IEA Bioenergy
Technology Collaboration Programme

Technology advances in liquid biofuels and renewable gas

Summary and conclusions from the IEA Bioenergy Workshop, Vienna, 17 October 2022

Workshop organized by IEA Bioenergy, in collaboration with the Austrian Ministry BMK* and BEST**

*Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology

**Bioenergy and Sustainable Technologies GmbH

Technology advances in liquid biofuels and renewable gas

Summary and conclusions from the IEA Bioenergy Workshop, Vienna, 17 October 2022

Published by IEA Bioenergy

IEA Bioenergy: ExCo: 2023: 01

Index

Key messages from the workshop

- Both climate change and energy security are major reasons to urgently move away from fossil fuels such as oil and gas. This requires a combination of energy conservation, energy efficiency, electrification and shifting applications to renewable fuels – there is no silver bullet.
- Renewable liquid transport fuels will need to have an increasing role in the transport system and the role of renewable gases will need to increase in the gas distribution system. In both cases bioenergy plays a vital role. The current push on biomethane at (European) policy level also helps further developments.
- Biomethane can be used without changing (natural) gas transmission/distribution infrastructure or end user equipment so it provides a renewable solution that is immediately applicable.
- Biogas sectors are starting to focus more on upgrading to biomethane which can be fed into the gas grid or used decentral as natural gas substitute. The upgrading also facilitates capture and use of biogenic CO_2 from the biogas.
- Gasification pathways are also promising to deliver biomethane (SNG) which can be fed into the grid to replace fossil gas. Technologies have been proven and are ready to take the next step to commercial scale projects.
- Accelerating the deployment of renewable gas requires solid planning and strategies, a stable and supportive policy framework, the removal of unnecessary barriers, easy market access, the possibility to trade products cross border, the unlocking of sustainable feedstocks and the recognition of the multifunctionality of biogas/biomethane systems.
- Thermochemical and biochemical routes to produce advanced liquid biofuels are entering the market, with new projects coming online and further deployment expected in the coming years. While most current projects and technologies still focus on road biofuels, developments increasingly focus on sustainable aviation fuels.
- Policy development is essential for the deployment of biofuels. Financing is the most critical factor, and the largest risk for investors is the political risk of changing policies, considering that investments need to have a 15-to-20-year time perspective.
- Different industries that process biomass are turning into biorefineries, creating a variety of products, together contributing to the overall business case, and avoiding wastes in the process. Biofuels/bioenergy are an inherent part of these systems. Circularity of carbon and nutrients is a common goal in all these projects.
- Biorefining to multiple products is a central principle in all biobased developments.

Executive summary

Luc Pelkmans, Technical Coordinator, IEA Bioenergy

The IEA Technology Collaboration Programme on Bioenergy (IEA Bioenergy) held its biannual workshop on 17 October 2022 in Vienna, in conjunction with its Executive Committee meeting (ExCo90). The workshop on ‘Technology advances in liquid biofuels and renewable gas’ was in hybrid form, with a mix of physical and remote presentations and was organised in collaboration with the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) and BEST - Bioenergy and Sustainable Technologies GmbH.

After an introduction session, the workshop consisted of three parts:

1. advances in renewable gas / biomethane,
2. advances in liquid biofuels,
3. related developments in Austria.

The workshop had around one hundred physical participants in Vienna. More than 150 people followed the workshop online. The PowerPoint presentations and recordings are available for downloading from IEA Bioenergy’s website[1].

Urgency to move away from fossil fuels

Climate change is accelerating and already creating extreme weather events. Moreover, high energy prices around the world are impacting people’s lives because of the disruptions in fossil fuel trade created by the war in Ukraine. Both climate change and energy security are major reasons to urgently move away from fossil fuels such as oil and gas. Energy savings and renewable energy are the key tools to achieve that. Renewable transport fuels and renewable gases will need to have an increasing role in the transport system and the gas distribution system respectively, with bioenergy playing a vital role. Meanwhile, increasing prices for oil and gas have totally changed the picture and prospects of renewable fuels compared to one or two years ago. In many parts of the world - and particularly in the EU - there is growing emphasis on climate ambitions and energy security, with increased ambitions on biomethane and liquid biofuels.

[1] https://www.ieabioenergy.com/blog/publications/ws28-technology-advances-in-liquid-biofuels-and-renewable-gas/

Renewable gas

Renewable gases will be key components of a global energy system aiming at net zero greenhouse gas emissions by 2050. With global fossil gas demand decreasing in emission reduction scenarios, and new demand emerging from transport sectors and industry, biomethane (CH_4) and hydrogen (H_2) will be most critical, with biomethane as the largest renewable contributor in gas grids, as it can be used without changing gas transmission/distribution infrastructure or end user equipment.

Technical presentations in the renewable gas session of the workshop focused on new developments related to biomethane. The current focus on biomethane at (European) policy level also helps further developments.

- Biogas technologies based on anaerobic digestion (AD) are mature. In terms of technology advance, much is happening in terms of upgrading to biomethane. This also facilitates the use of biogenic CO_2 from the biogas, either to boost the production of biomethane (with input of hydrogen), either to capture the CO_2 for other utilisations.
- Biomass and waste gasification pathways are gaining traction, with increased focus on syngas conversion to fuels or chemicals. The gasification pathway is also promising to deliver biomethane (SNG) which can be fed into the grid to replace fossil gas. Technologies have been proven and are ready to take the next step to commercial scale projects, particularly now it becomes clear that (fossil) gas prices will remain at elevated levels compared to pre-2021 levels.
- The use of low quality and waste feedstocks – facilitated by dedicated pre-treatment – also opens a much broader feedstock base. The carbon from these waste streams can be used for other processes to produce renewable gases, advanced biofuels, chemicals, and other products.

Deployment of renewable gases

Moving away from fossil gas requires a combination of energy conservation, energy efficiency, electrification and shifting gas applications to renewable gas. Moreover, new renewable gas demands will emerge, for instance in steel production. There is no silver bullet for all energy applications; it is important to diversify energy sources. In the next 10-20-30 years there will be a push for all solutions that can move us away from our fossil fuel addiction. We should also consider that there are regional differences, with some regions moving faster than others, or putting a different focus depending on the resources/local options they have.
Considering that there are limits to biomass/biomethane potentials, we need to be selective and - particularly at the medium term - aim the application of biomass at sectors that have limited other options, also considering where hydrogen comes in.

Actions to accelerate deployment can be structured in the following areas:

(1) *Planning & strategies*: biomethane targets should be anchored in legislation, making sure that there are solid trajectories and milestones to achieve the target. Strategies need to include the consideration of available substrates and development costs, defined development targets and consideration of needed infrastructure.

(2) *Policy framework & finance*: It is crucial to have long term perspectives and security for commercial scale investments. Dedicated and innovative finance instruments can mitigate investment risks. Gas prices are now more favourable for renewable gases; however, we cannot predict fossil gas prices after the current energy crisis. So there need to be mechanisms to monetize CO_2 emissions and put mandates on gas markets to create stable conditions for investments.

(3) *Market*: easy market access is to be ensured. This implies dismantling of unnecessary burdens and inhibiting regulations on technical and regulatory level, e.g., regarding accessibility to the gas grid. It is crucial to connect producers and customers of renewable gas – also cross border -, particularly through renewable gas certificates. This is comparable to what happens for renewable power delivery.

(4) *Sustainable feedstocks*: there is a wide variety of potential feedstocks and untapped resources for biomethane, also considering competition of uses and feedstock sustainability. Next to the municipal and industrial waste sector, it is important to continue working with the agricultural world to mobilize manure and residues such as straw and anticipate for changes in farming in the coming decades, including sequential crop models.

(5) *Recognize externalities*: the multifunctionality of biogas/biomethane systems should be recognized. Next to tackling certain waste and emission issues, co-products from the conversion processes in the biomethane value chain (digestate as organic fertiliser, CO2) are important to consider.

Advanced liquid biofuels

While electrification is accelerating for road vehicles in several countries, biofuels provide a means to replace fossil fuels from the legacy fleet, which is still predominantly reliant on liquid fuels. In the medium to long term the focus of biofuels is expected to move to hard-to-abate transport sectors such as aviation and shipping. A strong growth in so-called 'advanced biofuel technologies' will be required, starting from a variety of feedstocks, particularly underutilised heterogeneous biomass resources.

Technical presentations in the biofuels session of the workshop focused on new developments and market entries of advanced biofuels based on lignocellulosic biomass and wastes. Three types of advanced biofuel technologies were in focus:

- *Fermentation to advanced ethanol* is currently being rolled out at commercial scale. Examples were highlighted for Europe and India. These technologies provide versatile platforms to use ethanol as feedstock for various applications, from sustainable aviation fuels (SAF) to biobased chemicals. Further focus in these processes is on yield improvements and the valorisation of by-products, such as vinasse (as fertiliser), high concentration CO2, or lignin.
- Projects involving *gasification and further synthesis to biofuel* (methanol, Fischer-Tropsch fuels) are also being deployed at commercial scale, with some flagship projects in the US. Concrete new projects in France and the Netherlands were highlighted in the workshop.
- *Hydrothermal liquefaction to biocrude* is a pre-commercial technology but taking concrete steps to commercialisation. The biocrude can be processed in refineries, where it can be converted to fuels and chemicals.

While many current projects and technologies still focus on road biofuels, the interest in production sustainable aviation fuel (SAF) is clearly growing, driven by policy developments and long-term sector commitments.

Deployment of advanced biofuels

The main challenges for advanced biofuels are:
(1) the high production costs compared to their fossil alternative,
(2) scattered and time dependent raw material,
(3) requirements for further process optimisation, and
(4) valorisation of by-products.

Policy development is essential for the deployment of biofuels. Financing is the most critical factor, and the largest risk for investors is the political risk of changing policies. Investments need to have a 15 to 20 years perspective, so a stable, long term regulatory framework is key for securing progress. Harmonized long term policies are also needed to allow improvement of established biofuels options. There is an ongoing need to further advanced research, demonstration, and deployment (RD&D), with production support in commercialisation.

Further, we need to educate decision makers on all levels (not just the higher levels) and push for science-based strategies where bioenergy is one part of the transition. Policy needs to be more based on science, less on feelings and guesses or unrealistic expectations.

Austrian developments

Relevant projects and industry realisations were presented in the session on Austrian developments. In many of them biofuel/biogas is a co-product of food and/or industrial bioproducts. All examples can be qualified as biorefineries, creating a variety of products, together contributing to the overall business case, and avoiding wastes in the process. Biofuels/bioenergy are an inherent part of these systems. Circularity of carbon and nutrients is a common goal in all these projects. Biorefining to multiple products is a central principle in all biobased developments.

