IEA Bioenergy
Technology Collaboration Programme

Annual Report 2021

Technology Collaboration Programme
by iea

IEA Bioenergy is an international collaborative agreement set up in 1978 by the International Energy Agency (IEA) to improve international co-operation and information exchange between national bioenergy RD&D programmes. IEA Bioenergy aims to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use.

Paul Bennett, Chair of the IEA Bioenergy TCP in 2021

To: IEA Headquarters, Paris

IEA BIOENERGY ANNUAL REPORT 2021

Under the IEA Framework for International Energy Technology Cooperation the Executive Committee of each Technology Collaboration Programme (TCP) must produce an Annual Report for IEA Headquarters.

This document contains the report of the IEA Bioenergy Executive Committee for 2021. This year, we have presented a special feature 'Sustainability of biomass for the biobased economy', prepared by Task 45.

The contributions from the Task Leaders and Operating Agents to this report are gratefully acknowledged.

Paul Bennett
Chair

Pearse Buckley
Secretary

Contents

IEA Bioenergy – Selected Highlights from 2021		2
Sustainability of biomass for the biobased economy		13
International Energy Agency		31
Introducing IEA Bioenergy		32
Progress Reports		35
1. The Executive Committee		35
2. Progress in 2021 in the Tasks		45
Task 32:	Biomass Combustion	45
Task 33:	Gasification of Biomass and Waste	52
Task 34:	Direct Thermochemical Liquefaction	56
Task 36:	Materials and energy valorisation of waste in a Circular Economy	61
Task 37:	Energy from Biogas	65
Task 39:	Commercialising Conventional and Advanced Transport Biofuels from Biomass and Other Renewable Feedstocks	80
Task 40:	Deployment of biobased value chains	95
Task 41:	Bioenergy Systems Analysis	100
Task 42:	Biorefining in a Circular Economy	102
Task 43:	Sustainable biomass supply integration for bioenergy within the broader bioeconomy	110
Task 44:	Flexible Bioenergy and System Integration	116
Task 45:	Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy	119
Appendix 1:	Task Participation in 2021	126
Appendix 2:	Budget in 2021: Summary Tables	127
Appendix 3:	Contracting Parties	129
Appendix 4:	List of Reports	130
Appendix 5:	Key Participants in Each Task	139
Appendix 6:	Contact List: Operating Agents and Task Leaders	147
Appendix 7:	Contact List: ExCo Members and Alternate Members	153
Appendix 8:	Some Useful Addresses	158

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Further information on IEA Bioenergy can be obtained from the Executive Committee Secretary, see back cover of this Annual Report.

1. IEA Bioenergy Triannual Online Conference 2021[1]

Between 29 November and 9 December 2021, IEA Bioenergy held its triannual conference. The central theme of the conference was 'The role of biomass in the transition towards a carbon neutral society'. The conference consisted of 10 technical sessions and 4 panel sessions, spread over two weeks. Each day was dedicated to a central topic such as feedstock mobilisation/ sustainability governance; transport biofuels; green gas; circular economy and industry; and bioenergy in the energy system. Almost 1200 people participated in one or more of the conference sessions. They were from around 90 countries from all over the globe.

Overall highlights:

Bioenergy's role in decarbonisation is substantial; BECCS is one of the critical options to remove CO_2 from the atmosphere

Reaching net-zero greenhouse gas (GHG) emissions globally requires an unprecedented transformation of the energy system. A portfolio of options will be needed; there are no silver bullets and we don't have the luxury to dismiss good options. A strong boost will be needed for all relevant options, also for bioenergy. The role of bioenergy in net-zero scenarios of IEA, IRENA, IPCC, is substantial – up to 20% of total energy supply in 2050 at the global level, based on realistic sustainable biomass potentials.

Next to deep and rapid reductions of GHG emissions, carbon dioxide removal (CDR) from the atmosphere will be absolutely necessary to limit global warming. Bioenergy combined with stable geological storage of carbon (BECCS) is one of the critical CDR options.

Bioenergy is part of a broader bioeconomy; sustainability governance is a key requirement

Bioenergy should not be considered in isolation, but as part of a broader bioeconomy, which includes forestry, agriculture, the food industry, the wood processing industries, biomaterials and biochemicals production, waste management and the energy sector. It is by definition cross-cutting and requires a holistic approach over different policy fields.

Good practices show multiple co-benefits (beyond energy), for example, rural development, waste management, circular economy, soil improvement or land restoration. Impacts on the different Sustainable Development Goals (SDGs) need to be considered; depending on the contextual conditions there can be synergies or trade-offs.

1 https://www.ieabioenergyconference2021.org/

Sustainability governance is a key requirement. To de-risk investments there needs to be a clear understanding of what sustainable biomass means and how much biomass can be mobilised within sustainability constraints.

Transition is accelerating; biomass mobilisation is needed; priorities of biomass use will evolve

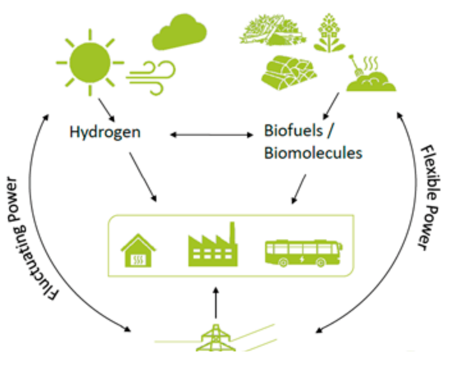
Company ambitions in terms of decarbonisation goals are growing fast, both in sectors which are relatively easy to transform (e.g. light industries, services), and in harder to abate sectors (e.g. aviation or heavy industries). Companies and sectors are taking concrete steps to handle the transition in practice. This requires major investments; companies are vulnerable during transition periods and need a stable policy framework.

There is a gradual shift of biofuels/biomass to difficult-to-electrify sectors (such as aviation, marine transport, industry), although short term displacement of fossil fuels in current systems (e.g. in road transport, heat systems) remains important.

With the trend towards lower value/underutilised heterogeneous biomass resources on the one hand, and higher value applications of biomass (advanced transport fuels, biobased chemicals) on the other hand, there is a need to connect the local and dispersed biomass feedstock base with centralised processing at scale. Biohubs, providing storage and pretreatment at the regional level, can be a tool to make such connections.

Flexibility is one of the key characteristics of bioenergy; there are important synergies with hydrogen

In the near future the integration of energy vectors (power, heat, gas) will be essential to facilitate variable renewables such as solar or wind energy, where dispatchable renewable energy sources such as bioenergy gain importance for grid balancing and cover seasonal fluctuations (particularly for heat). Fossil gas replacement requires much more attention, with biomethane being one of the major options.



Biomass in the future energy system. Source: DBFZ

In an energy mix dominated by wind and solar, flexibility (short and long term) and Bio-CCUS are expected to be two of the more important characteristics of bioenergy. There are important potential interactions and synergies between bioenergy and green hydrogen deployment, for example to combine biogenic CO_2 (from biobased processes) with renewable hydrogen to produce e-fuels.

