Contribution of sustainable biomass and bioenergy in industry transitions towards a circular economy

Summary and conclusions from the IEA Bioenergy eWorkshop, 19-20 October 2020

Technology Collaboration Programme
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1. Key messages from the workshop

- Biomass is a key component to reduce the climate impact of industries, next to electrification, hydrogen & CCUS (carbon capture and utilisation/storage). It is important to increase awareness of the role of biomass and bioenergy, both to industry and authorities.

- Industries need to take a long term perspective and make real engagements towards net carbon neutrality.

- The main challenge is the low cost of fossil alternatives (if carbon cost is not accounted for).

  - A correct and global CO_2 price for fossil resources would be needed. In the absence of a global carbon price regime, other policy options need to be implemented.

  - Due to different stages of development (also for biobased products), support for research, development and demonstration projects and de-risking measures for pre-commercial investments are required.

- Availability and access to biomass is crucial to increase the role of biomass in industry transitions.

  - This requires mobilizing biobased resources – also taking into account potential other uses – and setting up sustainable biomass supply chains.

  - Medium scale industries can often match their biomass demand to regionally available biomass.

  - Energy intensive industries need to look more widely for their feedstock sourcing and consider combinations with other solutions (e.g. electrification, hydrogen, CCUS) to further reduce their carbon footprint.

- Specific market strategies can be applied for low-carbon and biobased products, based on strong and credible green labels. Brand owners can also create a market pull, by requiring inputs with low carbon footprint to reduce their own carbon footprint.

2. Executive summary

Luc Pelkmans, Technical Coordinator, IEA Bioenergy

The IEA Technology Collaboration Programme on Bioenergy (IEA Bioenergy) held its biannual workshop on 19-20 October 2020 in conjunction with its Executive Committee meeting (ExCo86). The workshop was originally scheduled to be in Lyon (France), but due to COVID-19 restrictions it was held in virtual form. The workshop on 'Contribution of sustainable biomass and bioenergy in industry transitions towards a circular economy' was prepared in close collaboration with ADEME, the French Agency for the Ecological Transition.

The workshop consisted of three separate two-hour sessions around the role of biomass in different sectors/applications:

1. Medium and high temperature heat in industry

2. Energy intensive industries – steel and cement sectors

3. Chemical industries

Each session was concluded with a short panel discussion on challenges for such industry transitions and what is needed in terms of policies and market conditions to increase the role of biomass in these sectors. The workshop sessions each had between 200 and 250 participants.

2.1 IMPORTANT ROLE OF BIOMASS IN REDUCING THE CLIMATE IMPACT OF INDUSTRIES

According to IEA's Sustainable Development Scenario (up to 2070), about one third of global CO_2 emission reductions, relative to baseline trends, will need to come from industry. Broadly speaking, options to reduce the climate impact of industries are efficiency measures, carbon capture and utilisation / storage (CCUS), electrification, hydrogen and the use of biomass. The share of bioenergy in industry is expected to double in the coming decades up to 15% of its final energy consumption.

About half of global industry CO_2 emissions are currently in China. China aims to reach carbon neutrality by 2060. Clean energy, including bioenergy, will play an increasing role in China's efforts to reduce greenhouse gas emissions. There is considerable opportunity to expand the use of biomass in China. Opportunities to combine bioenergy with CCUS will also be explored.

2.2 BIOMASS FOR MEDIUM AND HIGH TEMPERATURE PROCESS HEAT

So far, the application of bioenergy in industry is mainly performed in industries that can use their own biomass process residues to cover (some of) their own heat demand. Anaerobic digestion of process residues in food industries is an interesting way to replace natural gas consumption, although current uses of these process residues (e.g. as animal feed) are to be considered, as well as the management and distribution of digestate as a co-product of anaerobic digestion. With the increasing motivation in industry to reduce their carbon footprint, several other industry sectors are also shifting towards biomass based heat generation in cases where there are suitable biomass resources and technologies available nearby. Several fuel technology combinations are commercially available for producing biobased heat in industry, and there are many successful examples of biobased industrial heat. The heat demand in small and medium sized industries can often be better matched with the biomass resources that may be locally available. The optimal combination is very site specific and needs to be carefully assessed. Biomass projects are usually not considered as 'payback projects', but are part of the general management strategy of companies to move towards net zero carbon emissions.

2.3 BIOMASS IN ENERGY INTENSIVE INDUSTRIES

Cement and steel industries represent more than 50% of global direct CO_2 emissions in industry. It is important to remember that CO_2 emissions in these industries are not only generated through fuel combustion, but are also linked to the industrial process itself, e.g. iron ore reduction in steel industries or limestone calcination in cement industries.
Steelmaking is a highly carbon-intensive process due to its extensive use of coal as both an

energy source and a reductant. Around 20% of pulverized coal injection (PCI) could be replaced with biocoal (from slow pyrolysis) in blast furnaces with existing technologies. Lignin could also have great potential to reduce coal consumption. The economy of biocarbon usage as a PCI substitute is becoming a viable option with rising CO_2 emission trading costs. There are also opportunities to convert blast furnace gas (containing CO and CO_2) into low carbon fuels or chemicals.

The cement sector already uses different types of substitution fuels (particularly waste) for its energy needs, some of which can contain a certain fraction of biogenic carbon. The sector will need to move beyond traditional waste in terms of substitution fuels, as most waste fuels still contain a high fraction of fossil carbon. Moreover, energy related emissions represent only one third of the emissions from the cement industry; two third is related to the limestone calcination process. CCUS will be a crucial technology to reduce the climate impact of this sector.

2.4 BIOMASS IN CHEMICAL INDUSTRIES

From an industrial point of view, biomass has complex characteristics, in terms of cost, availability, variability and specificity. At the moment fossil resources are more managed in synergy through refining processes, while the concept of biorefining is less developed for biobased resources. More inter-sector integration and clustering will be needed for biobased industries. Next to techno-economics, new business models using biobased resources also need to include sustainability requirements on feedstock sourcing. The required scale of specific biobased chemicals production can be in balance with local biomass availability; for larger initiatives trading of sustainable biomass will be required. There are interesting developments of forest based industries to broaden their production to biofuels and biobased chemicals, as they have long experience in sustainable biomass feedstock supply. Other chemical industries have less experience in dealing with biomass sourcing. New biobased industries often rely on input of hydrogen and there are important initiatives towards green hydrogen, which also further improve the carbon footprint of these biobased products.

2.5 OVERALL CHALLENGES AND NEEDS IN TERMS OF POLICIES AND MARKET CONDITIONS

The main challenge to increase the role of biomass in industry sectors is the **cost difference** between biobased energy / products and fossil based energy / products (if carbon cost is not accounted for), particularly in these times when fossil prices are at record low levels. Cost competitiveness of industries is key and they often operate in international markets. So putting high requirements on local industry can lead to carbon leakage if (part of) production is shifted abroad. Overall, a meaningful and global CO_2 price for fossil resources would be needed. In the absence of a global carbon price regime, other policy options need to be implemented, such as public procurement of products with low life cycle emissions; carbon border tax adjustment or carbon contracts for difference. According to different stages of development (also for biobased products), support for research, development and demonstration projects and de-risking measures for pre-commercial investments would be required. It is also important to recognize and reward additional environmental services (not only renewable energy), e.g. reduction of waste, avoidance of methane emissions, etc. Overall, stable policies are important, as well as the removal of hindering regulations for certain biobased applications (e.g. restrictions for transport and processing of biobased waste).

Availability and access to biomass are crucial to increase the role of biomass in industry transitions. If industries can't rely on their own process residues, this requires mobilizing biobased resources – also taking into account potential other uses – and setting up sustainable biomass supply chains. Medium scale industries can often match their biomass demand to regionally available biomass. Energy intensive industries need to look more widely for their feedstock sourcing and consider combinations with other solutions (e.g. electrification, hydrogen, CCUS) to further reduce their carbon footprint.

There may be a willingness of consumers to pay a premium for green, biobased products. This will need to be based on strong and credible green labels (LCA based). Brand owners can also create a market pull, by requiring inputs with low carbon footprint to reduce their own carbon footprint.

The PowerPoint presentations can be downloaded from IEA Bioenergy's website **https://www.ieabioenergy.com/publications/iea-bioenergy-eworkshop-contribution-of-sustainable-biomass-and-bioenergy-in-industry-transitions-towards-a-circular-economy/**.

3. Workshop

3.1 SESSION 1: INTRODUCTION & BIOMASS FOR MEDIUM AND HIGH TEMPERATURE HEAT IN INDUSTRY

The presentations were moderated by Jim Spaeth, US Department of Energy, chair of IEA Bioenergy. Mark Brown, University of the Sunshine Coast, Australia, moderated the panel discussion at the end of the session.

During the workshop, several polls were taken among the audience through the interactive tool 'SLIDO'. An opening poll was about the background of the participants: 57% of respondents were from research institutes or universities; 16% from government agencies; 15% from industry; 9% consultants; and 8% other. (*multiple inputs were possible*)

3.1.1 French biomass policy framework (with focus on ADEME funding schemes)

David Marchal, deputy Executive Director for Expertise and Programs, ADEME, France

Essentially initiated in the beginning of the 1990s the French bioeconomy policy framework is based on national and European objectives, crossing fields of energy, forestry, agriculture and environment. The development of renewable energy use constitutes by far the main driving force of this framework even if the development of biobased chemistry, products and materials is also clearly included. These sectors having a lower technological maturity level compared to biomass energy, the public support for these is mainly focused on innovation.

In France, biomass is the leading renewable energy today. Quantitative and progressive objectives for renewable energy issued from biomass (biomass energy, biofuels, biogas) are included in legislative 10-years-energy plan up to 2030.