WORKSHOP

Introduction & keynotes

Paul Bennett (Scion, New Zealand), the current Chair of IEA Bioenergy, welcomed all participants in Vienna, as well as online. In his introduction he emphasized that we are living unprecedented times. Climate change is already creating extreme weather events, and high energy prices around the world are impacting people's lives because of the disruptions in fossil fuel trade created by the war in Ukraine. Both climate change and energy security are major reasons to urgently move away from fossil fuels. Bioenergy is one of the key tools to do this and this is also recognized in all climate mitigation scenarios.

However, the key role of bioenergy is regularly undermined by certain actors, often based on biased analyses about sustainability and availability of biomass, and this is also slowing deployment of bioenergy. From our network of experts in the bioenergy field we need to counter some of these biased analyses and increase our efforts to share robust and fact-based analyses, demonstrate good practice and thereby also reach out beyond the bioenergy world.

Renewable gas and transport biofuels are some of the key areas where bioenergy can make a difference, and Dr Bennett welcomed that developments in these areas would be in focus of this workshop.

Hannes Bauer, BMK (Austria) also welcomed the audience as local host of the event. He gave a background on the Austrian situation, where 21% of the energy supply comes from biomass, predominantly for heating purposes. Most of the biomass used is woody biomass, directly or indirectly derived from Austria's forests. 48% of Austria's surface is covered by forest, and this area, as well as the stock of wood, is still increasing. Nevertheless, wood extraction in Austrian forests is approaching its limits and other types of biomasses need to be considered as well.

The Austrian Ministry BMK highly values its participation in the IEA Bioenergy TCP (as well as other TCPs in the IEA framework), which provides an opportunity for Austrian experts to interact and exchange experiences with the international community.

EU Research and Innovation Policy for Renewable Fuels

Maria Georgiadou, DG Research & Innovation, European Commission

Ms Georgiadou gave an online presentation. She pointed to the **European Green Deal**, which aims to transform the EU's economy for a sustainable future, with important emphasis on climate ambitions, energy security and ecosystem preservation. The **"Fit for 55" package** includes concrete proposals for new legislation and revisions of current Directives and Regulations for a common target of 55% lower greenhouse gas (GHG) emissions by 2030 compared to 1990. Several of these proposals have a direct link with biomass, for example ReFuelEU Aviation, FuelEU Maritime, as well as the revision of the Renewable Energy Directive and the LULUCF Regulation.

The Russian invasion in Ukraine triggered increased ambitions in the **REPowerEU** Plan, proposed in May 2022. The proposal includes an increased 2030 target for renewable energy from 40 to 45% and contains a **Biomethane Action Plan** to double EU's biomethane production to 35 billion m_N^3 (bcm) per year by 2030 to substitute imports of Russian gas. This implies that R&I gaps for biomethane expansion need to be addressed and EU Member States need to reflect on integrating biomethane in their national strategies. The following table provides an overview of the framework for the EU Biomethane Action Plan.

Biomethane Action Plan	
Sustainable production and use of biogas and biomethane **at EU and national/regional level and injection of biomethane into the gas grid**	□ Biomethane industrial **partnership/ forum** promoting sustainable production and use □ Biomethane **national strategies** or integrate in **NECPs** □ Broadening the scope of the **fuel supply obligation** in RED □ Participatory **multi-stakeholder engagement** □ Speed up **permitting** □ **Co-operation** with neighbouring and enlargement countries
Incentives for biogas upgrading **into biomethane**	□ **Reduce the costs** for economic operators
Adaptation and adjustment of existing and deployment of new infrastructure **for the transport of increased shares of biomethane through the EU gas grid**	□ Regional assessment of **network development** □ Assess **infrastructure challenges** □ **Standardization**
R&I gaps	□ Development of **innovative technologies for production** □ **Innovative technologies for the upgrade** of biogas to biomethane □ Innovative solutions and research on **barriers and integration** of biomethane to the gas grid □ **Expansion of the sustainable biomass potential** to ensure availability of resources for reaching the bio methane production target
Access to finance	□ Access to **grants and loans** □ **Innovation Fund** □ Access to **other** financial instruments

Table 1: Framework for the EU Biomethane Action Plan[2]

In terms of Research & Innovation, the European Commission will revamp its Strategic Energy Technology Plan (SET Plan) by the end of 2022, to align its activities with REPowerEU and the European Green Deal.

Through several EU Funding programmes the EU will aid transitions, e.g., through Horizon Europe for research and innovation, LIFE for pilot projects for mitigation and adaptation, the Innovation Fund for first-of-a-kind upscaling to commercial level, the Connecting Europe Facility and InvestEU-EIB for debt financing. On international level, the EU participates in Mission Innovation 2.0, amongst others in the Innovation Platform for International Sustainable Aviation Fuel and the Integrated Biorefineries Mission.

[2] European Commission Staff Working Document SWD(2022) 230 final. Implementing the REPower EU Action Plan: Investment needs, hydrogen accelerator and achieving the bio-methane targets. 18 May 2022. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230&from=EN

Session 1: Advances in renewable gas

This session was moderated by **Jan Liebetrau (Rytec, Germany)**, leader of IEA Bioenergy Task 37 (biogas), and **Berend Vreugdenhil (TNO, the Netherlands)**, leader of IEA Bioenergy Task 33 (gasification).

Renewable gases will be key components of a global energy system aiming at net zero greenhouse gas emissions by 2050. With global fossil gas demand to be substituted and new applications demanding renewable gas in emission reduction scenarios, biomethane and hydrogen (H2) will be most critical, with biomethane as the largest contributor in existing gas grids, as it can be used without changing gas transmission/distribution infrastructure or end user equipment.

The first part of this session considered technology developments, both in anaerobic digestion and in gasification pathways to produce biomethane. The second part was a panel discussion around the central question 'What is needed to accelerate the deployment of renewable gases?'

Biological methanation / Power to Methane

Robert Böhm, Hitachi Zosen Inova Schmack (Germany)

Renewable gases will play a significant role in meeting climate goals, with biomethane playing a key role. Mr Böhm presented a concept to combine biogas and power-to-methane through a biological process.
A methanation process combines hydrogen with CO_2 containing flows to produce methane (CH_4). Such processes can be catalytic or biological, where micro-organisms convert the H_2 and CO_2 to methane.
An interesting application is to treat biogas - which contains 50-55% methane and around 40% CO_2 – in such a biological methanation process and thereby convert most of the CO_2 in the raw biogas also to methane. This results in >96% methane concentrations in the output; after removal of sulphur and ammonia it is ready to be injected into the gas grid.

The value proposition of the concept is 4-fold:

- Conversion of hydrogen to synthetic methane
- Upgrading of raw gases from biogas and synthesis gas plants
- Use of CO_2 as a raw material and reduction of direct emissions
- Seamless injection of renewable methane into existing infrastructure

The next figure shows the schematics of a plant which is being installed in Switzerland (near Zurich). Part of the power produced in an energy-from-waste (EfW) plant is used to produce hydrogen for the methanation plant. The biogas comes from a wastewater treatment plant. Biomethane is injected into the gas grid, and heat from the process is fed into a district heating grid (together with heat from the EfW plant).

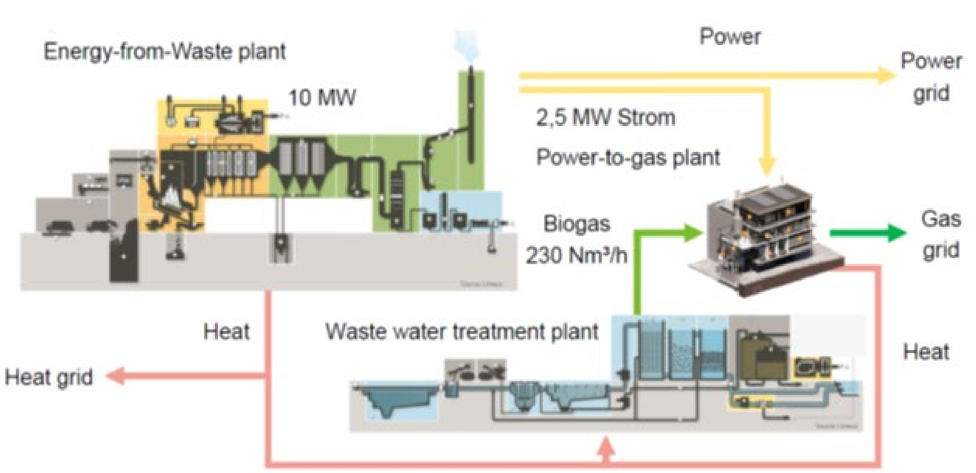


Figure 1: Electrolyser and biological methanation in Dietikon, Switzerland
(source: Hitachi Zosen Inova Schmack)

CO_2 separation from biogas upgrading

Philippe Lehmann, CO2 Energie AG (Switzerland)

Mr Lehmann had to apologize at last instance due to illness and could not give his presentation during the workshop. However, he provided his slides after the workshop, which are also available on the workshop webpage.

Raw biogas primarily consists of methane (CH_4) and carbon dioxide (CO_2) and some other trace components like H2S. When upgrading biogas to biomethane, the CO_2 is removed from the biogas, and commonly vented. However, capturing this CO_2 for further utilisation provides opportunities.

CO2 Energie AG is a young company based in Baden, Switzerland, which is installing a CO_2 capture and liquefaction plant connected to an existing biogas plant. The existing biogas plant at the site produces biogas, which is upgraded into biomethane for injection into the regional natural gas grid. The pilot project aims to capture and liquefy 3,200 tons of CO_2 per year from the biogas upgrading process for use as product gas in various industrial applications, for example as technical welding gas, in gas extinguishing systems, or for inerting.

As many biogas projects are considering upgrading the gas to biomethane, the removal of CO_2 and its potential valorisation is one of the key developments in this area.

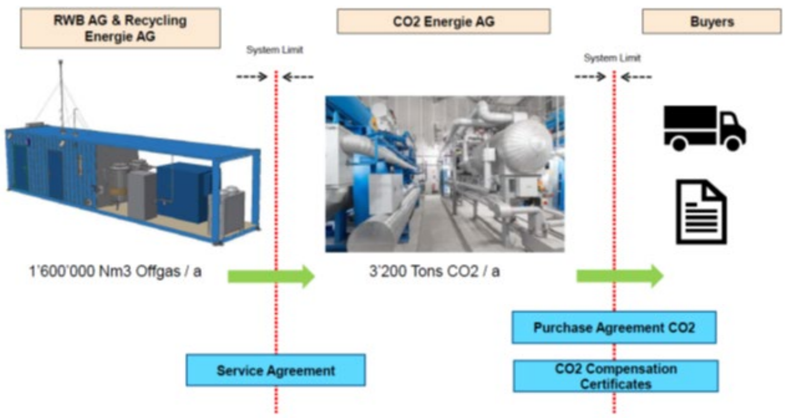


Figure 2: Value chain for the CO2 capture project in Baden, Switzerland (source: CO2 Energie AG)

Pre-treatment of wet and complex biomass

Heather Wray, TNO (the Netherlands)

This presentation focused on the Torwash technology, a wet torrefaction process which converts biogenic waste streams with high water and/or salts to a solid product and a liquid effluent. The base process is hydrothermal treatment, under water, at temperatures between 150-250°C. The concept leads to a modification of cellular surface properties; it enables mechanical dewatering to produce a solid fraction and almost complete removal of salts to the liquid phase. The mild process conditions allow for a liquid stream which is suitable for anaerobic digestion to produce biogas. The solid cakes can be used as fuel, or as input for a gasification processes.