Reliable and coherent political framework conditions needed for the necessary scale-up

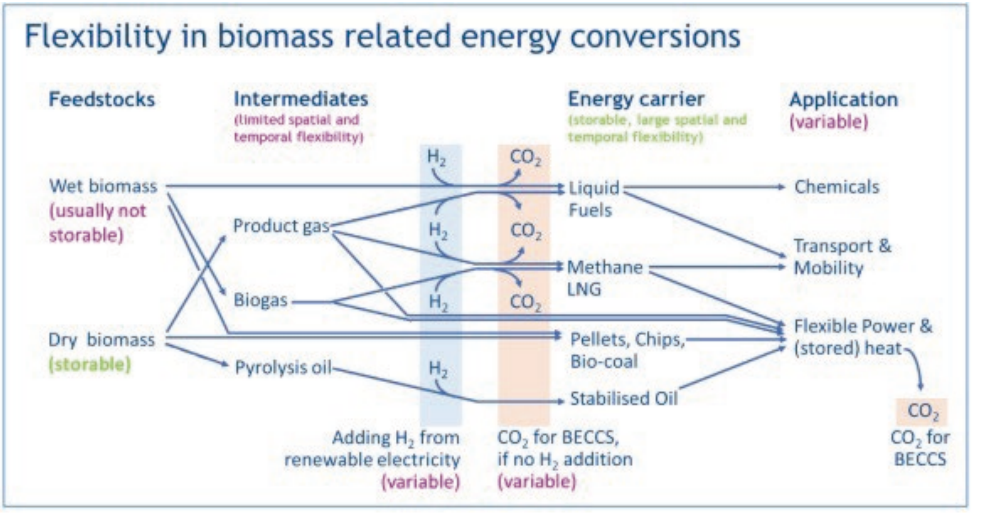
Reliable and coherent political framework conditions are of key importance to motivate investments and to scale up new technologies. The most important policy measures to support biomass applications are carbon pricing, support for RD&D to lower costs and obligations in specific markets.

Presentations, recordings, highlights, and poll results of all sessions, as well as a full conference report are available on the conference website: https://www.ieabioenergyconference2021.org.

2. Technologies for Flexible Bioenergy[2]

The increasing share of renewable energy sources such as photovoltaic systems and wind turbines, of which electricity production depends on weather conditions, leads to a need for more flexibility and controllability of other energy sources, energy carriers and energy storage devices. Flexibility can be defined from different perspectives, such as from system, process or component level perspective. Bioenergy and system integration cover multiple dimensions of flexibility, including temporal and spatial flexibility, as well as flexibility with respect to feedstock, operation, and end-products.

This report, produced by IEA Bioenergy Task 44 (*Flexible Bioenergy and System Integration*), highlights a number of technologies which make the inherent flexibility of sustainable bioenergy usable. A concise overview of the technical possibilities is presented in the base report; in the appendix more detailed information on individual flexible bioenergy technologies including references is given.



2 https://www.ieabioenergy.com/wp-content/uploads/2021/08/Task-44-Technologies-for-Flexible-Bioenergy.pdf

The flexibility of bioenergy has several dimensions:

- Short-term flexibility to balance and stabilise the electricity grid by both positive and negative ancillary services
- Long-term flexibility by biomass-based energy carriers that can be (seasonally) stored and transported within existing infrastructure

By far not all of the technically possible and successfully demonstrated process options are regularly applied. While burning biomass or biomass based intermediates and energy carriers for production of heat or combined heat and power is quite common, the flexibility of these units for **positive ancillary services** (adapt production depending on demand) is only rarely exploited; mostly in countries where suitable incentives such as a flexibility premium exist.

Negative ancillary service, i.e. the flexible up-take of electricity that cannot be used otherwise at time and site of its production by e.g. Power-to-Gas or Power-to-Liquid type processes, is technically solved and was successfully demonstrated only for biogas-upgrading by methanation of the CO_2 content. Flexible hydrogen addition to wood gasification gas or within hydrothermal gasification or liquefaction is still under development.

Long-term flexibility, i.e. the conversion of biomass to energy carriers that can be easily transported or stored within existing infrastructure, is quite common for liquid biofuels or for biogas upgrading to grid-compatible biomethane by CO_2 separation. The conversion of wood to non-solid energy carriers such as methane, stabilised pyrolysis oil, Fischer-Tropsch Diesel or similar has been demonstrated, but still needs to take further steps for good business cases.

As a common observation, the flexible processes that are successful in most countries are starting from waste streams that have to be treated but cannot easily be valorised otherwise, e.g. sewage sludge to biogas to biomethane. The flexible use of woody feedstock is so far limited from two sides: on the one hand, simple combustion to cover heat needs is a financially more attractive alternative to more complex conversion processes, as long as there is sufficient heat demand. On the other hand, due to the value of energy wood and the more complex processes, energy carriers based on wood have a higher price difference to fossil energy carriers than those starting from biogas from waste inputs.

With the further increasing share of variable renewables like PV and wind in the energy system, the flexibility of bioenergy, i.e. positive and negative ancillary services for the electricity grid and options for storage and transport within existing infrastructure, will become more and more important, but will depend on a suitable market design and, for some period, also support schemes to anticipate for upcoming higher flexibility needs in the energy system and to allow the stakeholders to decide for the better investments.

3. IEA Bioenergy Countries Report 2021 Update[3]

IEA Bioenergy published its updated Countries Report, showing the trends of bioenergy in the IEA Bioenergy member countries up to 2019, looking at the role of bioenergy in total energy supply (TES), in electricity use, total fuel/heat consumption, and in transport energy consumption.

Individual country reports are available at https://www.ieabioenergy.com/blog/publications/2021-country-reports/

The IEA Bioenergy member countries have distinct characteristics that impact their renewable energy and bioenergy potential. Country size and population density, as well as topography, climatic conditions and land use distribution are particularly important. Countries with low population density tend to have higher potential availability of domestic biomass resources, while countries with high population density tend to rely much more on imports for their energy and resource requirements.

Energy mix

In the overall energy supply, **coal, oil, and natural gas still play a dominant role in most countries**. Only in Brazil, Finland, France, Norway, Sweden and Switzerland do renewable energy and nuclear energy represent more than half of total energy supply.

- There is a **strong decreasing trend of coal in many countries**, particularly in Europe and North America. Nevertheless, coal still represents a major part of the energy mix in Asian countries, Australia, and South Africa.
- Oil has a substantial and relatively stable role in all countries, particularly in relation to its use in transport.
- Natural gas also has a substantial role and has reached similar or higher levels compared to oil in several countries. **Since 2015, most of the countries had an increase of natural gas use** – in several cases the increase in natural gas compensated (part of) the reduction of coal.
- Apart from countries with elevated levels of hydropower (Norway, Canada, New Zealand and Switzerland), **bioenergy represents more than half of renewable energy supply in most countries**.

3 https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountriesReport2021_final.pdf

Biomass types

Solid biomass remains the dominant type of biomass used for energy in all countries, but liquid biofuels, renewable waste and biogas/biomethane are also relevant.

