the bio-oil.

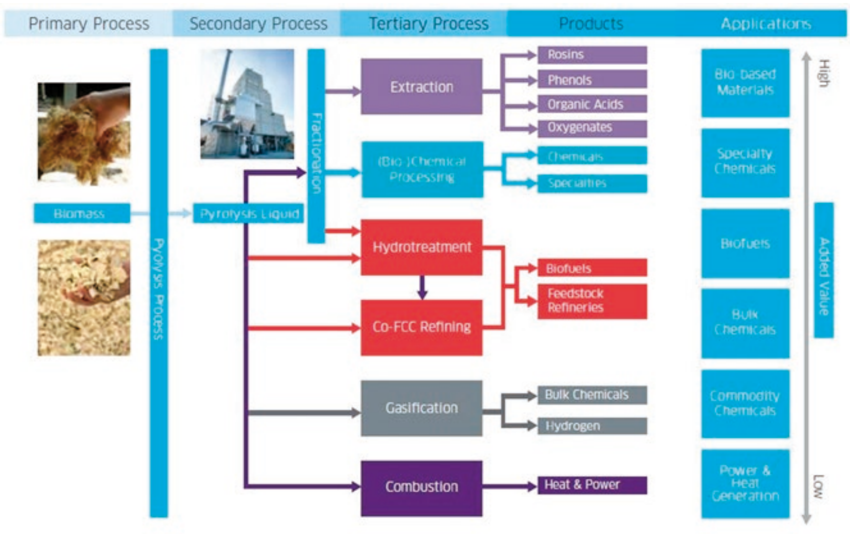

Figure based on BTG Biomass Technology Group B.V. intellectual property

Figure 5: future applications of fast pyrolysis bio-oil (source: BTG)

Mr. Richters also explained some of the key drivers for success, with the first being the team and its dedication. Time and timing are also important, as developments have taken a long time to come to technology roll-out. Through building and operating the first plant, BTG Bioliquids has been able to learn by doing and prove the technology to customers. Information sharing and knowledge transfer are also important, as well as a continuous R&D towards more viable bio-oil applications. Partnerships are crucial. For technology roll-out, BTG Bioliquid is now partnering with an experienced EPC contractor in the energy industry. Moreover, actors in the value chain should be involved, from biomass providers to the offset side, with new opportunities now emerging for co-processing in petroleum refineries.

Investing in the biobased economy

Juha-Erkki Nieminen, Neste, Finland

Mr. Nieminen provided some background on the journey of Neste in the past 23 years, transforming from a regional oil refiner into a provider of renewable solutions, which have completely outgrown the fossil part of their business in the past five years. Their main product is renewable diesel but they are also moving into aviation fuels and renewable chemicals. Neste started in this biobased economy journey with innovation in 1996, patenting renewable diesel technology (NEXBTL). In 2003 policy became a main driver, with the EU Biofuels Directive and the US Energy Policy Act, both of which enabled risk taking due to a predictable outlook. This led to a first investment decision in 2005 for a commercial operation in Finland, which started operation in 2007. By 2011 new plants were installed in Finland, the Netherlands and Singapore, with a combined capacity of almost two million tonnes of renewable diesel per year. The period 2007-2012, focusing on installation and early operations of the first plants was the most difficult in terms of business and economics. They worked on improvements and turned the business around, now having the benefits of the first mover. Key factors were market acceptance, a market strategy, increased focus on waste and residues (now representing over 80% of the raw material base), and production improvements.

By 2022 Neste aims to have a total renewable products capacity close to 4.5 million tonnes per year.

In the coming decade there will be increased focus on sustainable aviation fuels and renewable plastics. Neste aims to help reduce its customers' greenhouse gas emissions by at least 20 million tons annually by 2030.