Since 2009, a dedicated scheme for the development of renewable heat production, "the Heat fund", has been set up by the Ministry of Ecological Transition. Ten years after its launch, it enabled a major development of heat production from biomass with a specific focus on the industry sector. The level of objectives for 2030 makes this tool even more necessary to pursue and amplify the development under sustainable conditions.

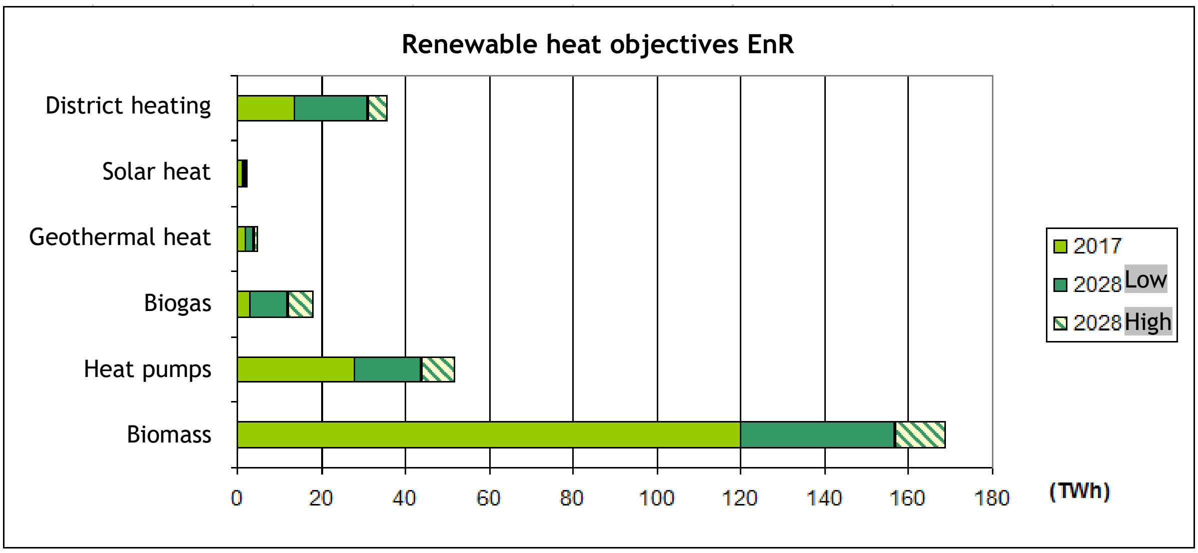

Figure 1: renewable heat objectives in France (source: ADEME)

In the post Covid period, new actions and support policies – including a 'Decarbonization Fund for industry' - will be launched by the French Recovery plan for the next 3 years, which includes an OPEX support (contract for difference) taking into account CO_2 avoidance and compensating for low gas prices.

3.1.2 The role of biomass in industry in the IEA Sustainable Development Scenario

Paolo Frankl, Head of Renewable Energy Division, International Energy Agency (IEA)

The IEA 'Sustainable Development Scenario' (SDS) sets out an ambitious and pragmatic vision of how the global energy sector can evolve in order to achieve the critical energy-related UN Sustainable Development Goals: to achieve universal access to energy (SDG 7), to reduce the severe health impacts of air pollution (part of SDG 3) and to tackle climate change (SDG 13). The SDS is aligned with the Paris Agreement calling for greenhouse gas emissions to peak as soon as possible and reduce rapidly thereafter, leading to a balance between anthropogenic emissions by sources and removals by sinks (i.e. net-zero emissions) in the second half of this century.

A large portfolio of innovative technologies are needed to achieve SDS targets. Progress with renewables in the power sector and with electric cars is encouraging, but alone not sufficient to reach climate goals. About half of all energy related CO_2 emissions today are from industry, transport and buildings. Modern bioenergy (including a combined use with carbon capture and utilisation or storage - CCUS) will play an important role, accounting for one fifth of required annual emission reductions relative to the 'Stated Policies Scenario', which implies that the use of modern bioenergy needs to triple from today's levels, with particular growth in transport and industry.

The main tools to reduce the climate impact of industries are electrification, bioenergy, hydrogen & CCUS. Heavy industries are the most difficult challenge, with chemical, steel and cement production representing 80% of total industrial CO_2 emissions. About half of global industry CO_2 emissions are currently in China.

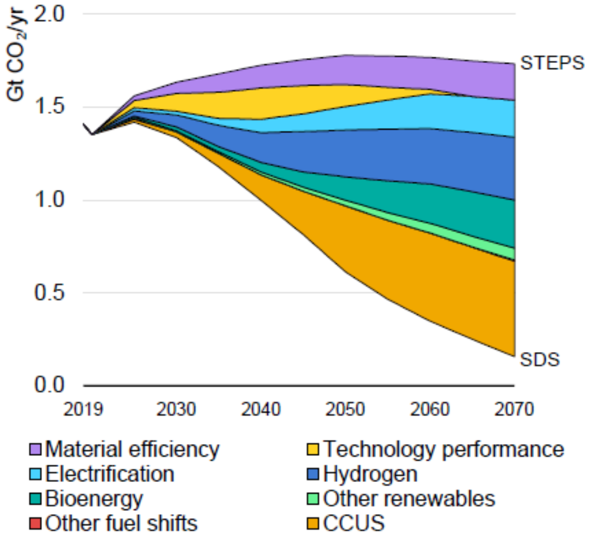

Figure 2: Reduction of direct CO_2 emissions in the global chemistry sector through different routes towards the Sustainable Development Scenario (basis is Stated Policies Scenario (STEPS) (source: IEA Energy Technology Perspectives 2020)

Maximising the potential of bioenergy depends on mobilising supply chains for abundant and untapped resources. Competing uses and sustainability of feedstocks are key considerations. It is important to measure and reward sustainability advantages (for bioenergy and other clean energy options) which helps compensating the cost gap with fossil fuels.

After this presentation a poll was taken among the audience on the most promising applications of biomass in industry. The highest preferences were for using biomass as input for biochemicals, or to use biomass to produce process steam.

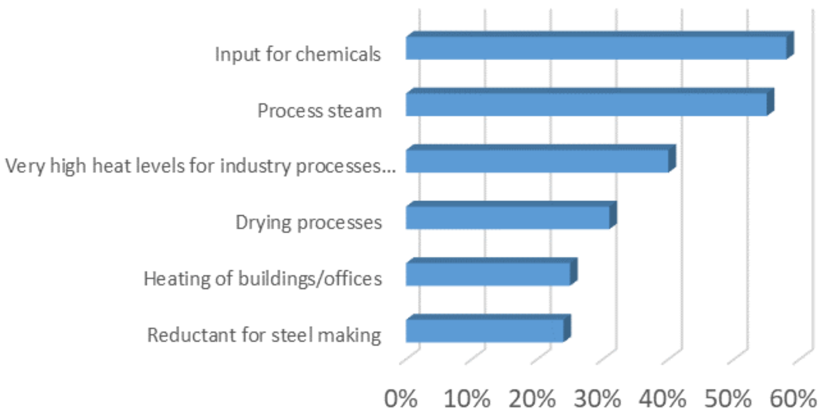

Figure 3: result of audience poll on most promising applications of biomass in industry (based on SLIDO poll, multiple selections possible – 113 participants answered).

3.1.3 Addressing barriers to high temperature biomass heat in industry: policy & market issues

Olle Olsson, Stockholm Environmental Institute (SEI), Sweden

Industrial heat represents one quarter of total global energy demand and more than 90% is based on fossil fuels. About half of industrial heat is required at high temperature (>400 °C).

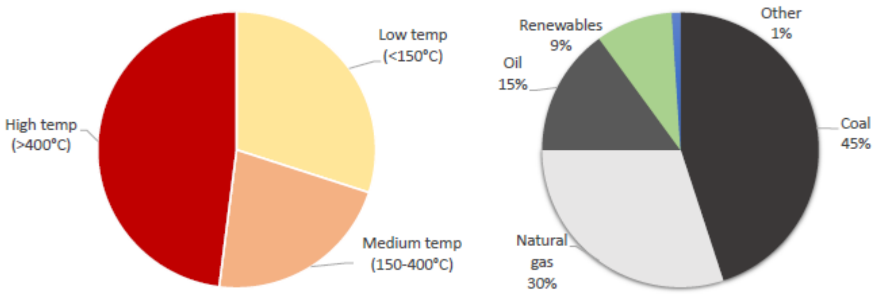

Figure 4: required temperature levels and current fuel mix for global industrial heat
(Source: IEA (2017): Renewable Energy for Industry)

It is important to remember that GHG emissions in industry are not only from fuel combustion, but are also linked to the industrial process itself, e.g. iron ore reduction in steel industries or limestone calcination in cement industries.

There are very diverse applications in industry, with varying needs in terms of temperature, the direct use of process heat, or indirect through a heat carrying medium (steam). Broadly speaking, options to reduce the climate impact of industries are efficiency measures, carbon capture and utilisation/storage (CCUS), the use of biomass and electrification (potentially via the hydrogen pathway).

Cost competitiveness of industries is key and they often operate in international markets. So putting high requirements on local industry can lead to carbon leakage if (part of) production is shifted abroad. In the absence of a global carbon price regime, other policy options will be needed, such as innovation support to induce technological shifts; public procurement of products with low life cycle emissions; ”Green clubs”; carbon border tax adjustment; carbon contracts for difference.

One should note that energy costs are not the only determining factor on sales prices, i.e. a 50% increase of energy cost may only result in a few % increase in product ‘sticker’ price. With increasing scale, costs of other technology options will also go down. There may also be a push from brand owners and OEMs towards lower life cycle emission products.

By mid-2021, IEA Bioenergy will publish a new report on ‘*Technology, markets and policy options for deployment of biomass for industrial heat*’, based on the lessons learned from a number of case studies (see presentation Koppejan).