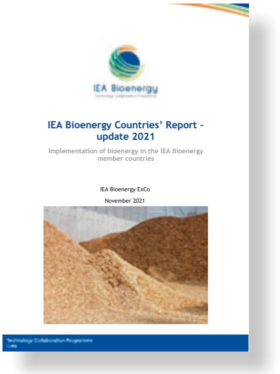
- Countries with the highest use of ***solid biomass*** for energy tend to have a high domestic forest area per capita and important wood processing industries, while their forests are still expanding.
- A few countries with limited domestic forest biomass potential (the Netherlands, the UK, Belgium, and Denmark) rely on solid biomass imports for energy – these countries have imposed sustainability requirements on (large scale) biomass use to mitigate some of the risks related to biomass sourcing from outside the country (which they cannot control with domestic forest policies).
- The amount of municipal solid waste (***MSW)*** used for power and/or heat production is clearly linked to the stage of waste management development in a country, which is quite advanced in Scandinavia and Western Europe where effective collection systems have been implemented and landfill is almost completely phased out.
- Germany is most advanced in ***biogas/biomethane***. Nevertheless, other countries are catching up; particularly Denmark has taken major steps in biogas/biomethane lately. Biogas had been primarily used directly for CHP generation; the raw gas is now more and more upgraded and fed into the gas grid. While biogas/biomethane use peaks above 25% of natural gas use in Denmark, it tends to be equivalent to 1-5% of natural gas use in most countries, showing that major steps will still be needed to phase out fossil gas.
- ***Liquid biofuels*** are on the rise, particularly as transport fuel. In Brazil and Sweden, the use of liquid biofuels is already equivalent to more than 15% of fossil oil use (for transport and heat production). In most other countries liquid biofuel use is equivalent to between 2 and 5% of fossil oil use, indicating that major steps will still be needed to phase out fossil oil.

Renewables and bioenergy in different sectors

Bioenergy plays a role in the three main energy sectors: electricity, fuel/heat consumption and transport energy consumption. **Particularly for heat and transport bioenergy/biofuels are the dominant renewable energy type.**

- The main growth of ***renewable electricity*** in the past decade has been in wind power, followed by solar power and biomass-based power. In Denmark, Finland and Estonia, bioenergy represents more than 15% of electricity production (predominantly through combined heat and power – CHP), followed by the UK, Sweden, Germany and Brazil. In other countries, typical levels of biomass-based electricity are 2-5%.
- For most countries solid biomass is the dominant fuel to produce bioelectricity. However, in Germany, Italy and Croatia bioelectricity is mainly produced from biogas. In Switzerland renewable MSW is the dominant fuel for bioelectricity.

- The ***main support systems*** for renewable power have been through feed-in tariff systems and obligations connected with tradable green certificates. Recently there is a trend to work with tender systems on a competitive basis. A point of attention is that, apart from the production cost per MWh, policy actions also need to reflect the multiple benefits of using bioenergy for electricity, including rural development, waste management and dispatchability.
- In most of the countries analysed, fossil fuels still dominate in ***fuel/heat provision***, typically exceeding 75% of total fuel/heat provision. Biomass is the dominant type of renewable heat. The most important progress in renewable heat has been made in countries with important shares of district heating (Denmark, Estonia, Sweden, Finland), particularly through the replacement of fossil fuels by biomass for centralised heat production.
- The ***main support systems*** for renewable heat have been subsidies for renewable heat projects and financial support for domestic renewable heat instalment. Several countries (particularly in Scandinavia) have implemented a CO_2 tax on fossil fuels which was an important driver for industries (and heat producers) to move from fossil fuels to bioenergy.
- Fossil fuels still represent over 95% of ***transport*** energy in most countries. This reflects the challenge to displace fossil fuels in the transport sector. Brazil and Sweden have achieved a renewable energy share in transport of 25% and 21%, respectively, with Norway and Finland also reaching more than 10%. Most other countries have renewable shares of 4 to 6% or lower.
- Biodiesel (including an increasing share of hydrotreated vegetable oil – HVO) and bioethanol are the dominant biofuel types. Bioethanol is mainly important in countries with high shares of gasoline cars (Brazil, USA, Canada). Biodiesel gains attention with the increased focus on heavy duty transport, which relies on diesel fuel. There is an increasing trend towards advanced (residue based) biofuels and drop-in biofuels to avoid blend walls (ethanol limits in gasoline and FAME limits in diesel).
- The ***main support systems*** for biofuels are tax incentives for biofuels and blending obligation systems. More systems start to be based on the carbon intensity of the fuels, e.g., the Californian Low Carbon Fuel Standard, or RenovaBio in Brazil. There is also support for (advanced) biofuel production facilities to move from pilot to commercial production.
- Renewable electricity is considered as an important option in transport, particularly in the coming decades and mainly in the light duty sector. As of today, electricity use only represents between 0.1 and 4% of transport energy (currently mostly in rail), with the renewable share depending on the national electricity mix. Sales of electric cars are substantially increasing in recent years and several regions have set high targets on EV sales. Nevertheless, with different EV introduction rates in different regions and considering typical vehicle lifetimes of over 10 years, the replacement of the car fleet will take time so that fuels will still be needed for the car



sector in the next few decades; moreover, the heavy-duty sector will still remain dependent on (predominantly diesel type) fuels for quite some time. Thus **renewable fuels will remain an important option to displace fossil fuels in transport**.

4. Sustainability Governance of Bioenergy and the Broader Bioeconomy[4]

The bioeconomy – and bioenergy as part of that – provides key opportunities to achieving the Sustainable Development Goals (SDGs), and to contribute to a "green" recovery after the COVID-19 pandemic. For this, though, it is crucial to assure sustainability governance of the bioeconomy, e.g., regarding access to land, conservation of biodiversity, mitigating climate change, providing employment, ensuring food security, and water availability.

This paper provides an overview of the status and recent developments of bioenergy and bioeconomy governance for the Sustainability Task of the Global Bioenergy Partnership, IEA Bioenergy, and the interested public.