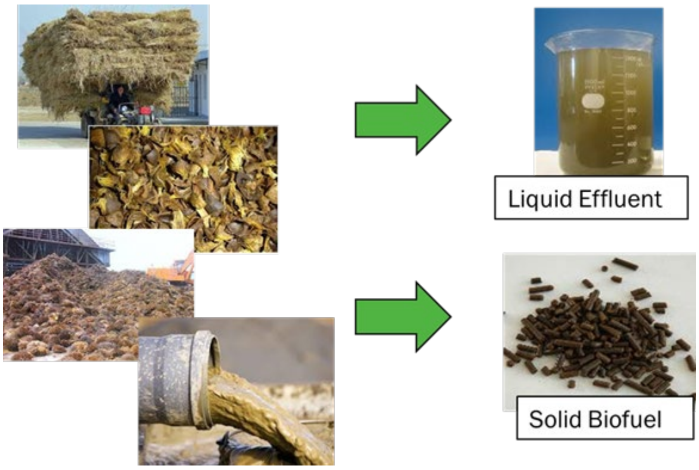


Figure 3: Torwash background - upgrading of biogenic waste streams to a solid biofuel and a liquid effluent (source: TNO)

Torwash can be considered as a pre-treatment process to unlock organic carbon from difficult waste streams. It broadens the available feedstocks to include low quality residues. The carbon can be used for other processes to produce advanced biofuels, chemicals, and other products.

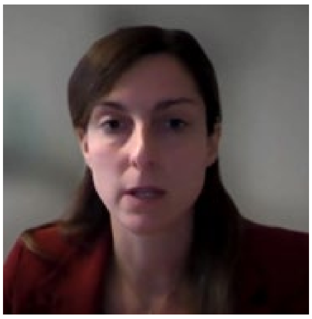
The following table shows typical inputs and outputs for the process, with the main driving force.

INPUT (application)	OUTPUT (product)	Driving force
Sludges – including industrial sludge	Fuel and struvite	Lowering disposal costs
Tropical plantation waste (EFB)	Fuel pellets	Solid biomass fuel □ power production
Agro-residues	Fuel + specialties	Waste-to-fuel and recovery of valuable by-products
Manure – liquid + solids	Fertilisers	Elimination of N-emissions
Grasses (wetlands, roadsides)	Peat substitute	Disposal costs + price of peat in potting soil
Regular plastics (PE, PP, PET, etc)	PE/PP granulates	Increasing amount of recyclable plastics
Biodegradable plastics (PLA)	Lactic acid solution	Enabling recycling to new virgin PLA

Table 2: typical inputs and outputs of the Torwash process, as well as the main driving force.

GAYA: Production of SNG from dry biomass and waste pyrogasification

Marion Maheut, ENGIE (France)



The GAYA project was a 10-year R&D programme, led by ENGIE, to demonstrate the technical, economic, and environmental viability of synthetic natural gas (SNG) production from biomass/waste gasification. A cutting-edge R&D and highly automized demonstration platform of 500 kW SNG was constructed near Lyon, France. It is in operation since 2015.

The following figure shows the challenges addressed along the process chain during the R&D and demonstration programmes within GAYA. The overall aim was to integrate and optimize the overall process chain, and prepare scale-up an industrialisation.

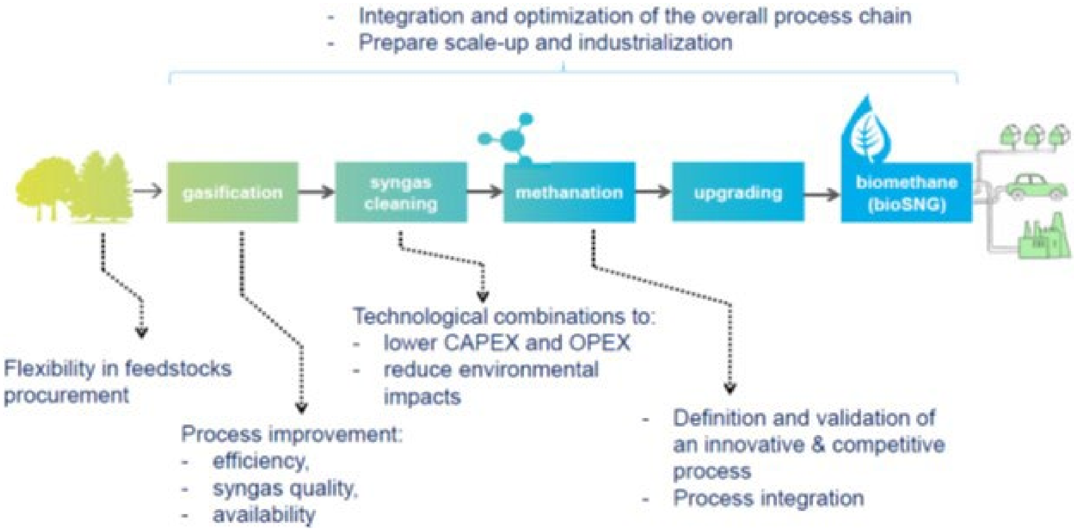


Figure 4: Challenges addressed in the GAYA R&D and demonstration programme (source: ENGIE)

Main results of the GAYA R&D and demonstration programme:

- The entire production chain has successfully been operated and proven to be robust and flexible to convert several feedstocks (woody residues, agricultural residues, non hazardous waste, …).
- The syngas cleaning process chain efficiently removes pollutants (tars, inorganic compounds).
- Validation of an in house innovative, highly flexible and cost effective methanation through a catalytic “isothermal” fluidized bed reactor
    - a single reactor for Water-Gas-Shift (WGS) and methanation
    - excellent heat management enabled by an intensified heat transfer between the fluiized bed and exchanger tubes
    - low operating pressure (2-5 bar) reducing CAPEX and OPEX
    - high flexbility in terms flowrate (20-150% of the normal load)
    - flexble for several syngas H_2/CO and H_2/CO_2 ratios; the WGS reaction allows to compensate low H_2/CO ratios
- Production of a high quality SNG, fully substitutable to natural gas.

The platform supports further industrialisation steps. ENGIE now plans to build its first industrial unit in Le Havre, France at a scale of 20MW. Starting in 2026, the Salamandre project will turn 70,000 tons of non-recyclable waste per year into 150 GWh of renewable gas and 45 GWh of renewable heat to meet urban and industrial needs.

Figure 5: GAYA SNG demonstration plant near Lyon (source: ENGIE)

GoBiGas: An industry relevant state-of-the-art reference for advanced biofuel production via gasification

Henrik Thunman, Chalmers University (Sweden)

In the GoBiGas project, a first-of-its-kind industrial scale biorefinery was built near Gothenburg, Sweden for the purpose of demonstrating and enabling commercial production of biomethane from woody biomass via gasification. The demonstration plant, with capacity of 20 MW biomethane (from 32 MW fuel), produced biomethane for the regional gas grid from 2014 to 2018. With more than 12,000 hours of operation, the GoBiGas project has demonstrated how the quality of the product gas from a biomass gasifier can be controlled using a range of different feedstocks including bark, wood pellets, wood chips and recovered wood. Results show that a biomass to biomethane efficiency of up to 70% is possible. It was also shown that the technology would be competitive at larger size.[3]

A second phase of GoBiGas would aim for a commercial scale plant of 80-100 MW biomethane. However, these plans were cancelled in 2015 for economic reasons.

[3] Göteborg Energi (2018) The GoBiGas Project - Demonstration of the Production of Biomethane from Biomass via Gasification. Available at: https://www.goteborgenergi.se/Files/Webb20/Kategoriserad%20information/Forskningsprojekt/The%20GoBiGas%20Project%20-%20Demonstration%20of%20the%20Production%20of%20Biomethane%20from%20Biomass%20v%20230507_6_0.pdf

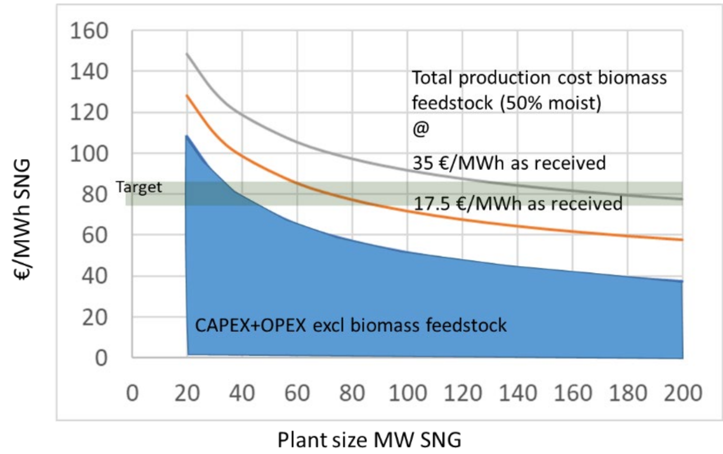


Figure 6: Estimation of SNG production costs from biomass in relation to scale of the plant, based on GoBiGas data (source: Chalmers University)

Panel discussion: What is needed to accelerate the deployment of renewable gases?

The technical presentations were followed by a panel discussion, also moderated by Jan Liebetrau and Berend Vreugdenhil.

The following panellist participated in the discussions:

- Günter Pauritsch, Austrian Energy Agency (Austria)
- Uwe Fritsche, IINAS (Germany)
- Henrik Thunman, Chalmers University (Sweden)
- Andreas Wolf, Austrian Biomethane Registry (Austria)
- Giulia Cancian, European Biogas Association (Belgium) (online)

All panellists gave an opening statement, in most cases supported by a few slides.