3.1.4 Case studies of biomass providing medium to high temperature heat in industry

Jaap Koppejan, ProBiomass BV, the Netherlands

Traditionally, the application of bioenergy in industry was performed in industries that can use their own biomass process residues to cover (some of) their own heat demand, e.g. sugar, wood processing, pulp and paper. With the increasing motivation in industry to reduce their carbon footprint, several other industry sectors are also shifting towards biomass based heat generation in cases where there are suitable biomass resources and technologies available nearby.

Mr. Koppejan presented four real life case studies using biomass to provide process heat with different technologies[1], with the optimum configuration depending on local availability of biomass resources, characteristics of the heat demand, availability of space, capital, etc.

The cases are:

1. Combustion of low-grade biomass (wood chips and composting residues) for process steam generation in a potato processing industry.

2. Gasification of paper rejects to displace natural gas usage in a pulp and paper process.

3. Producing process steam in a dairy factory via fast pyrolysis bio-oil.

4. Converting waste to energy to produce steam for paper production.

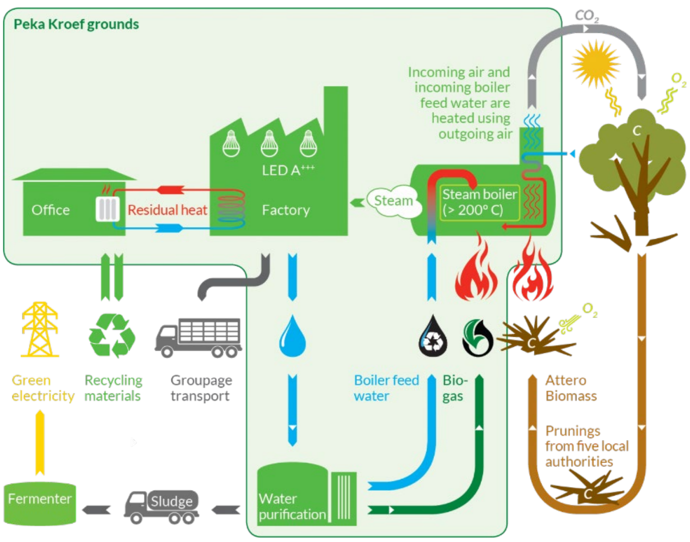

Figure 5: Schematic diagram of anticipated water and energy streams at PEKA Kroef, a potato processing company in the Netherlands. Process team is generated by a biomass fired boiler, operated by the waste processing company Attero. (source: PEKA Kroef)

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[1] The case study reports are available at: https://www.ieabioenergy.com/publications/new-publications-case-studies-illustrating-how-bioenergy-is-used-in-industry-to-provide-high-temperature-heat/

The general observations from the case studies are:

- Several fuel technology combinations are commercially available for producing biobased heat in industry, and there are many successful examples of biobased industrial heat.
- The potential is not limited to energy intensive industries (steel, cement etc); process industries also represent a large potential.
- In contrast to larger energy intensive industries which typically require that large volumes of biomass are shipped to an individual site, the heat demand in small and medium sized industries can often be better matched with the biomass resources that may be locally available.
- The optimal combination is very site specific and needs to be carefully assessed.

After this presentation a poll was taken among the audience: 'Which form of biomass do you think has most potential as a fuel for industrial heat?'
Participants indicated biogas/syngas and wood chips as the most promising biobased fuels for industrial heat.

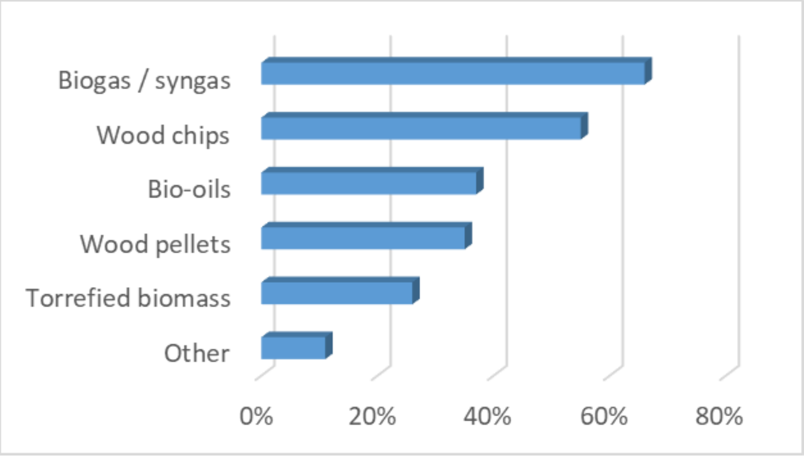


Figure 6: result of audience poll on most promising biobased fuels for industrial heat (based on SLIDO poll, multiple seletions allowed - 92 participants answered)

3.1.5 Nestlé France Biomass Boilers

Minh Hiep Nguyen, Nestlé France

Nestlé is one of the world's largest food & beverage companies. The company is committed to reach net zero emissions by 2050 for the full value chains.

Nestlé includes 22 factories in France, with the French branch being a reference for the whole Nestlé group in terms of emission reduction strategies. Compared to 2010, CO_2 emissions of Nestlé France have been reduced by 40%, through energy efficiency measures, the use of biomass boilers and on-site green electricity production / green power purchase agreements.

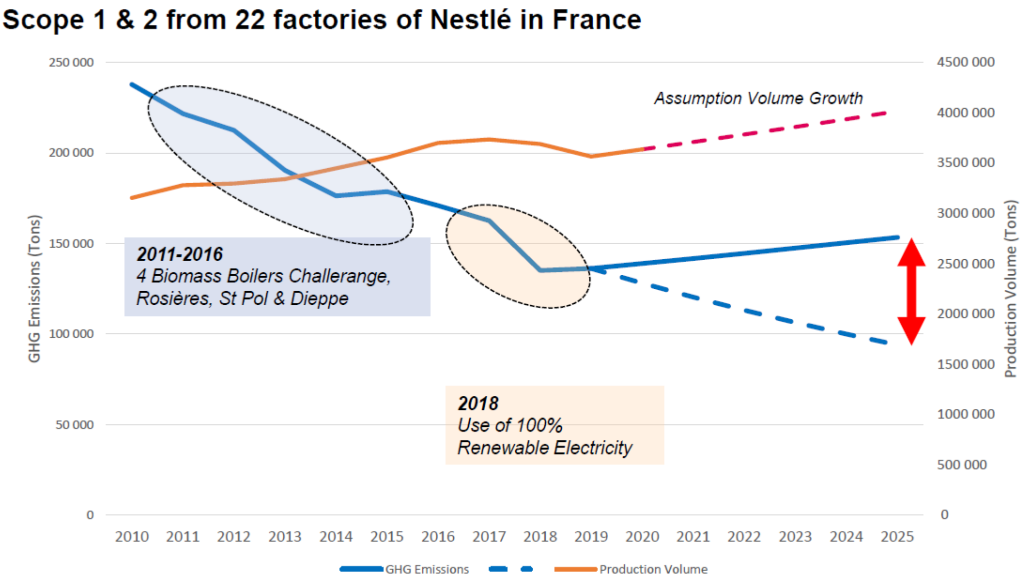


Figure 7: Reduction of Scope 1 and 2 GHG emissions of the Nestlé factories in France (source: Nestlé)

Currently four biomass boilers have been installed at Nestlé France (ranging from 5 to 22 MW), replacing heavy fuel oil boilers to provide process heat; four new biomass projects are planned for the coming five years. These projects receive financial support from ADEME, which is very helpful. Nevertheless, the biomass projects are not considered as 'payback projects', but are part of the general strategy of Nestlé to reach net zero carbon emissions, with full support of the top management.

3.1.6 Decarbonisation of whiskey production using circular economy bioenergy systems

Richard O'Shea, MAREI, Ireland

The need to reduce global GHG emissions may require the use of renewable gaseous fuels in the food and beverage industry to decarbonise processes that are difficult to electrify such as whiskey distillation. Large companies report their GHG emissions according to the Greenhouse Gas Protocol in terms of direct and indirect GHG emissions. Anaerobic digestion (AD) of distillery by-products can replace up to 64% of the natural gas consumption of the distillery and could reduce direct GHG emissions by 54% and deliver additional indirect GHG emission reductions (~41% of direct savings) if digestate replaces synthetic fertiliser used to cultivate barley consumed by the distillery.

On the other hand, a large part of the distillery by-products is currently used to produce animal feed (DDGS). The replacement of animal feed produced by the distillery with imported animal feed (e.g. distillers' grains from the USA and soybean meal from Argentina) could, in a worst-case scenario, negate a significant portion of direct and indirect GHG emission savings. The decision as to whether the GHG emissions associated with imported animal feed should be included in the calculation is not clear cut and can be subjective.

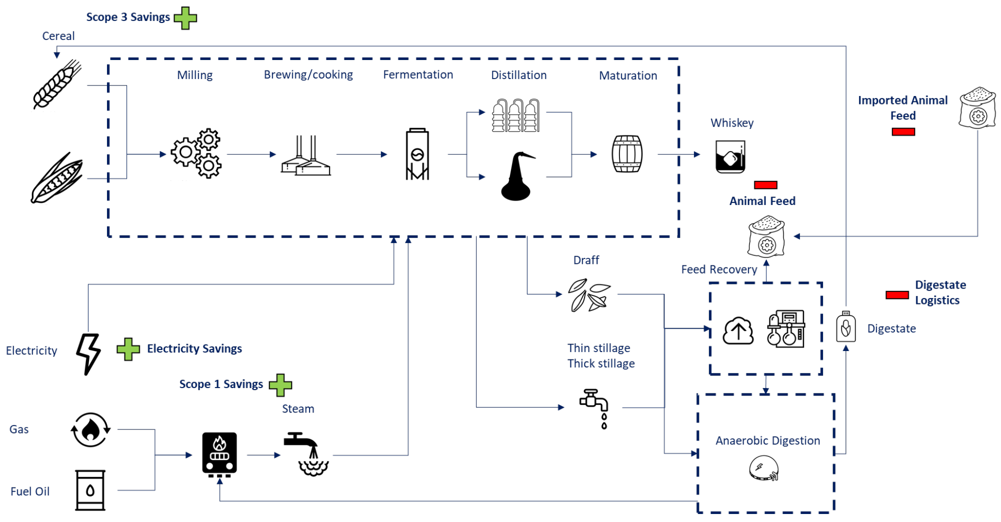


Figure 8: schematic overview of process and energy use (with positive and negative GHG impacts) when anaerobic digestion is integrated in whiskey production
(Source: MAREI)

Digestate management, particularly storage and transportation may pose a significant barrier to the implementation of an AD plant processing distillery by-products. Alternative methods of digestate transportation such as pipelines, and digestate treatment (separation, drying, and evaporation) should be assessed to mitigate logistical issues. To successfully integrate AD with a distillery, future research should conduct multi criteria decision analysis to identify the most suitable share of distillery by-products to use in an AD plant to balance positive and negative attributes of such projects.