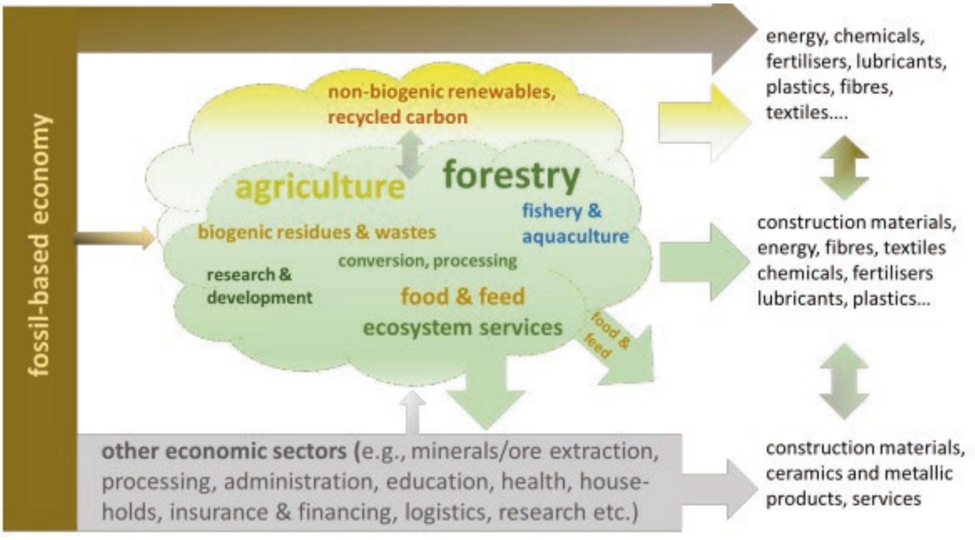
In particular, the objectives of this paper include:

- Provide an overview of the status of the bioenergy and bioeconomy particularly in terms of expected demand and respective impacts (Section 1).
- Define what governance is and summarise the status of bioenergy and bioeconomy governance (Section 2)
- Identify promising sustainability governance approaches for the bioeconomy (Section 3).
- Present perspectives on sustainability governance of the bioeconomy (Section 4)

Throughout this report, bioenergy is referred to as part of the broader bioeconomy, similar to food and feed, fisheries, forestry, and waste management being part of the bioeconomy.

Yet, bioenergy is dealt with specifically, as it has a prominent role in the energy system and is already subject to sustainability governance.

4 http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/TFS/Bioeconomy/IINAS__2021__Sustainability_governance_of_bioenergy_and_bioeconomy_-_final.pdf



Source: Fritsche et al. (2020); yellow- and green-shaded clouds represent renewable economy, green-shaded cloud represents bioeconomy (as part of renewable economy); right side represents outputs to society (products and services); arrows = outputs; double-arrows = substitution potentials

Key messages:

1. The importance of bioenergy and bioeconomy governance is increasingly recognised and implemented on different levels, though without comprehensive cross-sectoral and transboundary coordination. Yet, the nature of connections between primary production (agriculture, forestry, etc.) and conversion (chemicals, construction, energy, fibre, food etc.) requires considering their interactions across sectors, and beyond national boundaries.
2. Given the close interaction of agriculture, forestry, food and the materials and energy sectors it seems appropriate to consider **all uses of biomass** under the bioeconomy concept. Yet, as of today, there is no coherent or comprehensive governance framework for the bioeconomy.
3. Bioeconomy governance is a complex field given the variety of actors, sectors, and interests interacting. There are different approaches to safeguard or enhance the sustainability of the bioeconomy. To assure that sustainability requirements are indeed fulfilled, such approaches should be accountable and based on principles such as assessment of risk, participation, and monitoring.
4. There are various possibilities for companies to demonstrate compliance with sustainability criteria, or to minimise risk, through the supply chain of the company: certification schemes, verification, or due diligence (or a combination of them).
5. There is increasing interest of many stakeholders to work collaboratively on improving sustainability governance of the bioeconomy. The possible extension of the GBEP Sustainability Indicators for Bioenergy to the broader bioeconomy may be a key opportunity to deliver on that ambition, and initiatives such as the Global Bioeconomy Summits could help exchanging views and supporting alignment between countries.

5 Progress in the Commercialization of Biojet/Sustainable Aviation Fuels: Technologies, potential and challenges[5]

This report, prepared by IEA Bioenergy Task 39, provides an extensive analysis of the current and potential technologies for production of biomass based sustainable aviation fuels (Biojet/SAF).

Sustainable Aviation Fuels will have to play a major role if the aviation sector is to significantly reduce its carbon footprint. However, to date, commercialisation has been slow and current policies have proved inadequate to accelerate commercialisation and widespread deployment of the various technologies described in the report.

As described in IEA's recent publication *Net Zero by 2050: A Roadmap for the Global Energy Sector*, although synthetic hydrogen-based jetfuels will also play an important role in the future, **in the short-to-mid-term biojet fuels will predominate**. Commercial battery electric and hydrogen aircraft are expected to play a small role in the 2050 timeframe.

Annual volumes of biojet fuel have increased in recent years, from less than 10 million litres in 2018 to likely more than 1 billion litres by 2023 (and potentially ~8 billion litres by 2030!), with the **vast majority of this volumes derived from lipids/oleochemicals via the HEFA (hydrotreated esters and fatty acids) pathway**. As described in the report, the upgrading of fats, oils and greases (FOGs) to HEFA is fully commercialised and biojet production is relatively simple compared to other pathways. Currently, these facilities are primarily used to make renewable diesel (driven by incentivising policies for road transport), however, about 15% of this renewable diesel could be separated and used as Biojet/SAF, provided some additional infrastructure is established at the refinery.

The report summarises the various technologies that are currently being pursued to produce Biojet/SAF from alternative feedstocks, with several commercial-scale facilities coming online over the next few years. The various technologies include gasification and Fischer-Tropsch to jet, alcohol-to-jet and catalytic hydrothermolysis jet (CHJ). Several of these pathways and fuels have already received certification, under ASTM, to be used in commercial aviation. Although other technologies, such as pyrolysis and hydrothermal liquefaction are under development, they are not yet ASTM certified.

5 https://www.ieabioenergy.com/wp-content/uploads/2021/06/IEA-Bioenergy-Task-39-Progress-in-the-commercialisation-of-biojet-fuels-May-2021-1.pdf

As deployment of HEFA is constrained by the limited availability of fats and oils, most of the technologies/pathways to Biojet/SAF will need to be pursued if we are to deliver the significant fuel volumes required to decarbonise aviation.

As highlighted in the report, some of the Biojet/SAF processes have encountered high capital and feedstock costs while some of the other approaches are dealing with technology challenges. The report recognises that Biojet/SAF fuel prices are likely to remain significantly higher than conventional jet fuel. **The "right" policies will be needed to bridge the price gap and incentivise the production and use of biojet fuels and other sustainable aviation fuels.**

Although ongoing improvements and optimisation of the various processes will continue to reduce the cost of Biojet/SAF production and use, meeting the sector's decarbonisation targets will be challenging and requires strong commitment of the aviation sector.

Sustainability of biomass for the biobased economy

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1. Introduction

The recently launched Working Group I contribution to the Sixth Assessment Report of the IPCC highlighted once more the unprecedented rate of global warming driven by greenhouse gas (GHG) emissions from human activities. Limiting global warming to 1.5-2°C at the end of the 21st century requires deep GHG emissions reductions, reaching net zero around 2050, followed by net negative emissions. The IEA World Energy Outlook (WEO) 2021 stresses the important role of bioenergy in meeting these net zero targets, especially in sectors which are difficult to decarbonise, and by providing negative emissions through combining bioenergy with carbon capture and storage and/or utilisation (BECCS/BECCU) [1]. Bioenergy is currently the largest contributor to the global renewable energy mix and, according to the WEO, its share is expected to more than double by 2030 (Figure 1). Thus, related to the 2030 Agenda for Sustainable Development, bioenergy is expected to make critical contributions to the Sustainable Development Goals 13 (Climate Action) and 7 (Clean and Affordable Energy).