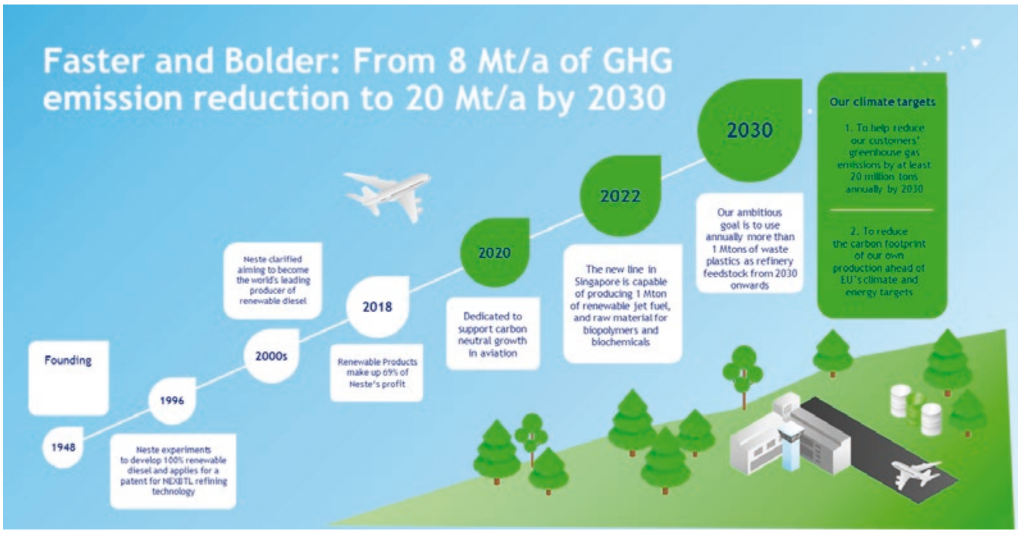

Figure 6: past and future milestones in the Neste transformation process (source: Neste)

Setting up biomass supply chains for advanced cellulosic ethanol production

Gloria Gaupmann, Clariant, Germany

The presentation focused on the biomass supply side, which is a challenge for a chemical company. Clariant developed the Sunliquid® technology platform providing access to sugars from agricultural residues to produce advanced cellulosic ethanol. The Sunliquid technology provides development opportunities for biobased products and has created extensive know-how in biocatalysis, strain optimization and heterogenous catalysis.

Clariant has a pilot plant in Germany and is now building a flagship commercial plant in Romania, which will be completed in 2020. The plant capacity is 50,000 tonnes of cellulosic ethanol per year, based on an annual processing of 250,000 tonnes of straw. This size is based on an assessment of availability within a certain radius (normally up to 50-100 km). Commercial licenses are also signed for plants in Slovakia and Poland.

Feedstock collection is a big part of the story for the Romanian plant. There is still frequent burning of excess straw in the fields in Romania to clear the land for the next crops. Setting up straw supply chains is nothing new, as straw supply chains are already established in countries like Denmark, Poland or Hungary. However, for Clariant this represented a steep learning curve.

One hectare of cropland can yield around four tonnes of straw per year. Securing 250,000 tonnes of straw means setting up long term contracts with over 100 farmers and effective interface management of stakeholders along the supply chain. The farmers are keen on the added value but they lack investment in facilities and in know-how. Clariant set up a dedicated feedstock team to support farmers in know-how, machinery, digitalisation and managing the paperwork. They also designed networks of intermediate storage systems; certification for EU RED requirements is performed from this first gathering point.