3.1.7 Panel discussion

The panel session was moderated by Mark Brown; all speakers participated. The audience could also provide input to the central questions through SLIDO.

Overall, there was agreement about the promising role of biomass as a renewable fuel for industries.

Challenges for using biomass as a fuel for process heat:

- The main challenge mentioned is the **low cost of the fossil alternatives** (if carbon cost is not accounted for). This was also indicated by three quarters of the SLIDO respondents in a related poll. This is less an issue in industries that can use their own biobased residues, e.g. pulp & paper industries or food industries, but very important for industries that need to purchase biomass feedstocks, or set up new biomass supply chains.

- Another challenge is the **availability and access to biomass**. Again this is easier if companies can rely on their own process residues. Biomass resources are preferably available in the neighbourhood of the industry. With medium scale installations this can match with locally / regionally available resources. Nevertheless, all steps in the supply chains, involving collection, transportation, storage, pretreatment requirements (e.g. drying) have a cost related to them, which can increase the cost difference with low-cost fossil fuels.

- Potential **other uses of the biomass feedstock** also need to be taken into account, and it may require compromises between benefits and potential drawbacks. A clear benefit of medium scale biomass combustion (for industry or for district heating) compared to small scale combustion is that it is more straightforward to control the combustion process and install flue gas cleaning, thereby reaching much lower levels of exhaust gas emissions (*even to the level of natural gas*).

What is needed (in terms of policies, market conditions) to increase the role of sustainable biomass in medium scale industries?

- Incentives and support mechanisms were mentioned as a means to bridge the cost gap with fossil fuels, but overall it was felt that this can only be a temporary measure. A **meaningful carbon price** would be crucial. It is also important to recognize additional environmental services (not only renewable energy), e.g. reduction of waste, avoidance of methane emissions, …

- Countries can define ambitious targets and policies to reduce the carbon footprint of industries. **Demonstration projects** are extremely valuable, to learn by doing and also increase awareness of sustainable solutions in industry.

- **Industries** themselves of course have an important role, and can also set ambitious targets, thereby **thinking long-term**, i.e. in the frame of their transition to more sustainable production. Industrial symbiosis where companies exchange material and energy flows can lead to mutual benefits, both on cost and environmental effects.

- Setting up **biomass supply chains** can be facilitated, e.g. by providing regional hubs. There can be incentives for purpose grown biomass on abandoned or degraded land in the frame of revitalising rural areas. It remains important to apply sustainability criteria, but these should be applied no matter what the end use of biomass is (not only for energy).

3.2 SESSION 2: BIOMASS IN ENERGY INTENSIVE INDUSTRIES - STEEL & CEMENT SECTORS

The presentations were moderated by Daniela Thrän, DBFZ/UFZ, Germany.
Paul Bennett, SCION, New Zealand, moderated the panel discussion at the end of the session. An opening poll was conducted among the audience on when global steel and cement facilities should reach carbon neutrality. Overall, 86% of respondents indicated that these sectors should reach carbon neutrality at least by 2050.

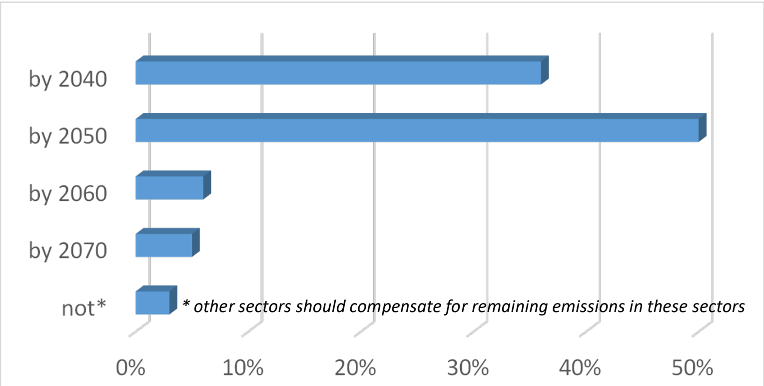


Figure 9: result of audience poll on when global steel and cement facilities should reach carbon neutrality (based on SLIDO poll – 64 participants answered)

3.2.1 Prospects for the use of biomass in steel industry

Juha Hakala, VTT, Finland

Steelmaking is a highly carbon-intensive process due to its extensive use of coal as both an energy source and a reductant. The direct CO_2 emissions of the Finnish ferrous industry exceed 4.1 million tonnes/a, accounting for almost 34% of total direct industry emissions in Finland. In crude steel production, over 70% of CO_2 emissions originate from the blast furnace (BF).

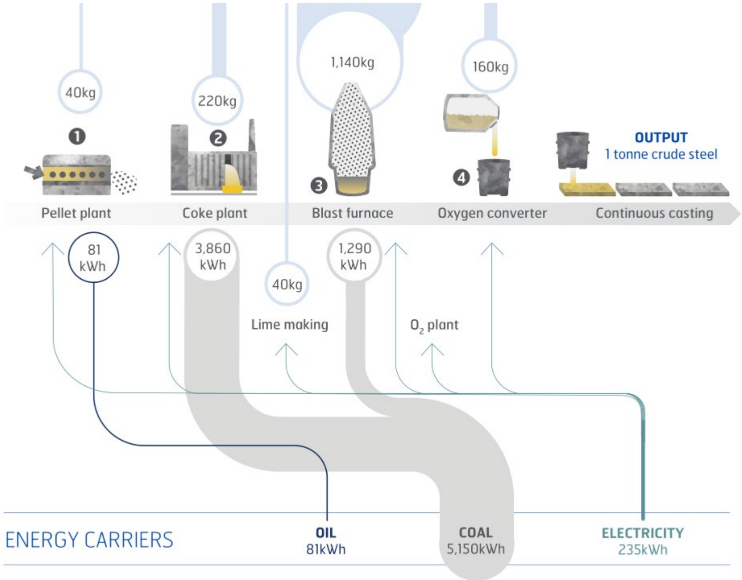


Figure 10: energy and GHG emissions in crude steel production[2]

Substitution of fossil carbon with biocarbon has been proposed to further reduce greenhouse gas (GHG) emissions associated with steel production. The first option is to use biocarbon as a substitute for the coal in the pulverized coal injection (PCI), which takes place through tuyeres in the lower part of the blast furnace. Slow pyrolysis is stated in literature as the most promising technology for upgrading biomass into a solid metallurgical reducer.

In a Finnish project 'Added Value from Forest Industry for Metals Producing and Processing Integrates' (FOR&MET, 2016-2019) side streams softwood bark from biorefineries, bark derived black pellets from steam explosion and residual hydrolysis lignin from sawdust-based bioethanol production were evaluated as raw material for PCI biocarbon. These evaluated side streams were considered applicable as sources for biocarbon for reduction processes with a sufficiently high carbon to oxygen ratio.

Approximately 20% (by weight) of PCI coal could be replaced with biocarbon in the blast furnace with existing technologies. Higher biocarbon shares may be possible via coal injection

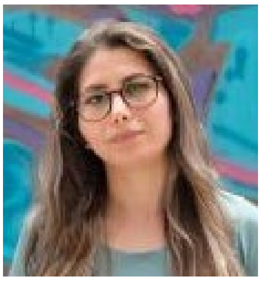
[2] HYBRIT. Summary of findings from HYBRIT Pre-Feasibility Study 2016–2017. 2017

system redesign (sizing of handling & pulverizing line, re-designing co-feed) and by optimization of detrimental elements.[3]

Various scenarios, including stand-alone production close to a steel mill and biorefinery integrated production of biocarbon, were further examined and techno-economic analysis of the use of biocarbon as a substitute for fossil PCI coal was carried out for each case. Clear benefits in production costs can be obtained by production integration, depending on the integration of the excess energy from pyrolysis and possibly available low-grade heat at the production site. It was concluded that the economy of biocarbon usage as a PCI substitute is becoming a viable option with rising CO_2 emission trading costs (reaching levels of 50-100 €/ton CO_2 in the 2030-2050 timeframe).

3.2.2 Alternative sustainable carbon sources as substitutes for metallurgical coal

Samane Maroufi, University of New South Wales, Australia



Each year over 1 billion tonnes of metallurgical coal (coking coal) is utilised to produce most of the 1.7 billion tonnes of steel produced worldwide.
Coking coal has several roles in steel making: thermal (source of energy), chemical (iron oxide reduction & providing carbon for the steel) and physical (influencing gas distribution & providing mechanical support). In that sense, prices for high quality metallurgical coal are about double the price of thermal coal.