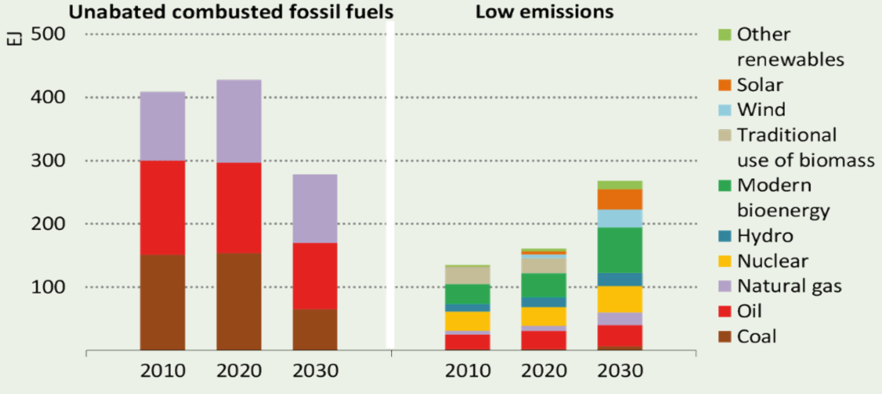

Figure 1: IEA WEO 2021 projected contribution of bioenergy to the energy mix [1].

Large scale deployment of bioenergy and other biobased products (such as chemicals and materials) requires the mobilisation of large quantities of biomass feedstock. The increasing biomass demand can partly be met by using residues and waste, but also requires dedicated feedstock production. However, there are sustainability challenges related to the use of biomass for energy and other biobased value chains. Besides that, the GHG mitigation effect of bioenergy deployment varies: there can be synergies as well as trade-offs with other important sustainability objectives such as protection of biodiversity, soil, and water resources, and improving socio-economic conditions, e.g., food security, energy security, employment opportunities, and rural development (Figure 2). For these reasons, the use of biomass for energy and other biobased products not only relates to SDGs 13 and 7, but also relates – directly or indirectly – to many other SDGs, such as SDG 2 (Zero Hunger), 6 (Clean Water and Sanitation), 8 (Decent Work and Economic Growth), 12 (Responsible Production and Consumption), and 15 (Life on Land) [8].

The importance of bioenergy in the transition towards a sustainable energy system and the wide range of possible consequences of bioenergy deployment have resulted in heated academic, political, and societal debates. Initially, concerns mainly related to food security impacts of using food crops for biofuel production, but have been broadened over time to address also other sustainability issues (e.g., biodiversity, land tenure), as well as other bioenergy systems (e.g., biogas) and other biobased applications (e.g., bioplastics). In the past two decades, several (voluntary) certification schemes, national and international policies, and agreements have been developed to address these sustainability concerns [19].

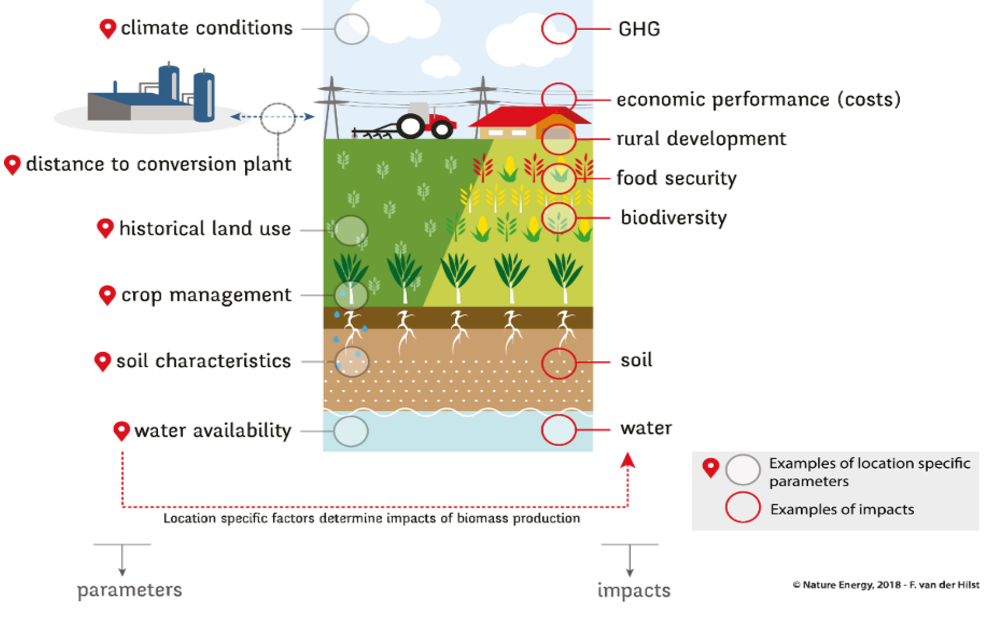

Figure 2: Biophysical and socio-economic conditions have a large influence on the sustainability impacts of bioenergy. These conditions are location specific and change over time. Adapted from Nature Energy [2], figure created by Studio Infograph.

There is consensus that biobased solutions require that biomass is sustainably sourced and efficiently used, and there is also some consensus on the key areas of concern. But there is a lack of agreement on how to assess sustainability of bioenergy and other biobased systems: what aspects of sustainability to quantify, what indicators to use, what methods to apply, and how to weigh synergies and trade-offs. The SDGs provide a useful framework, and indicators, that can be applied in assessment of sustainability of bioenergy. There are several reasons why sustainability assessment of bioenergy is a particularly complex issue:

1. The consequences of bioenergy deployment depend on the type of bioenergy system (i.e., feedstock type, conversion technology, end-use), the system it replaces (e.g., wood pellets replace coal in power plants, ethanol replaces gasoline in light-duty vehicles), and the counterfactual land and biomass use in the absence of bioenergy (e.g., would woody debris be left in the field, burned onsite, or used for firing the drying kiln at the mill?)
2. Sustainability depends on the management and design of each component of the biomass value chain (e.g., sugar cane production in intensively managed irrigated monocultures, or in small low-input plots by out-growers; biomass transportation by diesel truck or by electric train; efficiency and energy use in the conversion process). Thus, the same type of bioenergy system (same crop, conversion technology and end-use) can be very different depending on the design and management of the individual components.
3. The sustainability also depends on the biophysical and socio-economic conditions, which influence the management and design of biomass value chains as well as their environmental and socio-economic consequences. Due to this, sustainability impacts of bioenergy deployment will vary geographically and over time.

To complicate matters, there are differences between the impacts of single bioenergy projects and the cumulative impacts of multiple projects, and also between the local and global impacts of bioenergy. For example, on a global level bioenergy production may have very limited impact on food production, but establishment of bioenergy plantations on lands previously used for food production can cause severe food security impacts where people are dependent on their own food production for their subsistence. Likewise, there are differences between the impacts in the short and the longer term, e.g., converting land to dedicated energy crop production may cause a temporary increase in GHG emissions but may contribute to larger GHG savings in the longer-term. Furthermore, it is difficult to predict and quantify all potential indirect effects such as displacement (i.e., indirect land-use change and related impacts), rebound effects (e.g., when bioenergy supply leads to a decrease in fossil fuel prices resulting in increased fossil fuel consumption) or other dynamic effects (e.g., when dispatchable bioelectricity provides balancing power enhancing expansion of solar and wind). Finally, although the production and use of bioenergy can result in synergies between positive impacts, there will also be trade-offs between different sustainability impacts.