Günter Pauritsch of **the Austrian Energy Agency** shared some of the conclusions of the study 'Renewable Gas 2040'[4] which AEA performed for the Austrian Ministry BMK. The study estimated the demand for renewable gases from industry, transport, and energy in Austria in 2040, versus the potential for renewable gas supply from domestic biogenic resources (both through anaerobic digestion and gasification pathways).
Energy intensive industries (iron and steel production, glass making, chemical industries) would represent 70-75% of overall gas demand. Overall, the realisable potential of biomethane would only cover 15 to 22% of demand for renewable gases in 2040 in Austria. The supply gap would need to be covered through green hydrogen and/or imports of renewable gases. Mr Pauritsch concluded that it was important to aim for using renewable gas in sectors that have limited other options.

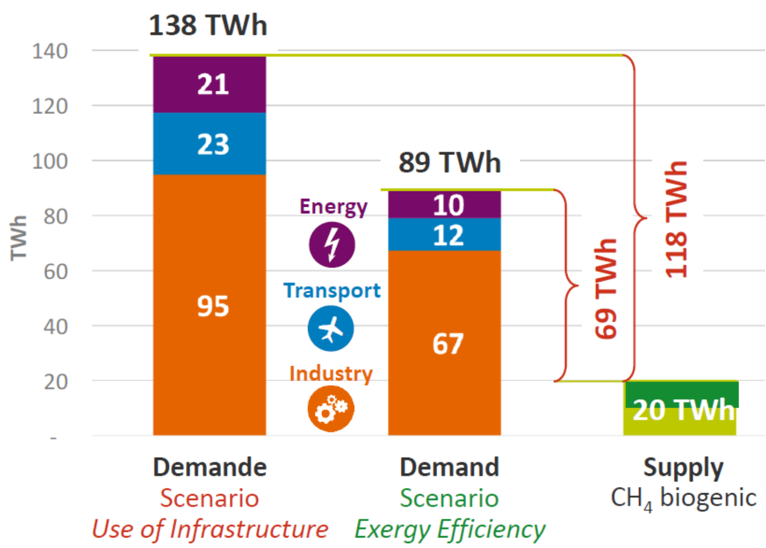


Figure 7: Demand for renewable gases in Austria in 2040 vs realisable potential of biomethane (source: AEA)

Henrik Thunman of **Chalmers University** referred to his earlier presentation. For gasification projects it is important to consider the syngas composition and how to best utilize it. in the GoBiGas case, the syngas already contained substantial levels of methane, so it makes sense to upgrade the rest to biomethane as well.
He stressed that commercial scale projects need to have a certain scale and represent important investments. It is therefore crucial to have long term perspectives and security for these investments.

Uwe Fritsche of **IINAS** referred to a project conducted within IEA Bioenergy on the perspectives of renewable gas[5]. Renewable gas is key in a global energy system aiming at zero GHG emissions by 2050, with biomethane being the largest contributor for renewable gas in gas grids in 2050. The main advantage is that biomethane requires no change in gas transmission/distribution infrastructure or end user equipment.

[4] M. Baumann et al. (2021). Erneuerbares Gas in Österreich 2040. Available (in German) at: https://www.bmk.gv.at/themen/energie/publikationen/erneuerbares-gas-2040.html
[5] IEA Bioenergy (2022). Renewable gas - Deployment, markets and sustainable trade. Reports available at: https://www.ieabioenergy.com/blog/publications/renewable-gas-%e2%80%90-deployment-markets-and-sustainable-trade/

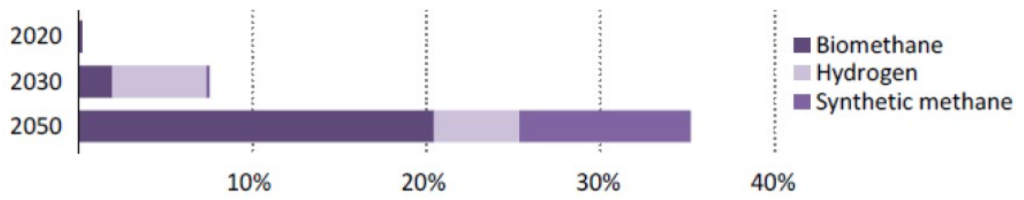


Figure 8: Gas grid shares of renewable gases in the IEA Net Zero Emissions by 2050 Scenario (source: IEA)

Policies seem to focus much more on the market introduction and trade of hydrogen than biomethane, although biomethane (e.g., bioLNG) is much easier to trade than hydrogen. A promising policy development at European level is the recent RePowerEU initiative, which aims to provide longer term perspectives for biomethane (*see presentation Georgiadou*).

When biogas is upgraded to biomethane, this provides a valuable source of high concentration CO_2. This CO_2 can be captured and sequestered (CCS), making it possible to achieve negative CO_2 balances in biomethane plants. It can also provide biogenic CO_2 for utilisation (CCU), towards CO_2-neutral products.

The main fields of action for the development of biomethane as a renewable gas are:

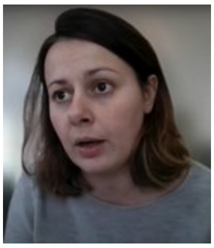
- Create strategies for biomethane sector development, including the consideration of available substrates and development costs, defined development targets and consideration of needed infrastructure
- Obligatory market implementation by means of a quota, considered as the most effective way of introducing renewable gas under the current conditions
- Incentives which reflect costs and long-term operation (amortisation) conditions and provide a secure market environment for the run up of technologies
- Dismantling of inhibiting regulations on technical and regulatory level
- Compatibility with other measures to develop the renewable gas sector and downstream technologies (e.g., Power-to-Gas).

In the long-term, the technology and sector specific support schemes need to be transferred into an overall market scheme, respectively an economy where CO_2 emissions have a monetary value. According to reduction targets and technology development the price for CO_2 will develop and drive the transformation.

The injection of renewable gases into natural gas grids is expected to play a key role in the energy transition. **Andreas Wolf** of the **Austrian Biomethane Registry** emphasized the importance of connecting producers and customers of renewable gas, comparable to what happens for renewable power delivery. Renewable gas certificates would enable the transfer of renewable gas to customers who are willing to buy renewable gas (for various purposes). Certificates can also transfer specific information to the customer and administrations.

Several countries have already implemented national systems to register renewable gas certificates. Aim is to ensure traceability and eligibility for target compliance via mass balancing, and to allocate the biomethane towards different applications, preventing any risk of double counting. For further acceleration of renewable gas, also cross-border exchanges would be required. The European Renewable Gas Registry (ERGaR) aims to provide for cross-border transfer of sustainability characteristics attached to the consignments and enable trading renewable gas across Europe.

Certificates can contain several layers, depending on the markets they serve. For example, when using biomethane as transport fuel, specific sustainable requirements need to be documented, as is prescribed in the Renewable Energy Directive.



Giulia Cancian of the **European Biogas Association** (EBA) considered the Biomethane Action Plan in the RePowerEU as a positive step. The plan established a Biomethane Industrial Partnership and targets 35 billion Nm^3 (bcm) of biomethane by 2030 at EU level. It sets out measures to be taken at both national and European levels to scale up biomethane production and consumption. The plan includes a recommendation to EU Member States to develop a national biomethane plan as soon as possible.

Work in 4 pillars is needed to unlock the potential of biomethane:

1. ***Planning***: anchor the biomethane targets in legislation and make sure that there are solid trajectories and milestones to achieve the target.
2. ***Market***: ensure easy market access, cut away red tapes and eliminate persisting internal market barriers.
3. ***Finance***: use dedicated and innovative finance instruments to mitigate risks and have the needed capital to roll out biomethane at scale.
4. ***Sustainable feedstocks***: tap into sustainable resources, such as waste, urban wastewater, and sustainable crops.

In 2020, EU countries were producing 15 bcm of biogas and 3 bcm of biomethane from almost 20,000 plants.
A recent study by the Gas for Climate initiative indicated a feedstock potential in the EU for 41 bcm biomethane by 2030 (*38 bcm through anaerobic digestion (AD), 3 bcm through gasification*). The main feedstocks would be animal manure, agricultural & food processing residues and sequential crops (see figure).
The same study indicated that by 2050, 150 bcm of biomethane could be made available (*90 bcm through AD; 60 bcm through gasification*).

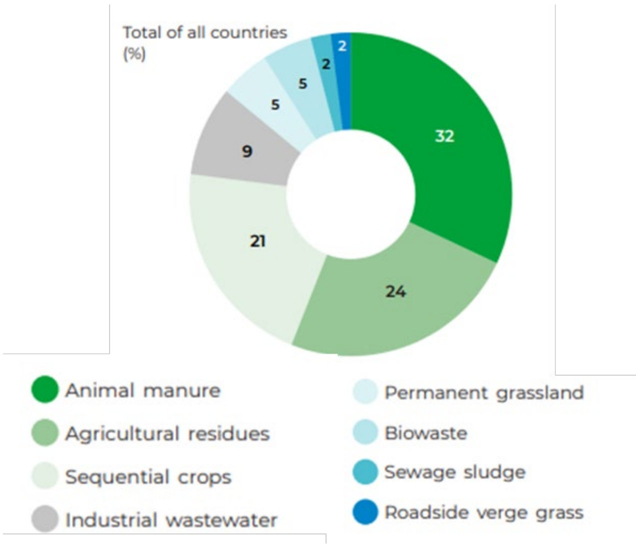


Figure 9: Biomethane potential in the EU (2030) & related feedstocks (source: Gas for Climate[6])

After the introductory statements, the floor was opened for questions from the audience. The following items were touched upon:

Do we need biomethane if we can electrify the whole energy system?
We need to electrify as far and fast as possible, and meanwhile decarbonize the power system. However, we need to consider that transitions do not happen overnight and we should not put our eggs in one basket – even electrification is not the silver bullet for all energy applications; it is important to diversify energy sources. In the next 10-20-30 years there will be a push for all solutions that can move us away from our fossil fuel addiction. Also mind that there are regional differences, with some regions moving faster than others, or putting a different focus depending on the resources/local options they have.

Towards 2030-2040 there will still be a lot of (fossil) gas demand, so biomethane will certainly provide a valuable contribution. Biomethane is attractive in the medium to short term as it is compatible with current gas infrastructure and gas applications and therefore of high value for a speedy implementation. However, it is important to realize that we cannot just substitute existing fossil gas applications with renewable gas as this would require extreme amounts of biomass – we need to acknowledge its limitations and realize that we have a big task ahead of us to deploy biomethane at scale. Moving away from fossil gas requires a combination of energy conservation, energy efficiency,

[6] Gas for Climate (2022). Biomethane production potentials in the EU. Report available at: https://gasforclimate2050.eu/wp-content/uploads/2022/10/Guidehouse_GfC_report_design_final_v3.pdf

electrification and shifting gas applications to renewable gas. Considering that there are limits to biomass/biomethane potentials, we need to be selective and particularly at the medium term aim the application of biomass at hard-to-abate sectors (e.g., high temperature heat in industries, long distance transport), also considering where hydrogen comes in. Synergies with hydrogen are important to consider; an IEA Bioenergy inter-Task project is exactly dealing with that.
In the medium to longer-term we also need to shift carbon-containing materials/chemicals to renewable or recycled carbon, and biomass will also play a vital role in this circular (bio)economy, where a cascading approach will be central.