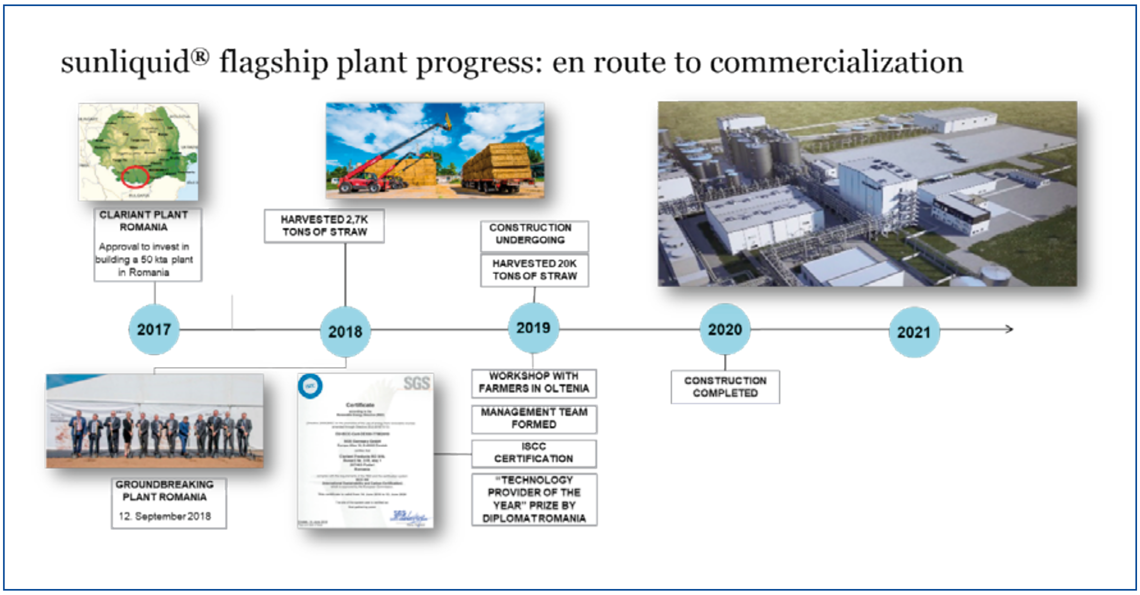

Figure 7: implementation steps for the advanced ethanol flagship plant in Romania (source: Clariant)

Session conclusions

Bert Annevelink, Wageningen Food & Biobased Research, the Netherlands, leader of IEA Bioenergy Task 42 (Biorefining in a Circular Economy), provided a synopsis of the presentations in this session, focusing on the barriers for setting up biobased business models and solutions identified in the different presentations. Extra time for discussion was included as several speakers of this session were unable to join the panel discussion at the end of the workshop.

Some of the barriers identified include

- feedstock cost, feedstock diversity and supply security;
- time needed from R&D to scale up and realize markets;
- high investments and risk profile for first of a kind installations ('valley of death');
- high price competitivity in chemical markets;
- absence of incentives for more environmentally friendly chemicals/products;
- policy uncertainty (e.g. hype in other technologies can reduce support for biobased options) – the risk of policy U-turns is detrimental for the investment climate;
- public opinion.

Some suggestions to deal with these barriers are:

- maximize the value created from the biomass through a mix of technologies and end products; move from bulk commodities to more finished products;
- develop technologies that are capable of dealing with varieties of feedstocks (including lower quality);
- demonstrate environmental benefits, e.g. through certification;
- get involved in the supply chain and promote knowledge to organize supply chains (also on how to govern sustainability);
- set up intermediate solutions like bio-hubs;
- continue to invest in improvements, and look at medium to long term perspectives;
- team up with good partners who have a strong belief in what you do – be selective, avoid partners that just aim for short term profits;
- prove the concept yourself;
- long term stable policy framework is a prerequisite for investments with a 15 to 20-year timeframe.

There was a question from the audience on whether electrification of the vehicle fleet impacts investor sentiment on advanced biofuels. There was consensus between the speakers that different solutions are needed in the transport sector, and electrification is complementary to renewable fuels. Investment decisions already consider the longer term where demand for biofuels may shift more to heavy duty traffic and renewable jet fuels.

Nevertheless, the need for complementary solutions in transport needs to be stressed more to policy makers as well as the public opinion, to avoid hype leading to policy U-turns.

Session 3: CO_2 capture as part of future biomass business models

This session was moderated by Janne Kärki, VTT, Finland

Outlook on bioenergy combined with carbon capture, utilization and storage (BECCUS)

Janne Kärki, VTT, Finland

Mr. Kärki stressed that net zero emissions should be reached by mid-century. The more emission reductions are delayed, the more CO_2 removal from the atmosphere is required, with projections up to 16 billion tonnes of CO_2 removal needs per year in 2100. CCS and bioenergy are among the most important technologies for achieving long term climate policy objectives, with bio-CCS/BECCS being the only industrial scale carbon negative technology that can be deployed today.

Several bioenergy activities combined with carbon capture are on-going at the global level. These are biomass combustion plants or waste to energy plants where CO_2 is captured from the exhaust gas; other options focus on using CO_2 side streams from ethanol production (mainly in the US) or from biogas upgrading.