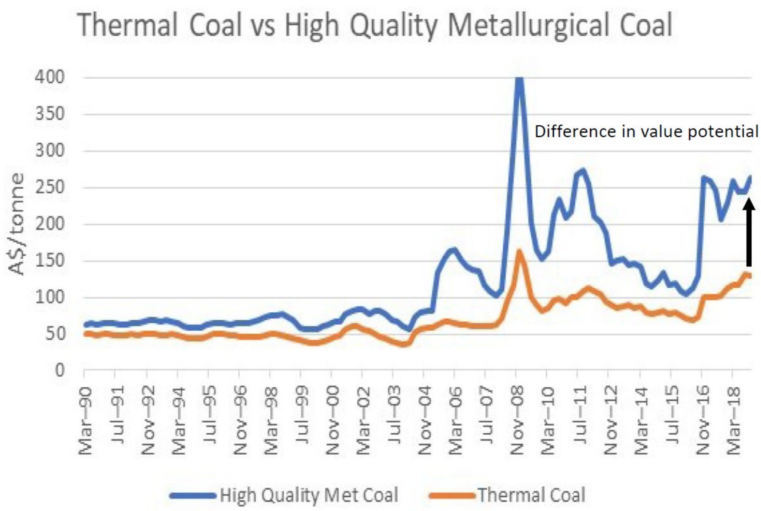


Figure 11: price difference between thermal coal and high quality metallurgical coal (in Australian dollar) (source of the data: Resources and Energy Quarterly – March 2019)

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[3] Hakala, J., Kangas†, P., Rintala, L., Fabritius, T., Koukkari, P. Biocarbon from bark or black pellets as an alternative for coal in steelmaking – technoeconomic evaluation. 2020. Scandinavian Journal of Forest Research. ISSN 1651-1891. doi.org/10.1080/02827581.2020.1843704

Steel industries are looking for opportunities to diversify away from coal as the cost of coking coal has been rising, high-quality coking coal is depleting at worldwide level, and environmental regulations regarding CO_2 emissions are tightening. More sustainable substitutes should not be associated with high costs, and should reduce the carbon footprint without seriously affecting process efficiency.

The Sustainable Materials Research a Technology group at the University of New South Wales (SMaRT@UNSW) tested different alternative carbon sources, including lignin residues from advanced bioethanol refineries.[4] The results from tests of the lignin showed that the impurities contained can be advantageous or at least tolerated by steel manufacturers. It was found that the lignin was also a suitable substitute at a range of temperatures with typical sponge iron product being produced.Overall, lignin could have great potential to reduce non-renewable coke consumption. Calculations suggest that if 10% of the world's gasoline demand were replaced with ethanol produced from lignocellulosic sources approximately 20% of fossil coke consumption could be replaced by renewable lignin. It could also significantly enhance the economics of lignocellulosic bioethanol production. Metallurgical coal typically trades at a premium to that of thermal coal. In replacing the relatively low value option of burning lignin in the lignocellulosic bioethanol refinery, the effective value of the lignin could be doubled if sold as a metallurgical coal replacement (ignoring any potential carbon credits).

3.2.3 Turning carbon emissions from blast furnace gas into bioethanol at ArcelorMittal Gent

Wim Van Der Stricht, ArcelorMittal, Belgium

ArcelorMittal is one of the leading global steel and mining companies, producing 90 million tonnes of crude steel in 2019. Steel is critically important in current and future society. As one of the only materials to be completely reusable and recyclable, it will play a critical role in building the circular economy of the future.

Steelmaking is responsible for 7% of global CO_2 emissions, so improving the environmental footprint of steelmaking is high on the agenda. The reduction of iron oxide (Fe_2O_3) with carbon sources leads to CO and CO_2 as co-products. The Steelanol project of ArcelorMittal in Ghent, Belgium, aims at (1) replacing fossil carbon by biobased carbon (from wood waste) as input in the blast furnace (BF), and (2) converting CO rich gases from the blast furnace into ethanol through gas fermentation (LanzaTech technology).

[4] Full report available at: https://www.ieabioenergy.com/publications/new-publication-alternative-sustainable-carbon-sources-as-substitutes-for-metallurgical-coal/

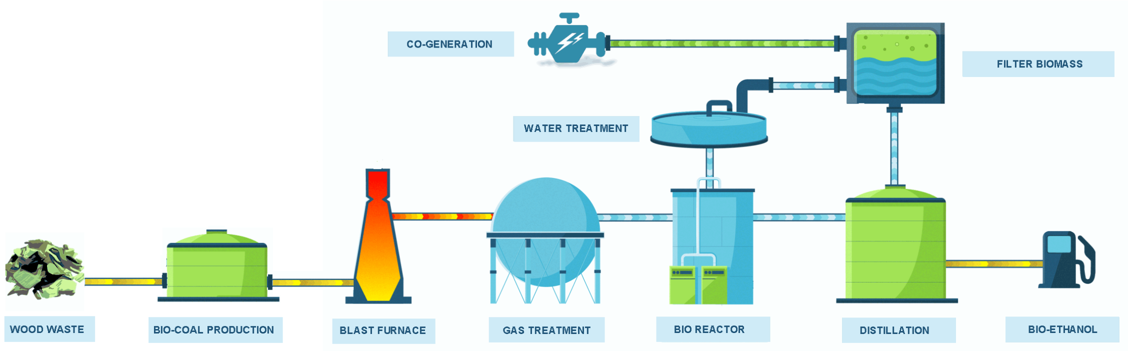


Figure 12: schematic overview of the Steelanol concept (source: ArcelorMittal)

The project in Ghent represents an investment of 165 Million euro, capable of producing 50 kton biocoal per year as input for the blast furnace (5-10% of powder coal input), and 65 kton per year ethanol from CO-rich blast furnace gases. The installation is expected to be in operation in 2022.

After this presentation a poll was taken among the audience on the most important co-benefits for industry to use biomass in metallurgical production. Four key benefits were indicated - each indicated by 30-40% of respondents - considering the different angles: internal decarbonisation targets, external requirements (ETS), fulfilling market demand, as well as opportunities to create additional value (utilisation of captured biobased carbon for chemicals/biofuels).

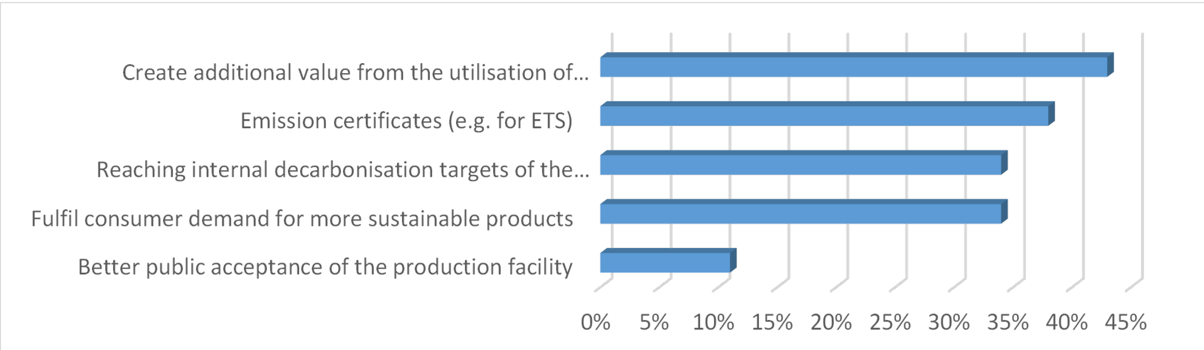


Figure 13: result of audience poll on the most important co-benefits for industry to use biomass in metallurgical production (based on SLIDO poll, multiple selections allowed – 53 participants answered)

3.2.4 The role of bioenergy in the decarbonization of the French cement industry

Elliot Mari, ADEME, France

Because of historical practices, the subject of bioenergy in the cement industry is closely related to the use of waste as substitution fuels. The sector has been processing different types of waste for a long time for its energy needs, some of which can contain a certain fraction of biogenic carbon.

Over the last 10 years, the share of fossil fuels in the thermal mix of the French cement portfolio has decreased by around 15% points. As part of its environmental commitments, the SFIC (French Cement Industry Association) aims to reach a substitution rate of 95% by 2050 of which 45% is composed of biogenic carbon.

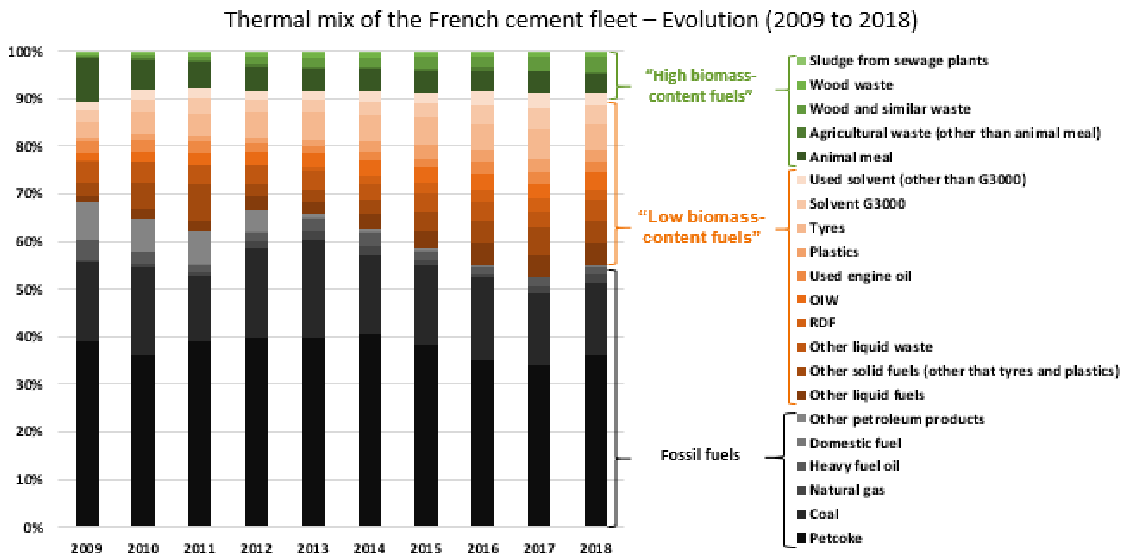


Figure 14: evolution of thermal fuel mix in French cement industries (source: ADEME)

The use of low biomass content waste fuels has been steadily increasing over the past 10 years in contrast to high biomass content fuels which have remained flat. Good quality biomass fuels tend to be less economical for the cement industry, as waste tends to come at zero or even negative cost. The cement production process has ideal features for processing all types of waste (even hazardous waste): high temperature (flame of 2000 C), long exposure and retention time in the kiln; most ashes and residues are recycled into the raw meal and incorporated into the clinker matrix.