Below, we provide an overview of key sustainability concerns of bioenergy and other biobased systems and how negative impacts can be avoided or mitigated, and positive impacts be promoted.

2. Land use change related to biomass production

Many sustainability concerns are related to land use and land-use change associated with dedicated biomass production. Negative impacts can occur as a consequence of direct land-use change, such as when natural ecosystems or lands used for food production are converted to energy crop production. When food production or other land use activities are displaced by dedicated energy crops, this can in turn result in indirect land-use change (ILUC), i.e., a change of land use that occurs elsewhere due to this displacement with energy crops [3]. While demand side responses (e.g., changes in food consumption) and dynamic effects in supply chains (e.g., intensification of food cropping and changes in animal feeding) can buffer some of the displacement effects, the ILUC that still occurs can cause impacts commonly associated with agriculture expansion, such as deforestation or conversion of other natural ecosystems with high-carbon stock and/or high biodiversity value, e.g., wetlands and peatland [4]. There can also be cascading effects, such as when expansion of energy crops displaces food crops to areas previously used for livestock production that in turn relocates to areas with natural vegetation [5]. Among potential detrimental effects, GHG emissions through land clearing associated with ILUC can negate some or all of the GHG emission savings from the bioenergy deployment.

Many studies have tried to quantify ILUC effects of bioenergy deployment, commonly using macro-economic models such as computable general equilibrium or partial equilibrium models to capture market mechanisms and competition. The results of these modelling efforts show large variation in the amount of ILUC resulting from bioenergy production. These variations can partly be explained by the differences in the structures of the models and the assumptions and input data used [5]. But the variation also reflects the challenges in modelling land-use change, which is shaped by a complex set of cultural, technological, biophysical, political, economic, and demographic factors that vary over space and time. Furthermore, as the models are constructed and calibrated based on historic experience and data they are not well-suited to capture innovation and emerging drivers of land-use and land use change.

Progress has been made in projecting the amount and location of land-use change resulting from biomass feedstock production, by using integrated assessment models or by linking economic models with spatial land use allocation models, but these projections remain very uncertain, and estimations of ILUC-related emissions are considered too uncertain to be included quantitatively in policy. Yet, given the risk of negative environmental and socio-economic impacts, the recast of the EU renewable energy directive (RED II) *aims to phase out so-called 'high-ILUC-risk' biofuels and promote the adoption of 'low-ILUC-risk' biofuels.* [4]. The contribution of high ILUC risk bioenergy is to be phased out by 2030, and only low ILUC risk bioenergy is to be counted against the renewable energy targets of Member States. The RED II defines low ILUC-risk biofuels, bioliquids and biomass fuels as '*biofuels, bioliquids and biomass fuels, the feedstock of which was produced within schemes which avoid displacement effects of food and feed-crop based biofuels, bioliquids and biomass fuels through improved agricultural practices as well as through the cultivation of crops on areas which were previously not used for cultivation of crops, and which were produced in accordance with the sustainability criteria for biofuels, bioliquids and biomass fuels.*'[4].

It is a dilemma that – on the one hand – current land uses (e.g., agriculture) cause many negative impacts, and land-use changes to dedicated energy crop (especially perennial) cultivation can help mitigating many of these impacts [6-8], but – on the other hand – the displacement of food production can result in ILUC causing negative impacts elsewhere. This dilemma is analogous to the exportation of impacts through international trade in agriculture and forest products driving land-use change in tropical forest and savanna biomes that cause GHG emissions and other environmental impacts.

3. Climate impacts of bioenergy systems

Use of bioenergy is a climate change mitigation strategy, as long as the GHG emissions associated with the bioenergy system are lower than the emissions of the displaced energy system. Bioenergy is often considered to be carbon neutral because the carbon that is released during combustion was previously sequestered from the atmosphere and will be sequestered again when the plants are regrown. However, the carbon neutrality of bioenergy has been strongly debated, and climate benefits are increasingly being questioned. The literature contains a wide range of findings with respect to climate impacts from strong positive to large negative effects, even for apparently similar bioenergy systems. IEA Bioenergy Task 45 (Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy – and previously Task 38) has investigated the basis for this divergence and developed a standard approach for quantifying the climate effects of forest bioenergy [9, 10]. Below, we summarise the major considerations reflected in this approach.

Bioenergy should not be assumed to be carbon neutral; assuming carbon neutrality is overly simplistic and does not accurately reflect the climate change impact of bioenergy systems. To quantify the climate effects of bioenergy, the following key elements must be considered:

1. *GHG emissions across the supply chain*, including N_2O emissions from fertiliser use, and fossil fuels used in biomass production, harvest, transport and processing, and emissions avoided, such as methane from manure stock-piling or disposal of organic residues to landfill
2. Any sustained *change in the carbon stock in vegetation and soil* at the site where biomass is extracted under the bioenergy scenario compared with a reference scenario in which bioenergy is not used
3. The *energy source displaced* by bioenergy. Displacing brown coal, a high GHG intensity energy source, offers greater benefits than displacing natural gas.
4. *Indirect market-driven and system-level effects*, such as indirect land use change or impacts on wood products or on the deployment of other energy options
5. Besides GHG effects, *non-GHG factors*, can also be significant. Specifically, bioenergy systems can change land albedo, increasing reflectance in some circumstances (such as where biomass harvest in boreal climates increases snow cover) or diminishing it (e.g., where evergreen trees displace deciduous vegetation).

Each of these elements can enhance or diminish the climate change benefits of bioenergy. Below we elaborate on points 2 to 4, addressing the critical aspects of the reference scenario and the system boundary The selection of the reference system, also known as the counterfactual, is a critical aspect: the refence should represent the most likely scenario in the absence of the bioenergy system. The refence system should describe the reference land use or use of the biomass resource, and the reference energy source. It may be relevant to consider several reference system options. In the case of forest bioenergy, it is sometimes suggested that a no-harvest reference should be applied, in order to calculate forgone sequestration. However, this would not represent the most likely alternative land use in the case of forests that are managed for timber production, as they would continue to be harvested to meet ongoing demand for wood products in the no-bioenergy scenario. Where a no-harvest reference is applied, it should be recognised that sequestration rate slows as forests approach maturity, and that forests managed for conservation alone may have increased risk of disturbance, such as wildfire.