UK • Drax Power Station, 1 t/d BECCS pilot **Netherlands** • Port of Rotterdam CCUS Backbone Initiative • Waste incinerator Bio-CCU pilot, AVR Duiven, 60 kt/a • Twence WtE Bio-CCU, 100 kt/a **USA/Canada** • Archer Daniel Midlands bioethanol with CCS, 1.1 Mt/a • Arkalon bioethanol with CCS, 0.7 Mt/a (EOR) • Bonanza bioethanol with CCS, 0.1 Mt/a (EOR) • Husky Energy bioethanol with CCS, 0.1 Mt/a (EOR)	**Japan** • Toshiba biomass-fuelled CHP with CCS, 500 t/d **China** • Biomass fired/co-fired plant(s) with CCS **Sweden** • Stockholm Exergi, VärtanCHP BECCS pilot **Norway** • Norwegian full-scale CCS projects (NorcemBrevik, FortumOslo Varme, Northern Lights) **Finland** • VTT, Bioruukkibio-CLC pilot unit

Table 1: Some activities on Bio-CCS (source: VTT)

He presented the case for pulp mills, which could be attractive for Bio-CCS. Pulp mills are large point sources of almost completely biobased CO_2, and they have excess heat available. Capture costs would be in to order of €50-90/tonne CO_2, depending on the degree of integration.

VTT is working on a combined heat and power (CHP) concept with Chemical-Looping Combustion of biomass (bio-CLC), which provides much higher CO_2 concentrations in the exhaust (as N_2 dilution from air is avoided) and would lead to low operational capture costs (€15-25/tonne CO_2), relatively low capital costs and high total efficiency.

He compared CCS and CCU, with climate impact in CCS coming from storing the generated CO_2 permanently back in the ground, while climate impacts in CCU come from the replacement of the use of fossil resources. (Bio)-CCU or power-to-X products can be carbon neutral energy carriers or materials if associated with renewable electricity.

In general, bio-CCS needs credits for negative CO_2 emissions for technology demonstration and commercialization at industrial scale. CCU business opportunities seem to be closer than with CCS, with several possible bio-CCU applications near to commercialization. Next to CO_2 capture cost, their deployment is highly dependent on electricity prices to produce renewable hydrogen.

Northern Lights – A European CO_2 transport and storage network

Emil Yde Aasen, Equinor, Norway

The Northern Lights project is part of the Norwegian full-scale CCS project and is developed between the partners Equinor, Shell and Total. The full-scale project includes capture of CO_2 from industrial capture sources in the Oslo-fjord region and shipping of liquid CO_2 from these capture sites to an onshore terminal on the Norwegian west coast. From there, the liquified CO_2 will be transported by pipeline to an offshore storage location subsea in the North Sea (about 3,000 m down), for permanent storage. This set-up, using ships from the CO_2 capture sites to the Northern Lights onshore site, enables the scale-up of a CO_2 transport and storage network which is open to CO_2 capture sites across Europe. The demonstration project is planned to be in operation in 2023. In the initial project they plan to store 1.5 million tonnes of CO_2 in phase 1 and another 3.5 million tonnes in phase 2. To date 15 partners have joined under a 'Project of Common Interest'.

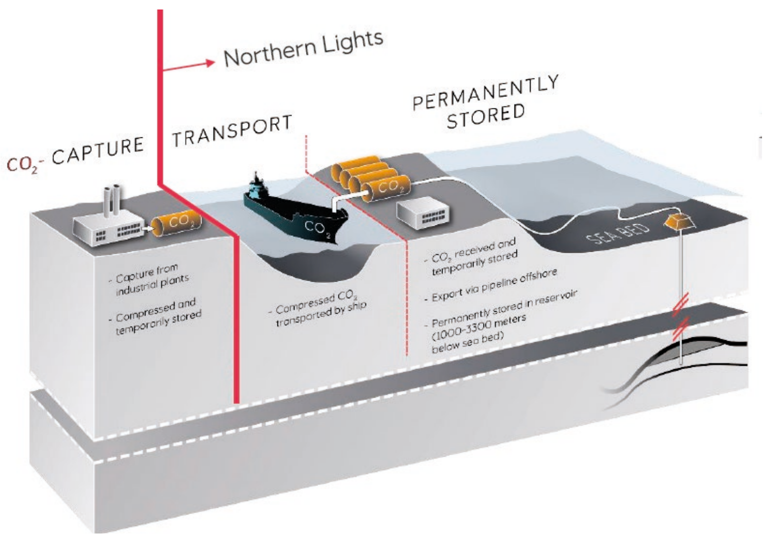

Figure 9: schematic representation of the Northern Lights CCS demonstration project (source: Northern Lights)

The following sectors are considered to have the largest potential to deliver CO_2: hydrogen and electricity production from natural gas; waste incineration; cement production; biomass and biofuel facilities; steel production; refineries; and aluminium industry. Sites which are within 20 km of ports are the low hanging fruits. According to public data in the European Pollutant Release and Transfer Register (E-PRTR), the potential for BECCS alone can be estimated at 469 million tonnes of CO_2 per year in Europe.