Carbon capture and utilisation
Carbon capture and utilisation is a central focus in future biomethane pathways, either to increase the output (turning CO_2 into additional biomethane), either using the CO_2 for other applications to produce fuels or products (CCU). This is often claimed to be carbon-negative, however, that is only the case if this carbon is stored for a longer term, which is not valid for fuels or short lived (<10-20 years) products which can be carbon neutral at most.
There is a need for a global definition of these terms - what is carbon negative, what is carbon neutral - and their carbon accounting as these products are also traded.

Relationship with food security and agriculture
The Gas for Climate study accounts for competition of uses and pays attention to feedstock sustainability and untapped resources. It is important to continue working with the agricultural world to mobilize manure and anticipate for changes in farming in the coming decades. Sequential crop models, which cover the land between crops and have positive externalities on soil and water quality, need a further push and they can provide important amounts of biomass.

Biomethane from anaerobic digestion has a clear interaction with fertilizers, through the digestate that is produced as co-product. When fed back to soils digestate has positive impacts on soil health through the provision of accessible nutrients and stable organic carbon (in comparison to the raw manure). The interest for digestate is growing with the peaking price of synthetic fertilisers, which are mainly produced from fossil gas (and thereby also have a high carbon footprint). Regulations should follow to facilitate the replacement of fossil-based fertilizers by biobased/organic fertilizers. This is an ongoing process at EU level.

Social involvement
Social issues are to be considered. We cannot afford losing out of people in the energy transition and need partnerships. Multistakeholder engagement is needed as biomass links to different sectors, not the least agriculture, waste sectors and industries.
We need to keep communities on board and make citizens aware of direct benefits in their local community.

Overcoming obstacles
- We should make it as simple as possible for market participants and society. Gas grid requirements are to be harmonized, as well as certification requirements to avoid cross-border barriers for customers willing to purchase renewable gas.
- Different options to produce biomethane need to be recognized. The anaerobic digestion pathway dominates at the moment, but gasification pathways can also provide important contributions which should not be neglected in biomethane targets.
- There are various substrates, and for some there can be competition for their utilisation. This is to be recognized when determining potentials.
- Fossil gas has been cheap for a long time and we cannot predict which prices it will reach after the current energy crisis. So there need to be mechanisms to monetize CO_2 prices and put mandates on gas markets so there are stable conditions for investments.

Session 2: Advances in liquid biofuels

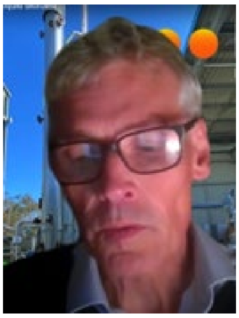
The technical session was moderated by **Glaucia Souza, University of São Paulo (Brazil)** co-leader of IEA Bioenergy Task 39 (transport biofuels); the panel discussion was moderated by **Jim Spaeth, US Department of Energy**.

Electrification is accelerating for road vehicles (particularly cars) but EVs still only represent a marginal share of vehicles on the road. Biofuels provide a means to replace fossil fuels from the legacy fleet, which is still predominantly reliant on liquid fuels. In the medium to long term the focus of biofuels is expected to move to hard-to-abate transport sectors such as aviation and shipping. A strong growth in so-called 'advanced technologies' will be required, starting from a variety of feedstocks, particularly underutilised heterogeneous biomass resources.

The first part of this session considered technology developments, particularly advanced biofuel technologies that are moving to the market. The second part was a panel discussion around the central question 'What is needed to accelerate the deployment of advanced biofuels?'

Hydro-Thermal Liquefaction (HTL) to produce drop-in biofuels and chemicals

Steve Rogers, Licella (Australia)



Hydrothermal liquefaction uses water under pressure and at high temperature to chemically transform solid carbon-based material into oil. This 'biocrude' can be further fractionated, co-processed or upgraded into a range of fuels and chemicals, in a similar mix of products as in petroleum refineries. In a traditional petroleum refinery, chemicals typically form 15% of the output in volume but represent 50% of the economic output.

The CAT-HTR™ process of Licella uses supercritical water conditions (374°C, 218 bar), in which water acts as

- a *solvent*, diffusing through the feedstock to selectively break polymer bonds. Hydrogen donated from the water forms H-bonds which stabilizes the oil.
- a *reagent*, promoting the removal of the oxygen bonds from biomass. Oxygen content is reduced from 45wt% in the biomass to 12-14wt% in the biocrude.
- a *control rod*, ensuring controlled homogenous heating, eliminating local hotspots).

In comparison to conventional pyrolysis oil, the resulting biocrude has higher energy density, much lower oxygen content, lower water content and lower corrosivity; it is more stable and easier to mix. HTL embraces moisture in biomass (no drying required) and can use a wider range of feedstocks.

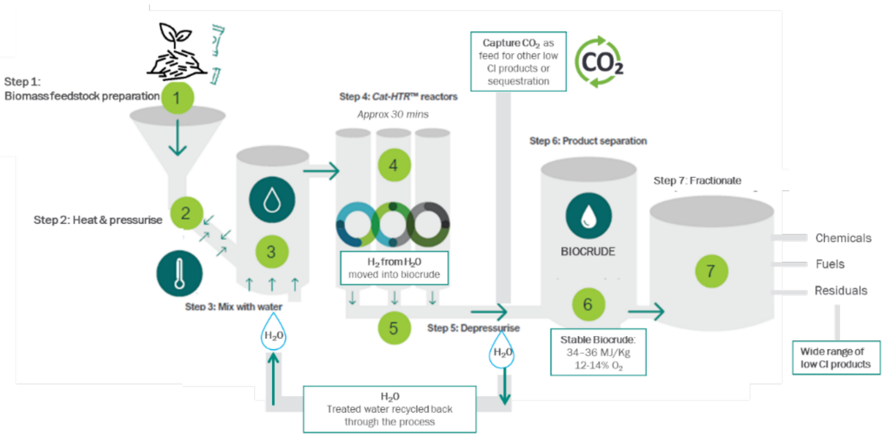
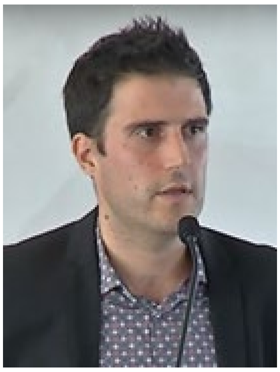


Figure 10: overview of how the hydrothermal liquefaction works (source: Licella)

Licella's first-generation Cat-HTR™ Small Pilot Plant was commissioned in 2007. Meanwhile, the Cat-HTR™ platform has gone through different reactor scale-ups to its current commercial-ready module. Licella tested all varieties of wood, residual biomass and non-recyclable plastics in its process. As technology provider, Licella partners with industries - mostly in Joint Ventures - to develop commercial projects. Arbios Biotech is a joint venture with an integrated forestry company to commercialize the technology for post-consumer biomass. Arbios has the world's first small-scale commercial HTL plant in Australia, with the ability to process 5,000 tons of post-consumer and residue biomass per year. It is also proceeding with the development of a new biomass to biofuels plant in British Columbia, Canada, starting with one processing line for 25,000 dry tons of residue wood biomass. The plant is scheduled to start producing biocrude in 2023.

BioTfueL®: Conversion of lignocellulosic biomass into biofuels via indirect thermochemical pathway

Mathieu Morin, IFP Energies nouvelles (France)



The purpose of the BioTfueL® project – launched in 2010 - was to develop, demonstrate and commercialize a full biomass-to-liquid chain. Two demonstratinon units were designed, built and operated since 2017:

1. ***Pre-treatment demonstration plant***, based in Venette (Oleon site, France). In this unit, lignocellulosic feedstocks (forest and agricultural residues, …) are dried and torrefied with a capacity of 3 ton per hour output. The torrefied biomass has a higher energy density and is easier to handle, grind and store than the raw biomass.
2. ***Gasification, gas treatment and Fischer-Tropsch demonstration plant***, based in Dunkirk (France). The main component is a 15 MW_{th} entrained flow gasifier, combined with H_2/CO adjustment, gas purification and synthetic hydrocarbons production by the Fischer-Tropsch process.

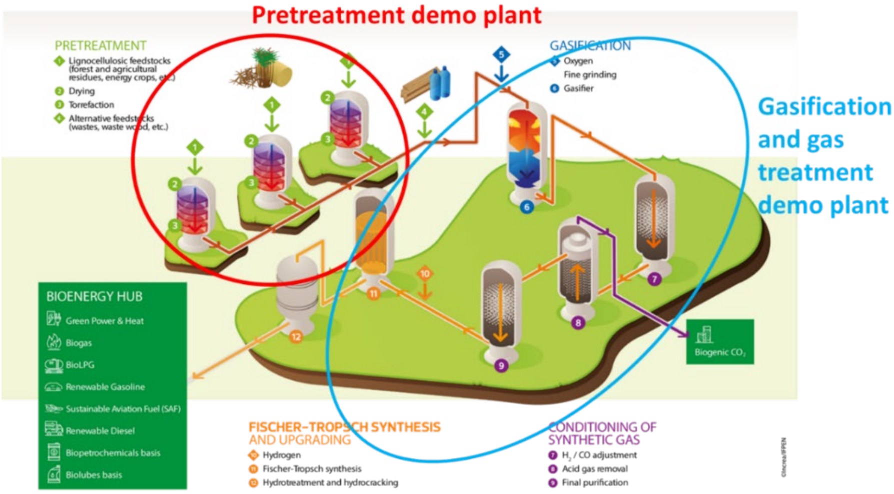


Figure 11: schematic process overview in the BioTfueL® demonstrators (source: IPF Energies Nouvelles)

Based on demonstration unit results obtained after more than 1500 hours of torrefaction and 1000 hours of gasification and four different types of biomasses, the BioTfueL® technology is today de-risked, optimized and ready for the commercialization. Axens, on behalf of the consortium and as the single licensor, will allow to propose a complete design for the biomass-to-liquid chain at industrial scale on a wide range of biomasses.

Several industrial projects are under development using the BioTfueL® technology and local biomass residues.

By the production of low carbon footprint advanced biofuels, the BioTfueL® process will contribute to the decarbonation of the transport sector especially the production of sustainable avion fuel (SAF), or green chemistry.