Switching to substitution fuels can be part of the decarbonisation strategy of cement production, but will be far from enough. Energy related emissions represent only one third of the emissions from the cement industry, two third being related to the limestone calcination process. Moreover, most alternative 'waste' fuels still contain a high fraction of fossil carbon. CCS will be a crucial technology to reduce the climate impact of this sector.

3.2.5 Biomass gasification for industrial kilns

Vesa Helanti, Valmet, Finland

Valmet is the leading global developer and supplier of process technologies, automation and services for the pulp, paper and energy industries. Since 2007 Valmet developed almost 100 new boiler plants, with a total capacity of ~12,000 MW_{th}; 68 of these were for biomass, 12 for waste (RDF) and 26 multifuel. Valmet has also installed 8 gasification plants for waste and biomass, based on Circulating Fluidized Bed (CFB) technology.

At a modern pulp mill much of the internal energy is already provided by biobased process residues. The lime kiln is the only major consumer of fossil energy - at a large pulp mill the lime kiln can use over 200 tonnes per day of heavy fuel oil or an equivalent amount of natural gas. By gasification the oil can be replaced with tree bark and other residual biomasses, which is available in or around the mill, making it economically beneficial. Valmet has installed CFB gasifiers for lime kilns in different parts of the world (Finland, Indonesia, China, Brazil).

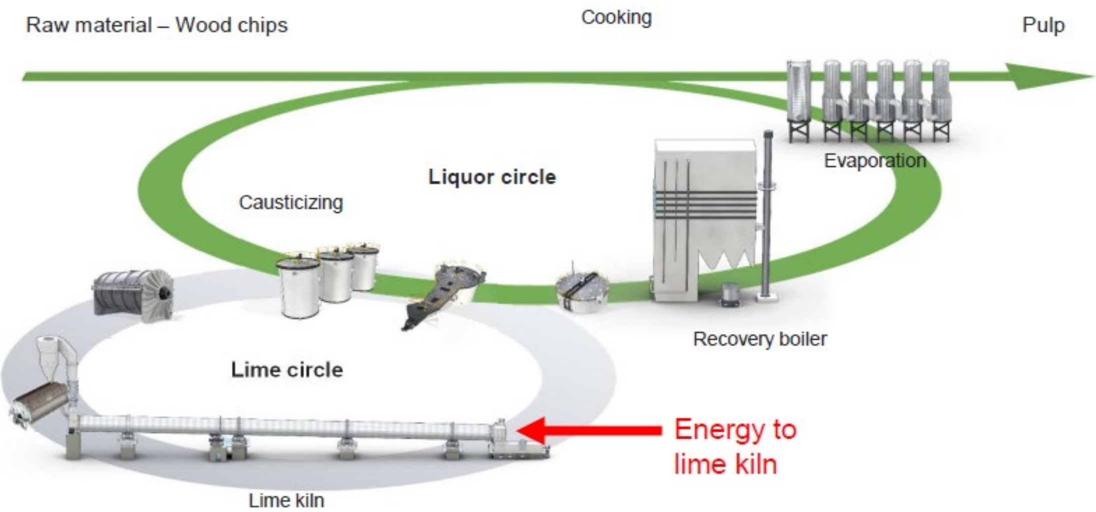


Figure 15: lime circle in the pulp production process (source: Valmet)

CFB gasifiers are suitable for biomass or sorted waste (SRF, RDF), preferably in continuous operation, providing hot product gas (not significantly pressurized) that can be used in industrial processes. Cement kilns are an obvious application to be explored.

3.2.6 Biomass in China industry

Dou Kejun, China National Renewable Energy Centre (CNREC)

At present, green and low-carbon development has become a global consensus. On 22 September 2020, in a statement to the United Nations General Assembly, President Xi Jinping stated that China aims to peak CO_2 emissions by 2030 and to reach carbon neutrality by 2060. That means that clean energy - including bioenergy - will play an increasing role in China's efforts to reduce greenhouse gas emissions.

Bioenergy currently only covers 1.2% of the total energy demand.

Industrial boilers have a total capacity of 3500 GW in China, of which 85% are coal boilers, 14% oil firing boilers and only 1% biomass & heat recovery boilers. The potential of biomass in China is estimated at around 460 million tons of standard coal equivalent (tce) (= 13.5 EJ), but only 57 million tce (=1.7 EJ) are currently used, so there is considerable opportunity to expand the use of biomass.

China produced about 1 billion tons of crude steel in 2019, representing 53% of global steel production. Carbon emissions of the steel sector will account for about 14% of China's total carbon emissions. Biomass as an alternative fuel has not been used in large-scale steel production, but small and medium-sized steel plants started using biomass as an alternative fuel as early as 10 years ago.

In addition, there are successful cases of biomass application in industrial production, such as gasification of plant residues to produce steam in a traditional Chinese medicine factory; steam production and biochar production from bamboo chips gasification; or replacing heavy oil in aluminium smelters and the paper industry.

Figure 16: Bamboo sawdust gasification plant (32,000 ton/a input capacity) in Anji, Zhejiang province

The total biomass energy utilization is expected to account for about 8% of the total energy consumption in 2050. The requirement for energy conservation and emission reductions in the industrial sector provides a huge market opportunity for bioenergy.

However, there are still challenges, for instance:

- The promotion of bioenergy in the industrial field needs to be initiated and awareness of the authorities on the role of bioenergy should be strengthened.
- The cost of new biomass products is still high in the near and medium term. The economic competitiveness of bioenergy should be improved, thereby considering the optimal scale and technical path, and identifying effective alternative models for biomass under economic scales.
- Assessment of biomass availability and effective collection strategies of raw material are critical. Matching economic scales of biomass supply and demand (e.g. biomass heating projects) is to be considered.
- China should actively explore opportunities to combine bioenergy with carbon capture and utilisation/storage (BECCUS) for their contribution to achieve carbon neutral goals, and strengthen international cooperation.

3.2.7 Panel discussion

The panel session was moderated by Paul Bennett; all speakers participated. The audience could also provide input to the central questions through SLIDO.

Challenges for using biomass in large industries:
As in the previous session, the **low cost of fossil fuels** (if no carbon cost is accounted for)

compared to biomass cost levels was identified as a major challenge. The forest industry is a possible substantial source of biomass at the regional level. However, size of consumption in large energy intensive industries can be a bottleneck and **access to biomass** is one of the biggest issues. For its installation in Belgium, ArcelorMittal already needs 100kt of waste wood per year to replace around 5% of its coal input. Local biomass resources might not be enough if mobilized, so global supply chains - with related sustainability credentials - may be needed. More difficult biomass types (e.g. agricultural residues) will need to be considered, including some pre-processing to suit process requirements. Biomass and/or waste can't replace all fossil input in energy intensive industries, so combinations with other solutions (e.g. electrification, hydrogen) will be needed to further reduce the carbon footprint in these sectors.

A poll of the audience on the factors that influence a decision to change from fossil fuels to biomass also indicated access to biomass as the main factor, next to the political framework in the country.

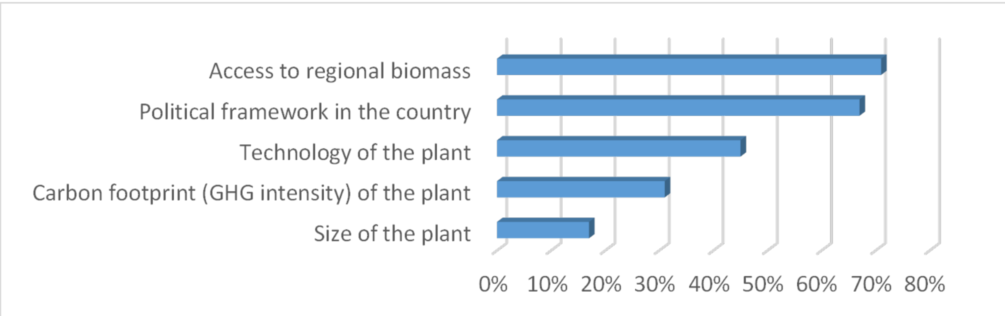


Figure 17: result of audience poll on the factors that influence a decision to change from fossil fuels to biomass (based on SLIDO poll, multiple selections allowed – 42 participants answered)

What is needed (in terms of policies, market conditions) to realize a decarbonisation of energy-intensive industries?

- A correct and global **price on fossil CO_2** would be needed, preferably at the global level. Industries need viable business models, and several are also operating in global markets, so they are sensitive to operational cost increases, even if the impact on final production cost may be relatively limited.

- Depending on different stages of development, corresponding **policies** should be formulated. Issues such as RD&D support for technology innovation, tax incentives, quotas, legal status clarity, encouraging substitution or encouraging technology upgrading should be considered. A high share of steel and cement production is located in emerging economies, where technologies may be less advanced. These need international cooperation and dedicated support/incentives to lower their carbon footprint.

- Industries need to take a **long term perspective** and have real engagement with social and environmental issues. Cement sectors need to look beyond zero cost wastes (which in the end are also limited), e.g. mixing biomass with waste resources.

3.3 SESSION 3: BIOMASS IN CHEMICAL/PROCESS INDUSTRIES

The presentations were moderated by Kees Kwant, Netherlands Enterprise Agency.
Ed de Jong, Avantium, the Netherlands, moderated the panel discussion at the end of the session.