Regarding the funding gap for CCS, the current cost is higher than the CO_2 price in ETS, which is now around €25/tonne. The funding gap can be bridged project-by-project through strategic fits, market pull, industrial value, public-private partnerships, dedicated public funding and private willingness to invest in CO_2 reduction projects.

Developing bioenergy with carbon capture and storage (BECCS) at Drax

Luc Pelkmans, IEA Bioenergy on behalf of Karl Smyth, Drax, UK

Due to unexpected circumstances, Mr. Smyth was not able to come to Estonia. His slides were presented by Luc Pelkmans, Technical Coordinator of IEA Bioenergy.

Between 2013 and 2018 Drax has converted four units of 645 MW coal power facilities to biomass. The ambition is to capture the CO_2 emissions in these facilities. This way 16 million tonnes of CO_2 per year could be sequestered. In a recent report of the UK Committee on Climate Change it was recognized that BECCS is essential to reach net zero emissions in the UK by 2050. Of the residual 85 million tonnes of CO_2 emissions per year in the UK, 50 million tonnes would need to be compensated through BECCS. The four Drax units could have a major role.

Early this year a BECCS pilot was commissioned at Drax, at one tonne of CO_2 capture per day. The chemical process for CO_2 removal is developed by C-Capture, a spin-off of Leeds University. The ambition is to have deployment of the first commercial scale BECCS unit at Drax by mid 2020s, representing 2.5 million tonnes of CO_2 per annum, and have full conversion of the biomass units to BECCS in the 2030s. Meanwhile a large-scale CO_2 transport and storage network is developed in the area.

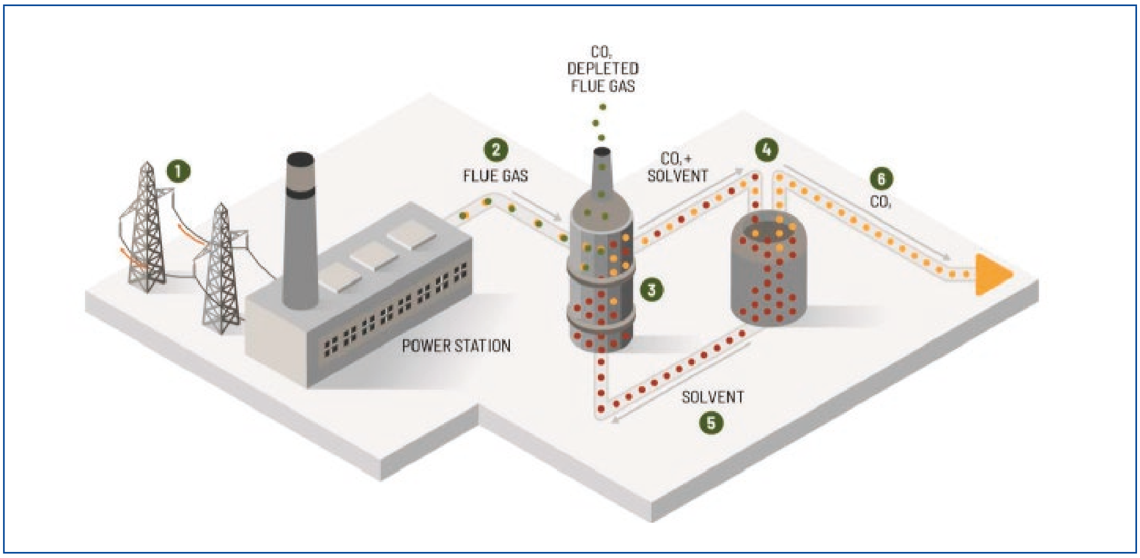

Figure 10: Operation of BECCS at the power station (source: Drax)

The second part of the presentation was about policies needed to support negative emissions in the UK, based on a recent report of Vivid Economics. The report concluded that Greenhouse Gas Removal (GGR) is vital to hit the 2050 Net Zero target, with BECCS and DACCS (direct air carbon capture and storage) expected to be the two dominant GGR options due to their scalability. Significant policy support will be required to enable GGR rollout at the scale required. Annual costs of GGRs are estimated at between £1-2 billion in 2030 and £6-30 billion in 2050.