HTW Gasification of biomass/waste to methanol

Elyas Moghaddam, Gidara Energy (the Netherlands)

The High Temperature Winkler (HTW) process is a commercially proven gasification technology, which can be applied to a diversity of feedstocks. The HTW gasifier is a bubbling fluidized-bed (BFB) reactor, capable of operating in in either oxy- or air blown modes. It can gasify a variety of different feedstocks, including all grades of more reactive low-rank coals with a higher ash softening temperature (i.e., brown coal), and also various forms of biomass. Wood, refuse derived fuel (RDF) and municipal solid waste (MSW) have all been successfully applied at commercial scale for the bio-methanol production route.
Due to efficient injection of oxygen along the reactor, resulting in several sub-zonal reaction spaces along the reactor, the syngas does not contain any higher molecular weight hydrocarbons, such as black tars, phenols, and other heavy aromatics.

A key HTW-to-Methanol reference plant, with capacity of 90 ktons per year methanol has been operated from 1986 to 1997 in Berrenrath, Germany. During the life span, a broad range of feedstock has been utilized (predominantly lignite, but also plastic residues, sewage sludge, SRF and waste wood), proving the volatility of the technology on larger scale. A new state-of-the-art HTW2.0 Pilot Plant is in operation since 2017 at the Technical University of Darmstadt, purposed for feedstock testing, testing of design parameters, process enhancement and operator training.

Gidara Energy, a joint venture between the Dutch engineering firm G.I. Dynamics and the US private equity firm Ara Partners, is developing a flagship HTW2.0-to-Methanol plant in the port of Amsterdam. The facility is scheduled to be in operation by the first quarter of 2025. It is intended to produce 87.5 ktons of methanol per year from non-recyclable waste (RDF/waste wood), destined as transport fuel. All remaining CO_2 from the process will be captured and applied in greenhouses.

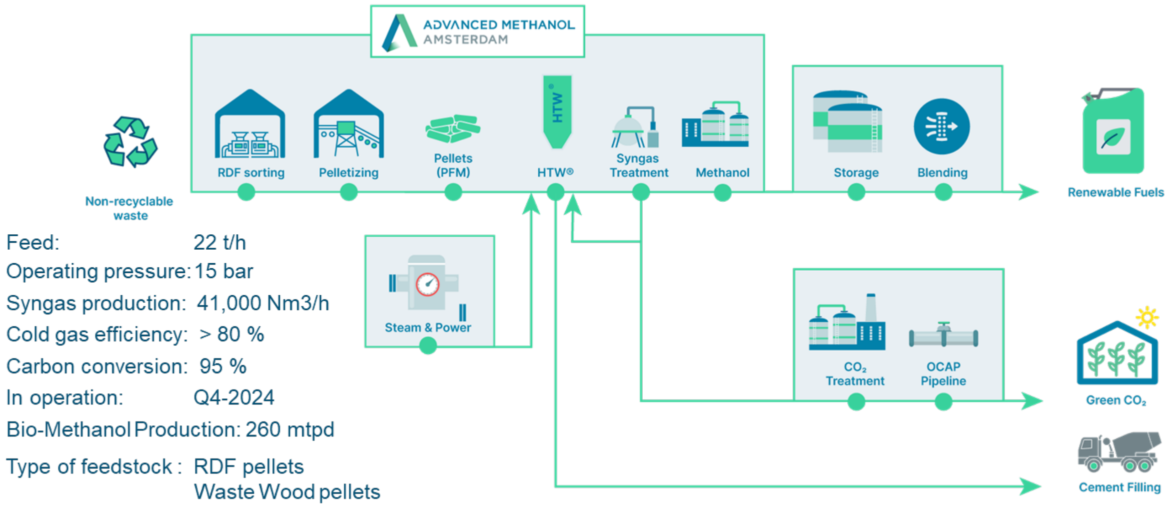


Figure 12: Flagship Facility "Advanced Methanol Amsterdam (AMA)" – process flow diagram (source: GIDARA Energy)

sunliquid® technology – low carbon cellulosic ethanol for sustainable mobility

Ralf Hortsch, Clariant (Germany)

There is increasing pressure to phase out fossil transport fuels, with an increasing role of advanced biofuels. The global cellulosic ethanol market is expected to grow at >60% CAGR from 2022 to 2030.
Clariant's sunliquid® technology for the production of cellulosic ethanol has a 16-year track record with project experience on pre-commercial and commercial scale using integrated enzyme production. In recent years 5 licenses were sold globally. Clariant itself invested in a commercial plant in Romania. Constructions are finalized and the plant is currently in start-up phase. The plant capacity is 50 ktons of cellulosic ethanol per year, based on an annual processing of 250 ktons of straw, which is sourced from farmers in the region around the plant. In Romania, there is excess of straw which has limited alternative use. On average farms are quite large, and they already have certificates for their grain production, so feedstock tracking - as required for the Renewable Energy Directive - is no problem.

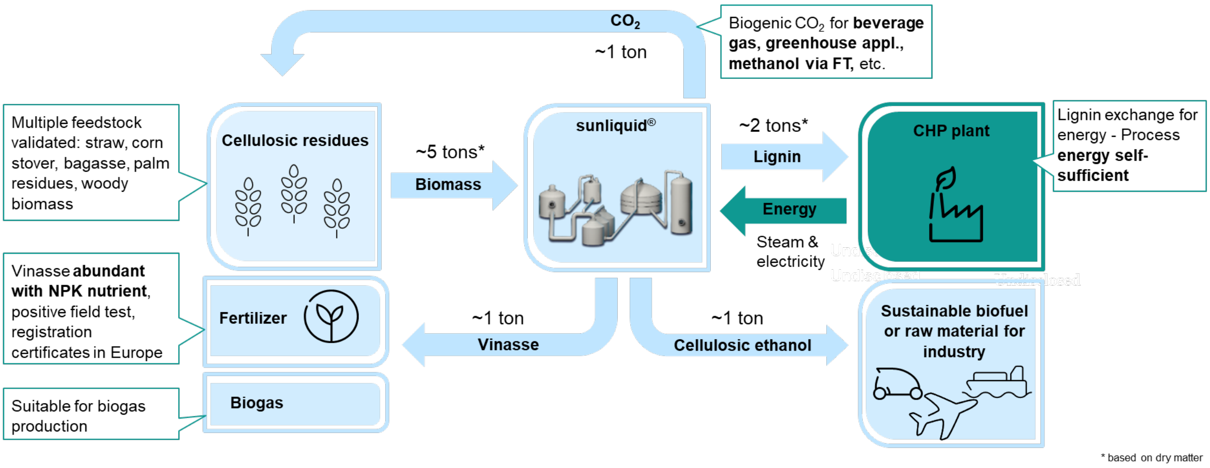


Figure 13: sunliquid® technology and process (source: Clariant)

While the process technology is implemented at commercial scale, further improvements are still pursued, turning cellulosic ethanol refineries to a prime example for a circular economy solution.

Future developments:
- Vinasse residue is abundant in nutrients, which could go back to the field as fertilizer. The vinasse can also go to an anaerobic digester to produce biogas; the digestate co-product can be used as fertilizer.
- CO_2 is available as a high concentration by-product. Different uses of the CO_2 are considered, e.g., in greenhouses, for industrial applications (e.g., in food industries), or to provide biogenic carbon for power-to-X applications. The CO_2 can also be sequestered to obtain negative emissions.
- Lignin is currently used in a CHP to provide energy for the process. In future, it may be redirected to other applications if there are more economic pathways.
- Towards the future, sunliquid® provides a versatile platform solution beyond cellulosic ethanol with bioethanol as feedstock for various applications, from sustainable aviation fuels (alcohol-to-jet) to bio-based chemicals. Technological advancements are enabling strong growth rates of sustainable aviation fuels beyond 2030.

Technologies for producing biofuels and chemicals from cellulosic feedstock

Mallikarjun Navalgund, Praj (India)

The Indian company Praj is a global player in the bioethanol field; their technologies are the backbone of 18% of EU's (first generation) bioethanol capacity. They are putting strong efforts in integrated biorefining – with advanced ethanol as major output - through the 'Enfinity' platform. This is an end-to-end integrated process, where feedstock pre-treatment plays a key role. Praj applies catalyst enhanced steam explosion pre-treatment, with additives. This leads to pre-treated biomass with high porosity, which provides better accessibility to enzymes (in the enzymatic hydrolysis), leading to low enzyme requirement, high conversion to sugars and low OPEX. Praj's pre-commercial plant with this platform has proven robustness, high yield of operations and predictability of scale up. This was evaluated by oil majors in 2019.

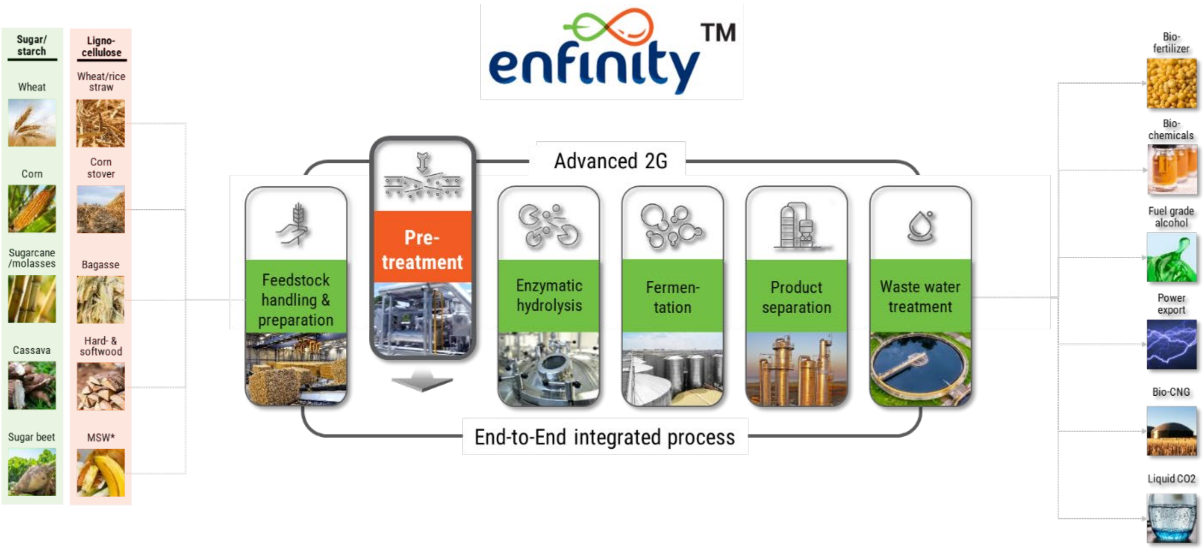


Figure 14: Praj Enfinity end-to-end integrated biorefinery process (source: Praj)

One of the world's first licensed commercial scale advanced bioethanol projects is based on Praj's Enfinity technology. It is built in Panipat, India and can convert 115 ktons per year of rice straw into 26.4 ktons per year advanced ethanol. Start-up is scheduled by the end of 2022. Two additional energy companies signed Praj licensing agreements, for comparable size plants in India and the plants are under construction.