An opening poll was taken among the audience on their willingness to pay more for biobased products (that have the same functionality as fossil based products). More than 85% of participants indicated that they were willing to pay more, with a large group willing to accept even up to 20% extra. However, participants to this workshop can't be considered as a representative sample of the general public, as they are motivated to follow this topic. So in reality willingness to pay extra will likely be a bit lower in society. This was also acknowledged by several of the speakers.

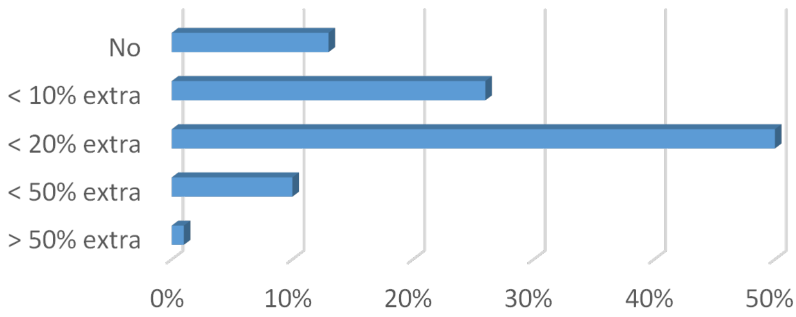


Figure 18: result of audience poll on the willingness to pay more for biobased products (based on SLIDO poll – 86 participants answered)

3.3.1 Valorization of biomass by chemistry

Stéphane Ledoux, AllEnvi, France

AllEnvi is a national alliance of environmental research organisations in France. Some of the questions addressed in AllEnvi are on the potential, prospects and limitations of chemistry from biomass.

From an industrial point of view, biomass has complex characteristics, in terms of cost, availability, variability and specificity, making it difficult to consider it as a real commodity. Secondary factors are sustainability and potential conflicts of use (resources and land).
The production of biomass in agriculture and forestry is well established, with well-balanced sectors, and available surpluses in France are rare. Emerging uses must be carefully integrated into existing sectors, with food production having higher priority.

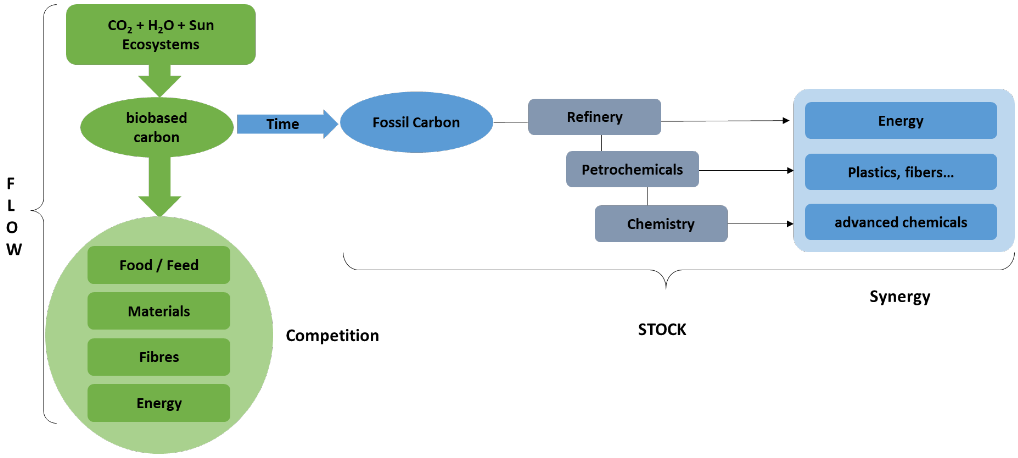


Figure 19: Flows vs Stocks for biobased vs fossil resources (source: AllEnvi)

In terms of organisation, biobased resources are different from fossil resources as they represent a continuous 'flow' (*limited by what is grown every season*), while fossil resources represent a 'stock' (*more available if needed, only depletable in the longer term*). At the moment fossil resources are more managed in synergy through refining processes, while the concept of biorefining is less developed for biobased resources, which leads to more competition between different applications.

While the common practice in industries is to balance technical and economic requirements (within environmental rules), new business models using biobased resources need to include sustainability requirements on feedstock sourcing in this balance. This makes the performance balance more complicated for industries.

Requirements for the emergence of a biobased chemistry can be summarized as follows:

- a new organic chemistry to transform/purify biobased compounds to desired products;
- usable and targeted feedstocks (available, sustainable and room for stable procurement);
- carefully targeted application markets;
- a multisectoral integration strategy, with a proper balance between food/feed, materials, fibres and energy.

3.3.2 Green Hydrogen Hub of Europe

Cas König, Groningen Seaports

Groningen Seaports combines two seaports in the North of the Netherlands, in Delfzijl and Eemshaven. Approximately 160 companies are settled in Eemshaven/Delfzijl. Delfzijl has a large chemical cluster, with 26 companies participating in 'Chemport Europe', an innovative ecosystem for green chemistry in Northern Netherlands. The Chemical Cluster Delfzijl specifically targets growth in circular economy and biobased chemicals. A consortium of Gasunie, Groningen Seaports and Shell Netherlands has launched the ambitious $NorthH_2$ green hydrogen project. $NorthH_2$ will represent one single integrated chain in which renewable power generated by offshore wind farms is used for large-scale green hydrogen production, transmission, storage and supply. It will supply large quantities of green hydrogen to industry in the Netherlands and Northwest Europe, reducing carbon emissions by some 7 megatons per year.

Green hydrogen will be supplied through a distribution network to the chemical companies in the seaports, which can use it to reduce the carbon footprint of their processes. This includes several biobased companies, such as BioMCN (biomethanol producer), SkyNRG (building a biokerosene plant) and Avantium (building a biorefinery based on glucose and lignin from non-food biomass).

Figure 20: Hydrogen Backbone in Delfzijl (source: Groningen Seaports)

3.3.3 UPM Biofore – Beyond fossils: Pulp & paper industries moving to biobased chemicals

Michael Duetsch, UPM, Germany

UPM is a leading player in forest based industries, traditionally focusing on pulp and paper production, but lately broadening its focus towards biofuels and biochemicals. The word 'Biofore' means the integration of biobased and forest industries into a new, future-oriented industry category characterised by efficiency, innovation and sustainability.

UPM follows strict principles in all forestry and wood sourcing operations, processing 27 million m³ wood annually. The forest industry creates an economic incentive for forest growth and sustainable forest management, leading to higher carbon storage in forests and materials.

A new growth era for UPM is creating new business in wood-based biochemicals. UPM develops an industrial scale biorefinery with annual output capacity of 220,000 tonnes in

Leuna, Germany, representing a 550 million Euro investment. The biorefinery is scheduled to be in operation in 2022. The technology will convert wood to drop-in and unique performance biochemicals such as bio-MEG (bio-monoethylene glycol) and bio-MPG (bio-monopropylene glycol), which are ready to be converted into various industrial products and everyday consumer goods such as PET-bottles, packaging, textiles, pharma, de-icing fluids, composites or detergents. The global MEG market is more than 30 million tonnes, currently based on non-renewable raw materials.

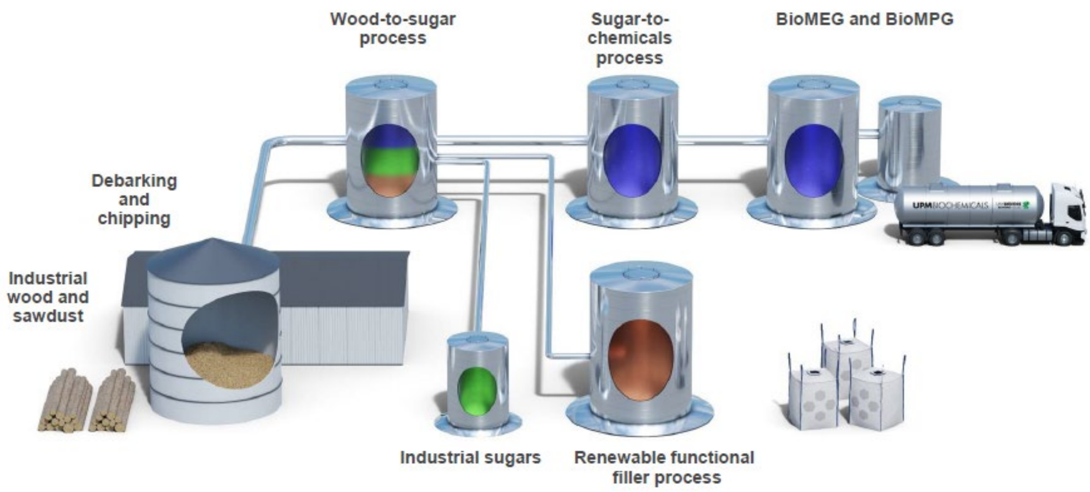


Figure 21: schematic process overview of the UPM biorefinery in Leuna, Germany (source: UPM)

3.3.4 Renewable acrylonitrile for carbon fibre production

Amit Goyal, Southern Research, United States

The presentation provided a case for converting biomass into a chemical at relatively small scale. Acrylonitrile (ACN) is a commodity petrochemical used notably in the production of acrylic fibre, acrylonitrile butadiene styrene (ABS), styrene-acrylonitrile resin (SAN), acrylamide and carbon fibres, of which markets are consistently growing. ACN is currently manufactured via ammoxidation of propylene. It has a global production of 6.9 million tonnes per year, and is produced in only 26 plants around the world. A typical carbon fibre line produces 1 kton per year, with a single line requiring 2.2 to 2.5 ktons of ACN. A 5 ktons per year ACN plant can supply 2 carbon fibre lines – most plants operate at this capacity at a single location. This implies rather low capex for first of a kind plants. In terms of feedstock it would require only around 100 tonnes of biomass per day. The majority of end users of ACN (not only carbon fibres) require small quantities per year (5 to 20 ktons). Currently it is sourced via rail cars from propylene ammoxidation plants located near gas terminals or petrochemical complexes, requiring long haul transportation of this class IV hazardous material, increasing costs and concerns for safety.