Next to direct policies (such as subsidies, obligations, tax credits), enabling policies (such as pilot projects, demonstration support, investment coordination, information provision) and integrating policies (e.g. in terms of land use) will also be needed in the short term.

Trading platform for negative CO_2 emissions

Marianne Tikkanen, Puro, Finland

Puro is the world's first marketplace to offer verified CO_2 removal certificates (CORCs). One CORC represents one tonne of net-negative CO_2 removal. Any net-negative technology can qualify if it guarantees long term storage (>50 years) and if the CO_2 removal can be measured.

CO_2 removals must be proven ex-post through LCA for the past 6-12 months.

Distinction is made between technical capture of CO_2 (e.g. from exhaust gas or from air) and natural photosynthesis (through biomass and underground microbes). So far Puro recognizes three end storage options: carbonated building elements, wooden building elements and biochar (which hardly decomposes in a 50-year timeframe). More options will follow. So far afforestation has not been included, as the permanence issue has not been solved.

In October 2019, CORC certificates were traded for on average €22.67, which is a little below ETS CO_2 prices. Buyers come from a range of industries – IT-digital, travel/logistics, consultants, agri-food, offset retailers, energy. Business reasons are diverse, but often include pressure from customers or competitors. The extra revenue that CO_2 removal certificates bring, stimulates the net-negative businesses that store more CO_2 than they emit.

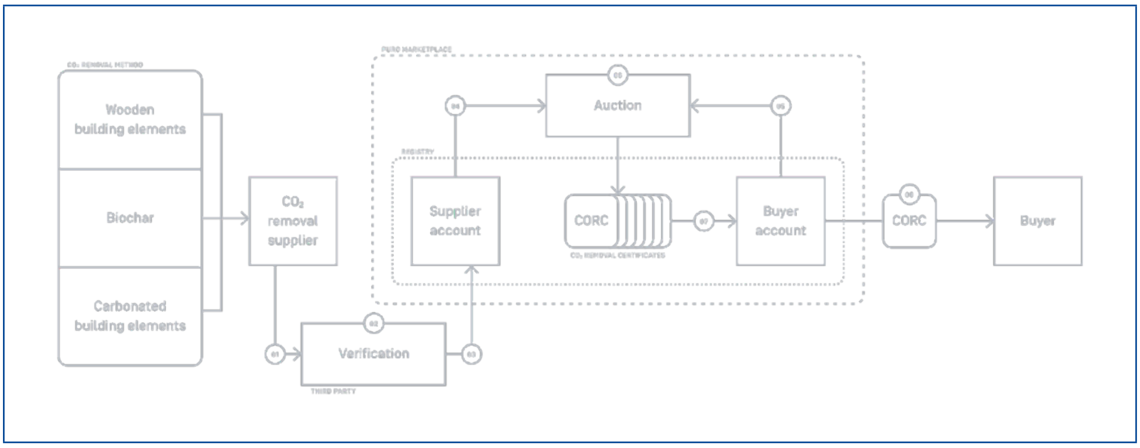

Figure 11: operation of the CO_2 removal certificates marketplace (source: Puro)

Session conclusions

Olle Olsson, Stockholm Environment Institute, Sweden, provided a review of the session. Bio-CCS/BECCS is the most market ready negative emission technology today, with many activities around the world, and it is indispensable to reach net zero emissions by mid-century. Certain sectors are particularly suited for carbon capture. Carbon transport and storage is being developed – also serving the fossil sector – where bioenergy can tap into. In review of technologies, policies are needed as are technology development, infrastructure and some business model. Credits for negative CO_2 emissions will be needed, which could be provided through taxation of CO_2 emissions. Alternatively, voluntary compensation systems could complement policies.

Panel discussion

The closing panel session was moderated by Jim Spaeth, US Department of Energy. Panel participants were Olle Olsson (SEI), Emil Yde Aasen (Equinor), Karel Lember (Estonian Ministry of Economic Affairs and Communications), Mark Brown (USC) and Gloria Gaupmann (Clariant).

The central items for the panel discussion were:

- challenges and opportunities to expand biomass mobilization in a sustainable way and setting up supply chains;
- main barriers for industry investments in biobased business models and BECCS;
- recommendations to overcome these barriers.