Panel discussion: What is needed to accelerate the deployment of advanced biofuels?

The technical presentations were followed by a panel discussion, moderated by Jim Spaeth, US Department of Energy. The following panellist participated:

- Tomas Ekbom, Svebio (Sweden)
- Jack Saddler, UBC (Canada)
- Patrik Klintbom, RISE / ETIP Bioenergy (Sweden)
- Fuli Li, Qingdao Institute of Bioenergy and Bioprocess Technology (China)
- Sunil Kumar, Min. Petroleum & Gas (India)

Due to time constraints, this session was limited to initial statements of the panellists and a few specific questions.

All panellists gave an opening statement, in some cases supported by a few slides.

Tomas Ekbom, Svebio (Sweden), co-leader of IEA Bioenergy Task 39 (transport biofuels) pointed to very promising developments in Sweden, including new plants announced for the production of hydrotreated vegetable oil (HVO), sustainable aviation fuels (SAF) and bio-methanol. Three of these projects aim to produce e-fuels, starting from CO_2 and hydrogen. One oil refinery has started co-processing of pyrolysis oil (from sawdust) in their facilities.

Various studies and workshops on the topic concluded that policy development is critical for deployment of biofuels.

- Financing is the most critical factor, and the largest risk for investors is the political risk.
- A stable, long term regulatory framework is key for securing progress for investments which need to have 15 to 20 years perspective.
- Harmonized long term policies are also needed to allow improvement of established biofuels options
- R&D&D of new biofuels technologies should be advanced, with production support in commercialization.

Jack Saddler, University of British Columbia (Canada) put focus on aviation biofuels. 1.5°C projections estimate that about 200 billion litres per year of biojet fuel will be required by 2050, while production in 2019 was at 140 million litres (already a strong increase from 7 million litres in 2018). This is likely to involve around 5 billion USD investment per year over the next decades, with scale-up of new technologies. Only one technology is commercial for sustainable aviation fuels (SAF): hydroprocessed esters and fatty acids (HEFA). Gasification with Fischer-Tropsch synthesis, and alcohol-to-jet are advocated to be the next commercial SAF technologies. Lower carbon intensity (CI) jet fuel via co-processing can be produced now. Other technologies, such as Power-to-Liquids will take much longer to reach commercial scale.

The biggest challenge for commercialization is the high price of SAF. SAF will potentially always be more expensive, although significant cost reductions will take place over time. Policies are essential and there are significant developments on this front in the EU and USA that will have a major impact on SAF development.

Patrik Klintbom, RISE (Sweden) explained the role of ETIP Bioenergy, of which he is the Chair. The European Technology and Innovation Platform on Bioenergy (ETIP Bioenergy) aims to bring together actors from academia, industries, civil society, and others that are engaged in the development of sustainable bioenergy and competitive biofuel technologies; its role is also to present an unbiased, united and consolidated view on biofuels and bioenergy. ETIP Bioenergy also acts as the main interlocutor for DG R&I to implement the Strategic Energy Technology Plan in the field of biofuels and bioenergy for the full TRL scale. ETIP Bioenergy is currently working on an update of the Strategic Research and Innovation Agenda (SRIA) to identify research and innovation action to push the sector of biofuels forward (but it also includes electrofuels and integration of hydrogen). ETIP Bioenergy considers the full biobased value chains and increases its interaction with societal stakeholders.

What do we need to do to overcome barriers to deployment?

- Educate decision makers on all levels (not just the higher levels) and push for science-based strategies where bioenergy is one part of the transition (more science, less feelings and guesses).
- Overcome policy barriers, e.g., uncertainties created through primary biomass discussions send bad signals to industries which are supposed to invest. Developments need stable policy schemes.
- Reach outside and interact with a wide range of stakeholders.
  - Recognize that no one is perfect. The bioenergy sector has and will continue to evolve and adapt to new situations, also in terms of sustainability.
  - Put bioenergy in a system perspective. Some sectors (long distance trucks, ships, aviation) have a permanent need for liquid fuels; the alternative for biofuel in these sectors is fossil fuel.
  - Come to realistic transition scenarios. Stop dreaming of solutions like hydrogen as a transport fuel in the short to medium term. Hydrogen has a clear space in hard-to-abate industry applications.

Fuli Li, Qingdao Institute of Bioenergy and Bioprocess Technology (China) talked about biofuel developments in China and indicated 3 areas of research and development.

(1) China has a policy to use 10% ethanol in gasoline (E10), which would require 10 million tons of ethanol in the future. But at this moment there is only a limited production of ethanol, primarily food-crop based. In China, there are many steel factories, using coal. About 90 billion Nm^3 syngas would be available from the steel industries which could be converted to ethanol (e.g., through LanzaTech technology). There are also developments to produce ethanol from lignocellulosic agricultural waste and residues.

(2) There are commercial biodiesel facilities in China, but also further research work is ongoing on the catalytic conversion of bio-oils to biodiesel. Challenges related to feedstock impurities and catalyst life are being researched.

(3) Biomass to high-quality jet fuels is still in pilot scale or industrial demonstration stage. Biomass gasification and syngas synthesis to jet fuel is developed at QIBEBT and a 100 ton per year pilot system will be operated by end 2022.

Energy is an essential factor of modern society, connecting with diverse dimensions such as economy, society, ecology, environment, engineering, science and technology, climate, energy security etc. Any disturbance from any dimension can be conducted to others through energy. Digging into big data can help reveal new knowledge which will be helpful for smart development and intelligent government decisions.

Sunil Kumar, Indian Ministry of Petroleum and Gas talked about the journey and challenges of biofuels and biogas in India. Energy security and environmental concerns are generally key drivers, but in India bioenergy is also a tool to enhance rural development. India aims for a sustainable energy transition and has implemented a national biofuel policy. Various policy programs are functional and India has made remarkable progress, e.g., in bioethanol, with a share in gasoline consumption increasing from 1% in 2014 to 10% in 2020. Another biofuel which has made remarkable progress is renewable gas, with the build-up of over 5000 biogas plants.

Three major challenges for biofuel deployment:

- The main challenge of advanced biofuel and renewable gas plants is the *raw material* (e.g., straw), which is scattered and very time dependent – linked to typical 45 days harvest seasons - so it needs to be aggregated and stored properly. The government has planned block wise mapping of biomass production and set up a model of aggregating biomass for advanced ethanol, connecting farmers, aggregators, and oil companies. This model is now tested in practice, with the first commercial advanced bioethanol project in start-up.
- Second major challenge is *yield improvement*. Because of relatively low yields, CAPEX and OPEX (related to the electricity and enzyme cost) per output is high. The government is working with technology providers and scientists to improve yields and obtain advanced biofuels at reasonable cost.
- Third challenge is the *valorisation of the by-product*, lignin-rich residues. Scientists are working to produce high value chemicals from these residues. A new plant, which will start operations next year, is based on bamboo biomass and will also produce acetic acids, which will give more cashflow than the main advanced bioethanol product.

Session 3: Developments in Austria

The last session of the day focused on concrete developments related to renewable gas and advanced biofuels in Austria.
This session was moderated by **Dina Bacovsky** of **BEST Bioenergy and Sustainable Technologies** in Austria and **Hannes Bauer** of the **Austrian Ministry BMK**.

Gösser green brewery

Andreas Werner, Brau Union Österreich

The Gösser green brewery started its green journey in 1997 with a wastewater treatment plant, producing biogas which could cover 10% of its thermal energy demand. In 2007, the brewery was connected to a district heating system (using waste heat from the neighbouring wood processing plant); in 2012, a thermal solar panel plant was installed; and in 2015, biogas production from spent grains was added. The thermal energy of the brewery is now 100% renewable and what is still needed in terms of electricity is covered through renewable power bought from the grid.

Next step in the developments is to purify part of the biogas (not all is not needed for internal processes) and supply that to the public natural gas grid. In the company's strategic plan, it is also considered to use the biomethane for its own delivery trucks.
The residue stream of biogas production is a digestate which contains a high proportion of valuable nutrients, particularly phosphate and potassium. The digestate is upgraded/dewatered to an organic certified fertilizer which can be spread over agricultural fields. The carbon in the digestate builds up organic matter in soils, and CO_2 certificates are considered for that. CO_2 from biogas upgrading to biomethane could also be used for CCU applications.
Overall, the brewery aims for a closed carbon and nutrient cycle economy.

Figure 15: Green brewery in Göss, Austria (source: Brau Union Österreich)

Bio-electric syngas technology for the production of biomass derived fuels and platform chemicals

Bernhard Drosg, BEST Bioenergy and Sustainable Technologies

Electro-fermentation can provide an efficient tool to influence bacterial metabolism and product formation. The project BesTECH aims at developing an electrically enhanced bioconversion process to establish a biotechnological platform that can provide biofuels and biochemicals from low-cost biomass.

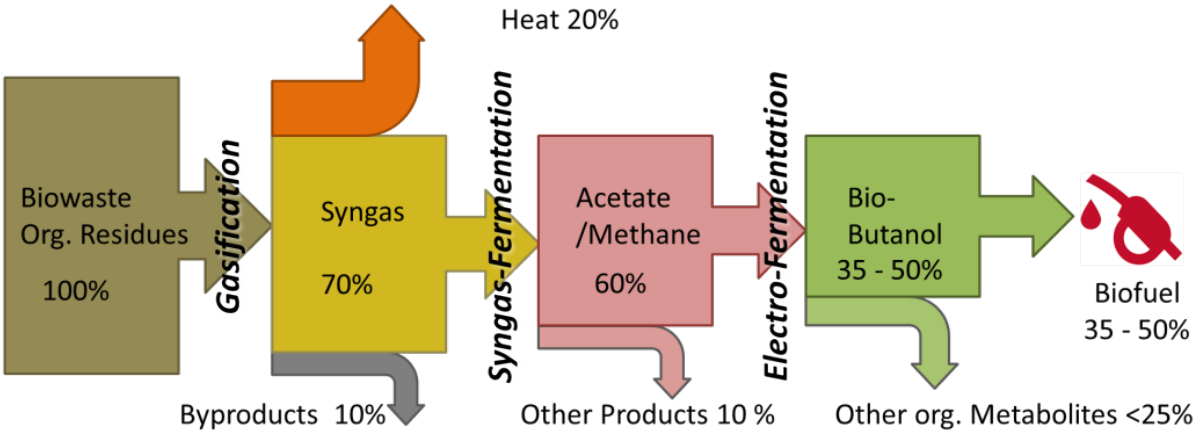


Figure 16: Proposed conversion of biomass through a cascade of conversion technologies: gasification, biological syngas- and electro-fermentation (source: BEST)

- The first step in the process is to convert biomass feedstocks of varying or minor quality into syngas. Biomass and other carbonaceous materials can be gasified to produce syngas with high concentrations of CO, H_2 and CO_2. Such low-cost feedstock materials include waste wood, agricultural residues and by-products, municipal organic wastes and wastes from the pulp and paper industry.
- The subsequent step, syngas fermentation, is a biotechnological process to convert the generated gaseous compounds to alcohols and organic acids (mostly ethanol and acetic acid) by utilizing chemoautotrophic microorganisms that can metabolize gaseous substrates. Biotechnological processes are much less demanding on gas quality and removal of impurities than catalytic processes. This is important as syngas cleaning and conditioning is a substantial cost component of gasification pathways.
- The output is then used as input for microbial electrosynthesis that enables to convert carbon building blocks (CO_2, CO, and acetic acid) into higher value products, serving as biofuels or biochemicals. The focus is to optimize the biotransformation of gaseous substrates into long chain fatty acids and alcohols (e.g., caproic acid, butanol, hexanol, 1,2-butandiol) and methane as final products.