Carbon stock in vegetation and soil varies seasonally in annual systems and can fluctuate from year to year in variable climates. A sustained decline can occur if fertility is depleted through excessive removal of residues for bioenergy. In forest systems managed as even-aged stands, carbon stock fluctuates widely at stand level across the rotation, but at landscape level the losses in harvested stands are balanced by growth in other stands, such that carbon stock remains constant or increases if growth equals or exceeds harvest. If bioenergy incentives encourage a change in management that reduces the long-term average carbon stock through intensified harvest, this will decrease the climate benefit. On the other hand, improved forest management that stimulates growth through fertilisation, improved site preparation and use of superior genetic material can minimise or avoid such a decline in forest carbon stock. This raises the importance of considering socio-economic factors that may be influenced by bioenergy policies. Besides providing incentives for improved forest management, policies promoting bioenergy could stimulate retention or expansion of forests, which would add to the climate benefit [12, 13].

Applying a system-level perspective is important, to capture flow-on effects. In the case of forests, biomass for energy is usually a co-product of timber production, derived from harvest slash that would otherwise have decayed in the forest, or from mill residues, or construction and demolition waste. Biomass for bioenergy tends to be a low value product compared with sawlogs, and thus is usually not the primary driver in determining forest management and harvest scheduling. Therefore, it is important to assess bioenergy within the context of forest products markets.

The role of bioenergy within the energy system should also be considered. Because bioenergy is a dispatchable energy source, it can provide balancing power to give grid stability, supporting the expansion of intermittent renewables, and therefore has a key role to play in energy system transition [14]. An Australian study identified that inclusion of bioenergy could reduce the levelised cost of electricity in a 100% renewable energy scenario because it decreased the required capacity of wind and solar facilities [15].

A strongly-debated aspect in the case of bioenergy from existing forests is the issue of payback time. If the use of bioenergy leads to a reduction in average forest carbon stock, this is a "GHG cost" that must be "repaid" by displacing fossil fuel emissions before the bioenergy system delivers a net climate benefit. However, a focus on payback time is unhelpful. Firstly, the quantification of payback time is uncertain, due to imperfect knowledge of the future, and the need to include indirect effects as described above, such as the potential for bioenergy to support energy system transition. Second, payback time is subjective, because it is strongly dependent on the details of the reference system chosen as the counterfactual. Third, there is no consensus on what an acceptable payback time is. While the urgency to address climate change is sometimes cited as reason to exclude options with payback times longer than a decade [e.g. 16], this perspective is inconsistent with the modelling presented by the IPCC that shows many pathways consistent with achieving the "well-below 2°C" goal of the Paris Agreement, a large proportion of which involve "overshoot" followed by a phase of net negative emissions. Furthermore, a focus on payback time is restrictive: the most important climate change mitigation measure is the transformation of energy, industry, and transport systems so that fossil carbon remains underground. But a focus on short term emission reductions can lead to decisions that lock in future emissions, such as the construction of new fossil fuel power plants, and make medium- to long-term climate goals more difficult to achieve.

Climate benefits of bioenergy are maximised when:

- bioenergy is used to displace fossil fuels, especially high GHG-intensity energy systems based on coal;
- biomass is used efficiently to generate energy products, such as in combined heat and power plants;
- bioenergy feedstocks comprise organic residues that would otherwise be landfilled, such as food processing wastes and urban green waste;
- bioenergy is a co-product of a forest managed to produce multiple wood products, where high quality timber is used for building materials that displace GHG-intensive building materials, the residues and end-of-life wood products are used for bioenergy, and improved forest management is applied, to enhance forest growth rate;
- Bioenergy is linked to CO_2 capture and storage (BECCS), as a carbon dioxide removal strategy, that can contribute to net negative emissions required to meet global and national net zero targets. BECCS is in advanced stages of technical development, and commercial-scale operations have been demonstrated. Global potential mitigation is estimated at around 10 Gt CO_2e/year [11].

4. Other environmental impacts

Biodiversity

The impact of biodiversity (SDG 15 – life on land) is one of the key areas of concern related to the sustainability of bioenergy. Studies on biodiversity impacts of bioenergy show a high variety in results due to large differences in bioenergy systems, management, and the biophysical and socio-economic context, but also due to large differences in definitions and indicators of biodiversity, the spatial and temporal scale of assessment, and the methodologies applied. To date, there is no single indicator that captures the complexity of biodiversity and there is no general consensus on a suitable (set of) proxy indicators.

Dedicated energy crop production can affect biodiversity in several ways, including through land-use change, overexploitation, pollution, and spreading invasive species [17]. Negative impacts on biodiversity occur when natural vegetation (primary and secondary forest, natural grasslands, wetlands) is converted to agricultural land, in particular in the tropics, causing habitat loss and fragmentation of remnant vegetation. Negative impacts can also occur when biodiverse grazing lands are converted to forests for wood production and/or in-forest carbon storage. Conversely, when abandoned cropland, degraded or marginal lands are converted to second generation energy crops, positive impacts can occur. Perennial crops can provide habitat or shelter for specific species and improve connectivity or support restoration of degraded or marginal land, resulting in biodiversity benefits. Also, when intensively manged cropland is replaced by less intensively managed second generation energy crops, biodiversity is positively affected. However, this may result in negative impacts elsewhere due to ILUC.

Agricultural intensification to increase yields can reduce the pressures on land following the growing demand for food, bioenergy, and other biobased products. But while it reduces the risk of agricultural expansion into sensitive habitats, agricultural intensification is likely to decrease agrobiodiversity and increase pollution if achieved through monocultures and high input of fertilisers and pesticides [18]. In the past two decades, there has been much debate on whether land sparing (intensification of agriculture to increase yields, enabling "spare" land to be set aside for nature conservation) or land sharing (i.e., practices that support high level of biodiversity within agricultural lands) is the best approach for biodiversity conservation. Although this debate is not settled yet, there seems to be an increasing understanding that this is not a dichotomy, but a continuum and that suitability of solutions is highly dependent on the context.

If the dedicated energy crops are non-native species, they can be invasive which can threaten biodiversity. However, bioenergy markets can also facilitate the eradication of invasive species that threaten biodiversity and water availability. By using the biomass of invasive alien plants for bioenergy production, their costly removal can become more economically viable [19]. Besides land-use change, climate change is a key threat to biodiversity. By contributing to GHG mitigation, bioenergy can reduce the potential biodiversity loss due to climate change.

Water

The large majority of water use for bioenergy production (>90%) is related to energy crop cultivation. The agricultural sector is responsible for 70% of global fresh water use. Direct and indirect land-use changes and agricultural intensification resulting from dedicated energy crop production may alter the water balance of a water basin due to changes in precipitation interception, evapotranspiration, run-off, infiltration and percolation, and water withdrawals for irrigation. The amount of water lost through evapotranspiration depends on the type of crop, growing cycle and growth stage, and management practices, as well as local water availability and climate and soil characteristics. Therefore, the influence of bioenergy on water availability and quality (SDG 6 – Clean water and sanitation) varies over space and time and can be positive or negative.