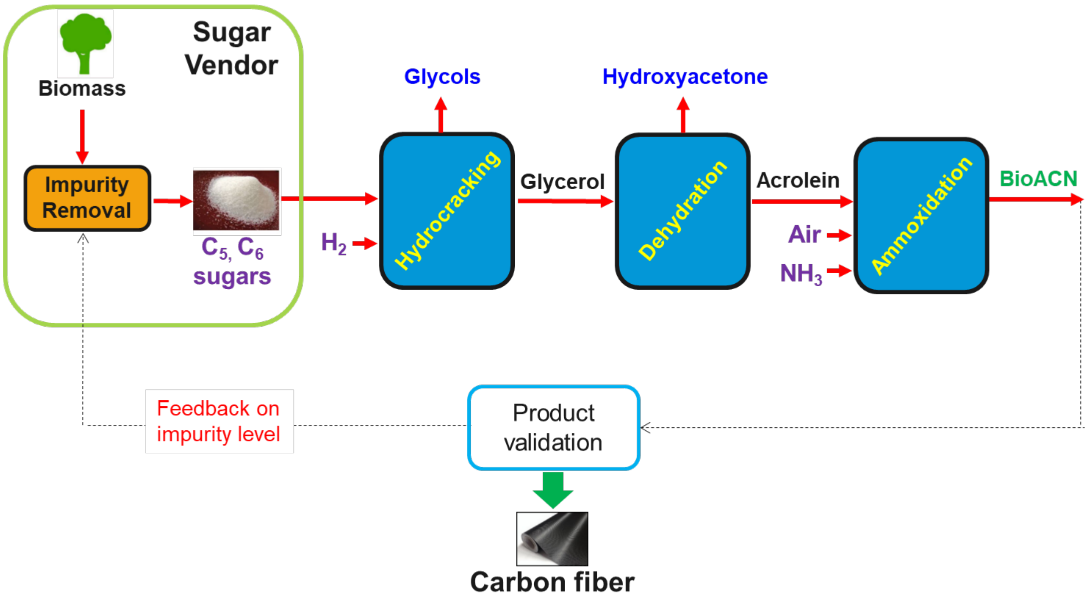


Figure 22: Acrylonitrile production process from biomass (source: Southern Research)

As an alternative feedstock, lignocellulosic biomass is rather low cost, ubiquitous and renewable, providing an opportunity to produce locally to meet small user demand. This motivated Southern Research (SR) to develop a novel, thermo-catalytic biomass to acrylonitrile (B2ACN) process. Briefly, B2ACN consists of three steps starting from C5/C6 sugars: (i) hydrocracking, (ii) dehydration and (iii) ammoxidation. SR has completed the development and testing of novel, high performance catalysts for each step at laboratory and tested at pilot scales.

Techno-economic and life cycle assessment highlights compelling cost (1.2-1.5 $/kg) and environmental benefits (95% GHG reduction) of small-to-moderate scale ACN production (5 - 25 ktons/year). Critical performance attributes of produced bio-ACN were compared successfully with the petroleum derived counterpart for readiness of use in carbon fibres, a key emerging application market of ACN.

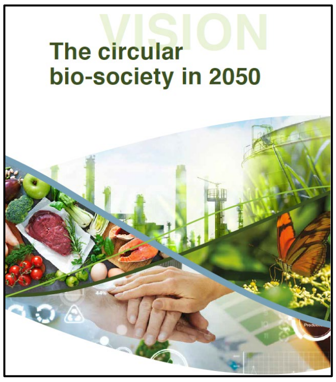
3.3.5 Towards the circular bio-society in 2050

Nelo Emerencia, Biobased Industries Consortium, Belgium

The Biobased Industries Consortium (BIC) is a non-profit organisation representing the private sector in a Public-Private Partnership (PPP) with the European Commission to support biobased research and innovation activities. BIC has over 240 industry members (large enterprises, SMEs and SMEs in clusters), as well as over 200 associate members, i.e. universities, research organisations, associations, etc. Represented sectors are agriculture, food & feed; aquaculture and marine; chemicals and materials; forestry and pulp & paper; market actors; technology providers; waste management & treatment. Recently there is expansion towards East Europe, considering the enormous potential in these regions.

The bio-based industry is at the heart of the circular bio-based economy, making bio-based products for application in all market segments, designing processes, products, services and

business models on 'circularity', and targeting 'zero-emissions' operations, thereby contributing to Europe's goal of climate-neutrality by 2050.
The sector's vision is 'the circular bio-society in 2050'. This vision will also serve as the framework for the development of a Strategic Research and Innovation Agenda (SIRA) for a public-private partnership on bio-based solutions 'Circular Bio-based Europe' (CBE) under Horizon Europe (2021-2027). The SIRA includes 4 pillars:



- integrate feedstock suppliers to foster food security and enhance biodiversity;
- accelerate commercialisation of innovative processing to create jobs and growth;
- integrate demand for biobased solutions to realize a climate-neutral circular economy;
- engage consumers and citizens to achieve a circular bioeconomic society.

The strongest drivers for these developments are (1) industries and (2) regions aiming for additional employment.

3.3.6 Panel discussion

The panel session was moderated by Ed de Jong; all speakers participated. The audience could also provide input to the central questions through SLIDO.

Challenges for biobased production in chemicals industries:

- Chemical industries are very cost driven. The **difference between costs of biobased and fossil resources** is a challenge, certainly in periods when fossil prices are at record low levels (without accounting for carbon costs). The chemical industry is not against the use of biomass, if it makes economic sense. However, compensation mechanisms / premiums for products with lower carbon footprint are currently limited. The 20% premium as indicated in the poll of the workshop participants was considered to be very optimistic.
- It was stated that **entering in established markets** of fossil-based chemicals is like jumping on a moving train, where it is expected that high product quality, production at scale and competitiveness are reached immediately. It is not easy for a young, developing industry to enter these markets. Cooperation with existing chemical industries is necessary to accelerate developments. For the production of unique high performance molecules, taking advantage of specific properties of biobased molecules, drivers may be different.
- Chemistry sectors are used to relatively clean predefined resources, with most production based on fossil resources. 15% of chemicals production worldwide is currently already biobased, mostly based on vegetable oils and starch. The sector is not used to handle solid biomass, with **varying feedstock quality**.
- Access to biomass needs to be secured and biomass **supply chains and biomass sourcing** have to be co-developed, a topic that is rather unfamiliar for several chemical industries. Initiatives of forest based industries (like UPM) to produce

biobased chemicals is an interesting development, as they have long experience in biomass feedstock supply.

- Biobased products tend to have better environmental performance than fossil-based chemicals, but this is not by definition. Good **LCA-based credentials** will be needed, as well as sustainability requirements related to the sustainable production of biomass to build consumer trust.

A poll related to this central question was earlier taken among the workshop audience (between the presentations). Access to biomass (related to its dispersed availability) and its sustainable production were indicated as the main challenges, next to feedstock quality, process complexity and resource cost.

What is needed (in terms of policies, market conditions) to realize markets for biobased chemicals/products?

- The true cost of non-renewable fossil based feedstocks needs to be reflected via a **carbon tax** or equivalent. In a related poll of the audience, more than 80% of the respondents indicated the need to have a carbon tax on fossil resources.

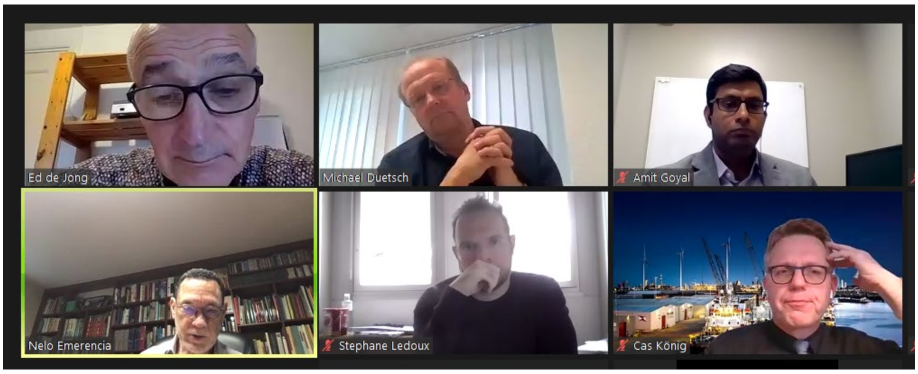
- **Support for demonstrations** and first of a kind installations, as well as **de-risking** of investments is also needed to reach commercial level, i.e. to bridge the valley of death.

- **Stable policies** are important, as well as the removal of hindering regulations for these new applications (e.g. restrictions for transport and processing of waste). Overall there are options for governments to steer markets such as market access restrictions for fossil based materials or mandatory green purchasing requirements (e.g. BioPreferred programme in the US.)

- The chemistry sector needs to develop its own **long term decarbonisation strategies**, in line with initiatives like the European Green Deal. They should be aware of the biobased opportunities, and its challenges.

- (limited) premiums can be acceptable for end use markets. However, it is important to develop strong and credible green labels to create trust with consumers.

- Brand owners can also create a **market pull**, by requiring inputs with low carbon footprint to reduce their own carbon footprint.



Speakers participating in the panel discussion of Session 3

3.4 CLOSING REMARKS

Luc Pelkmans, Technical Coordinator of IEA Bioenergy, provided a short summary of the conclusions of the three workshop sessions and thanked all speakers and participants for their active contributions.

4. Acknowledgements

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

IEA Bioenergy

Technology Collaboration Programme