Circular Economy in the Agrana Biorefinery Pischelsdorf

Josef Schuberth, Agrana

The factory of Agrana in Pischelsdorf processes around 1.1 million tonnes per year of feed wheat and feed corn into a range of high-quality products: wheat starch for the technical industry, wheat protein, DDGS, wheat gluten feed and bran for food and animal feed, bioethanol for blending with petrol, and liquid CO_2 for industrial use.

The refinery has high process integration, with cascaded use of streams, reaching high total yield in a whole range of products. Wheat has a very broad starch size distribution (from 1 to 40 µm); big kernels are good for further processing to starch, smaller particles (representing 40-50% of the wheat flower) are suitable for fermentation. Nearly 100% of the protein input – around 10% of the input mass - goes into the food chain, as high as possible.

Only condensate goes to the wastewater treatment, so the overall process has very little loss of organic material. Most of the heat is provided by steam from a nearby waste incineration (very high efficiency in summer). Inside the factory, 12 MW of heat is recovered and fed back into the processes, particularly the drying processes.

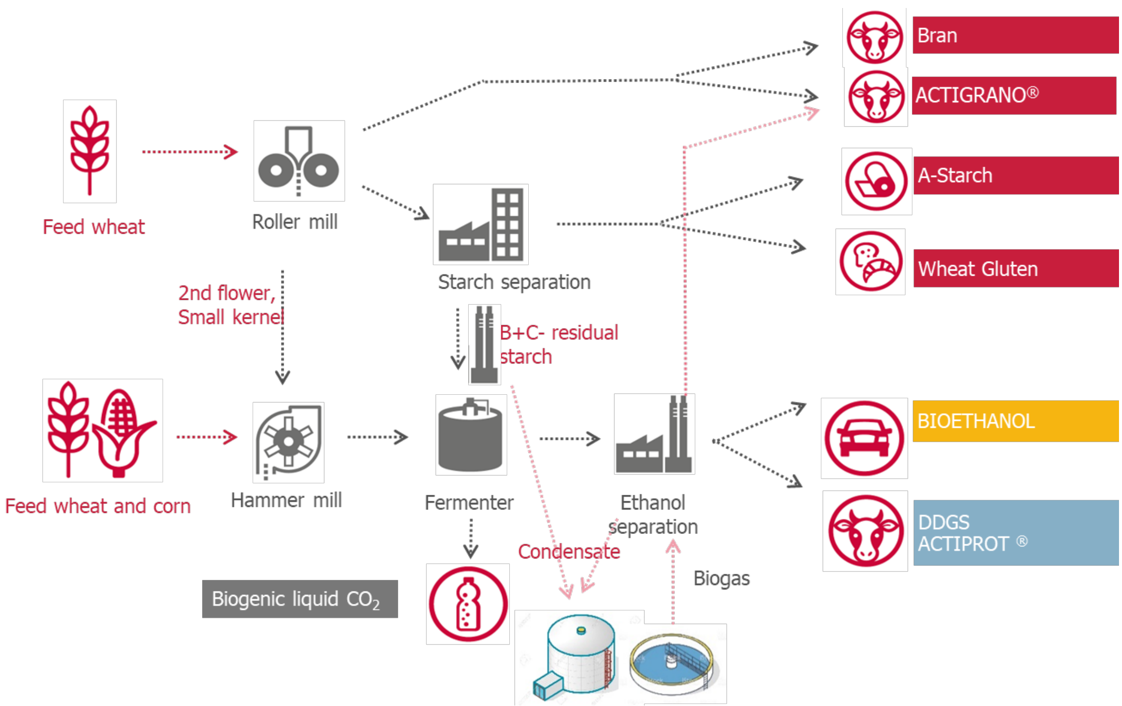


Figure 17: process integration in the Agrana biorefinery Pischendorf, with different inputs and outputs (source: Agrana)

Agrana is also looking into projects for the future.

1. *Green jet fuel from concentrated CO_2*: around 100.000 tons of highly concentrated CO_2 from the fermenter can be transformed into green jet fuel when combining the CO_2 with renewable hydrogen. Current roadblocks are the availability and price of renewable electricity, as well as regulatory obstacles in the EU Renewable Energy Directive on green hydrogen.
2. *Advanced ethanol or sustainable aviation fuel from agricultural residuals* (straw, leaves) through advanced ethanol fermentation processes. Important in this pathway is to return residues (which contain all the nutrients) back to the field.

2G-Bioethanol by utilization of wood sugars - the AustroCel BioRefinery

Petra Wollboldt, AustroCel Hallein

The AustroCel biorefinery in Hallein, near Salzburg, is an integrated pulp mill, processing around 356 ktons of wood chips from spruce per year into 140 ktons high purity dissolving pulp (mainly cellulose, used for fibres for textile production) and 45 ktons of lignosulfonate. The refinery also has a 33 MW_{th} CHP plant operating on woody biomass and internal residues to produce process energy, but it also feeds energy into the local district heating network.

The pulping process has two main by-products.

- Bleaching filtrates are fed into an anaerobic digestor, producing around 2000 m³ per hour biogas which is also producing renewable power and heat.
- Brown liquor, the by-product from the cooking process - containing lignins and lignocellulose – used to be treated in an evaporation plant, and most was combusted for internal energy. In 2021, an advanced ethanol process was installed, in which pre-concentrated brown liquor is fed to convert most of the sugars into bioethanol through an adapted yeast. The residual liquor goes back to the evaporation plant, where it is combusted in a recovery burner and chemicals are recovered. The fermentation process produces 20 million litres of advanced bioethanol per year, which is enough to replace 1% of gasoline demand in Austria.

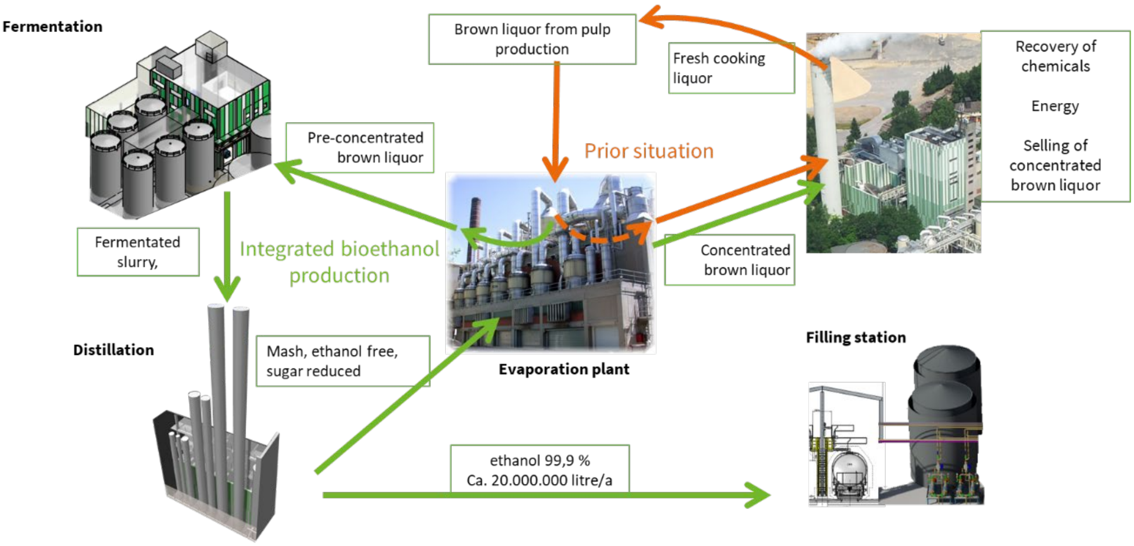


Figure 18: integration and processing of brown liquor, side-product of pulp production (source: Austrocel)

Closing

Luc Pelkmans, Technical Coordinator of IEA Bioenergy closed the workshop with a few highlights from the day.

- Biogas technologies are quite mature, but much is happening in terms of upgrading to biomethane and extracting and using the CO_2 from the biogas. The current push on biomethane at (European) policy level also helps further developments.
- Gasification pathways are coming up, with focus on syngas conversion to fuels or chemicals. The gasification pathway is also promising to deliver biomethane which can be fed into the grid to replace fossil gas.
- Thermochemical and biochemical routes to produce advanced biofuels are entering the market, with new projects coming online and further deployment expected in the coming years. While most current projects and technologies still focus on road biofuels, initiatives are also moving into ways to tag into future sustainable aviation fuel demand.
- Interesting Austrian developments were presented in the last session with concrete realisations in industries. Biorefining is key in all these examples, creating a variety of products, together contributing to the overall business case, and avoiding wastes in the process. Circularity of carbon and nutrients is a common goal in all these projects. Biorefining to multiple products is a central principle in all biobased developments.

Acknowledgements

The following people were involved in the organizing committee to develop the workshop programme: Luc Pelkmans, Dina Bacovsky, Hannes Bauer, Jan Liebetrau, Berend Vreugdenhil, Tomas Ekbom and Andrea Rossi. Their input, as well as the contributions of the speakers, panellists and moderators are gratefully acknowledged. A special thanks goes to BMK and BEST for hosting the event in Vienna, and particularly Dina Bacovsky and Hannes Bauer for taking care of all practical issues before and during the workshop.

Luc Pelkmans, the Technical Coordinator of IEA Bioenergy, prepared the text with input from the different speakers. ETA Florence arranged the final design and production.

IEA Bioenergy

Technology Collaboration Programme