Biomass mobilisation

- Most commercial forestry in developed countries is operating under sustainable forestry management schemes (FSC[2], PEFC[3]), or controlled by forestry law. There is hesitance at the forestry level to go beyond the existing standards. It is better to understand the current gaps and **integrate requirements into existing standards**, also recognizing that forestry produces a portfolio of products, only part of it being biomass for energy.
- Forestry and agriculture have a wealth of experience with multiple feedstocks and owners. Complexity comes in the **interface between supply chains and markets** they serve, and bio-hubs can be a promising tool to deal with this. It may be best to go for a few commodity products, with well-defined quality criteria. These commodities can be part of **trading platforms**.

2 Forest Stewardship Council

3 Program for the Endorsement of Forest Certification

- Integration throughout the value chain is a challenge for biobased industries and requires substantial efforts. Parties need to understand each other, and communication is a crucial issue. Policies and programs (such as the U.S. Biomass Crop Assistance Program) can facilitate **value chain integration**.

Business models

- The **complexity** of biobased systems must be recognized. To transition away from fossil resources, massive developments will be needed in the bioeconomy, with **high investment costs and long project timelines**. So, it is critical to ensure strong business models and supportive investment conditions.
- Cooperation is needed between the private sector, public sector and academia. It is important to create enabling **partnerships**. Knowledge and capability in supply chains connected to technology knowledge helped developments in Scandinavia.
- **First mover risks** are high, with opportunities only coming at later stages, creating multiple potential valleys of death in between. Technologies need to go through a learning curve (which the fossil industry had in the past century) – the question is how to speed up this learning curve.
- **Risk abatement and risk sharing** will be crucial, e.g. through public funding at the initial phase (to bring technology to a certain point) and public investment funds/loan guarantees at early market introduction. A positive opportunity is that current interest rates are low and a lot of venture capital is looking for good investment opportunities.
- Strong policy support is required, considering the **value proposition** provided by biobased solutions. The value proposition can represent a step change in industry, making it worthwhile to take the risk.
- Sustainability needs to be assured and the focus should be on technologies that have less concerns in this respect. **Sustainability advantages** need to be reflected through market value or market access. Without that, a cost disadvantage will likely remain in the long term. A stable long-term policy framework is crucial.
- There should be a **value of carbon** created across industries. This enables a short-term realisation of low-hanging fruit. Nevertheless, carbon prices should be at sufficient level to make a difference. In relation to CCS, some of the early lower cost opportunities will be at biomass facilities.
- **Real projects** move barriers more quickly than just talking about the theory. This is particularly the case for CCS, which had a bumpy ride, but things are now starting to happen. The opening of the transport and storage side facilitates developments in the capture side.
- **Communication and engagement with the local community** from the earliest project stages is very important. **Shared benefits/ownership** can be a powerful way to deal with local resistance to new facilities.

Recommendations

At the close of the panel discussion, panellists were asked for their final recommendations.

- **Communication and engagement** with the local community is very important. It is not only about risks and how these are covered, but also about communicating opportunities. Local support helps for scaling up and creating additional investments and can be particularly relevant for the concept of bio-hubs.
- We need to encourage the biobased sectors to take more risk and set up policy and investment frameworks that **improve their chances** to be successful.

- The bioenergy sector should explore and develop **CO_2 capture** as an option, which can be a main driver for support to the bioenergy sector.
- There are several studies on the **value of carbon reduction**. At a certain threshold level BECCS will be accelerated, looking at low hanging fruits. There are several emission points of CO_2 and things can evolve in parallel.
- The strength of IEA Bioenergy is in bringing disparate groups and networks together. Nevertheless, we need to **extend to who and how we communicate** (broaden our audience).

Closing remarks

Luc Pelkmans, Technical Coordinator of IEA Bioenergy, provided a short summary of the items discussed during the workshop and thanked all speakers and participants for their active contributions in the workshop.

ACKNOWLEDGEMENTS

The following people were involved in the organizing committee to develop the workshop programme: Luc Pelkmans, Jim Spaeth, Kees Kwant, Liisa Mällo, Olle Olsson, Bert Annevelink, Mark Brown and Antti Arasto. Their input, as well as the contributions of invited speakers, panellists and moderators are gratefully acknowledged. A special thanks goes to the Estonian Ministry of Economic Affairs and Communications for hosting the event, and particularly Liisa Mällo and Lilian Urba 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 Pearse Buckley, Jim Spaeth, Kees Kwant and the many different speakers. Pearse Buckley, the IEA Bioenergy Secretary, facilitated the editorial process and arranged the final design and production.

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