Most first generation energy crops have a relatively low water use efficiency (i.e., biomass production per unit of water). Second generation crops (often fast-growing species) and also sugar cane have a high water use efficiency. Some species such as eucalyptus have deep rooting systems, which has the advantage that they can tap into deep ground water and therefore survive and remain productive in relatively dry periods. However, as these species commonly have high growth rates, the total water consumption through evapotranspiration is relatively high compared to other land uses. This may be problematic especially in water scarce regions where water availability can be an issue. The use of marginal lands for the cultivation of energy crops that are relatively tolerant to marginal conditions (drought, salinity) can enhance the productive use of water. Conversely, energy crops that are tolerant of wet conditions can be cultivated in floodplains and riparian areas to contribute to flood protection. Climate change is expected to cause more extreme weather conditions, which will result in more water scarcity in some regions and more flooding in others. By contributing to GHG mitigation, bioenergy deployment reduces the impacts of climate change on water availability.

Although there are concerns about the impact of bioenergy processing on water quality (e.g., effluent of palm oil mills), most of the impacts of bioenergy on water quality are related to the cultivation of dedicated energy crops, specifically the run-off of agrochemicals, fertilisers, and sediment. Negative impacts on water quality occur when natural vegetation is converted to agricultural land. Generally, first generation energy crops require relatively high amounts of fertiliser and agrochemicals resulting in negative impacts on water quality. When intensively manged cropland is replaced by perennial energy crops, water quality improves. Also, agricultural intensification in response to land competition from energy crop production may result in negative impacts on water quality. The cultivation of perennial energy crops on abandoned cropland, in riparian areas, or as windbreaks between agricultural fields can enhance nutrient and sediment retention and therefore improve water quality [7, 8].

Soil

A key aspect of dedicated crop production concerns the impacts on soils through influencing erosion and soil organic matter content (SDG 15 – Life on land). In addition to carbon sequestration in the soil, soil organic matter is associated with other important soil functions such as water holding capacity, nutrient retention and soil structure which are all important for soil biodiversity and productivity. Soil organic matter content depends on soil type and climate as well as historic and current land use and land management. Soil disturbance decreases soil organic matter. Therefore, the conversion from natural vegetation to arable land, resulting directly or indirectly from energy crop production, causes a decrease in soil quality. This especially applies to annual crops. Also, residue removal (for bioenergy use) will decrease soil organic matter. On the other hand, the cultivation of perennial crops on abandoned agricultural land and marginal land with depleted soil carbon content will increase soil organic matter and can contribute to soil restoration. Soil erosion can be caused by rainfall or by wind. The soil erosion risk depends on soil, climate, and geomorphological factors, as well as land use and land management. The conversion of annual cropland, abandoned cropland and marginal land to perennial energy crops can reduce soil erosion risk through increased rooting system, high soil cover and low soil disturbance.

In general, negative impacts of bioenergy production on biodiversity, water availability, water quality and soil quality can be limited, and positive impacts can be enhanced, when:

- Direct or indirect conversion of native vegetation is avoided.
- Abandoned cropland, degraded or marginal lands are used for the cultivation of perennial energy crops (preferably native species).
- Energy crop production causing high evapotranspiration is avoided where it is expected to cause negative impacts on water availability for other users, i.e., mainly in water scarce areas.
- Best management practices are applied, including crop rotation and intercropping, no-till farming, and appropriate fertiliser, pesticide and irrigation use
- The heterogeneity in the landscape is enhanced through maintenance or creation of natural/semi-natural landscape elements, which contribute to connectivity and reduce fragmentation. Agroforestry or silvopastoral systems, wind breaks and riparian buffers with perennial energy crops, can provide these landscape functions while also providing biomass feedstock, increasing soil organic matter, and reducing soil erosion and nutrient leaching.

5. Socio-economic impacts

Besides the GHG mitigation potential, the increasing demand for bioenergy is also driven by its potential contribution to a number of socio-economic goals such as energy security and economic development. However, the socio-economic impacts of bioenergy are not unequivocally positive.

Bioenergy production and use can contribute to energy security (SDG 7 – Affordable and clean energy) by reducing the dependency on fossil fuels (and thereby the dependency on unstable regions and volatile markets); by diversifying the energy mix (and thereby increasing the security of supply); and by improving energy access (by offering opportunities for bioenergy applications for remote areas without grid connection). Bioenergy production could, however, also reduce energy security if bioenergy deployment results in higher energy prices potentially reducing energy access for people with scarce economic resources. Furthermore, deployment of modern bioenergy systems can lead to reduced energy security locally if it reduces the availability of biomass for traditional uses by the local population (i.e., cooking in developing countries) and no alternative to these traditional bioenergy uses is provided.

Bioenergy production and use can contribute to SDG 8 – Decent Work and Economic Growth. It can improve the national trade balance, depending on fossil fuel imports and the bioenergy potential of a country. The development of a bioenergy sector and enhanced domestic supply sectors can contribute to improved energy access, employment opportunities and increased incomes in rural areas enabling also other economic activities and rural development. Potential negative impacts include the loss of employment and economic activities associated with the competing (e.g., fossil) energy sectors, displacement of other land-based activities and associated industries, the seasonality of jobs in the bioenergy sector, and labour migration.

One of the key sustainability concerns of bioenergy production is the potential impact on food security (SDG 2 – Zero Hunger), especially in developing countries. According to the definition of the FAO [20], there are four pillars of food security: *availability, access, utilisation, and stability*. Concerns about food security impacts of bioenergy mostly relate to the competition for land, water, labour, and other resources, which could impact production (*availability*) and prices of food products. Higher food prices could negatively affect *access* to food, especially for food-importing countries and low-income urban households. However, as global food prices are subject to an interplay of many uncertain factors (e.g. weather, energy prices, speculation), the relationship between increased bioenergy production and higher food prices is debated [21]. When bioenergy production leads to a higher dependency of rural households on crop production for their income, it could make them more vulnerable to extreme weather events, and therefore reduces *stability* of food security. Competition for water can potentially reduce water availability for cleaning and cooking food, which negatively impacts the *utilisation* of food. However, bioenergy production can also positively affect food security. Technology spill-overs from dedicated energy crop production can increase food crop yields, thereby increasing food *availability*. The bioenergy sector can contribute to increased and stable employment and income of rural households, thereby improving *access* to food. Higher food prices due to bioenergy production could result in higher incomes of farmers and therefore increase their food *access*. Furthermore, the energy security benefits addressed above can positively affect the *utilisation* and *stability* aspects of food security, as it enhances reliable storage and cooking of food.

Other potential socio-economic issues raised include impacts on land rights, wellbeing, working conditions, health and safety, and equality. While linkages to bioenergy is not straightforward, these are highly important issues that need to be considered in the planning, design, implementation, and management of bioenergy projects, especially related to foreign investments in developing countries or in countries with weaker legislation, policy frameworks and institutions.

6. Synergies and trade-offs

As presented in the previous sections, the use of biomass for energy and other biobased products not only relates to SDGs 13 and 7, but also relates – directly or indirectly – to many other SDGs. The use of biomass for energy and other biobased products can lead to both synergies and trade-offs between the SDGs as well as between different indicators within an SDG (see Figure 3). The outcome depends on the bioenergy system and the system that is substituted, the design and management of the biomass system, and the biophysical and socio-economic context,

In a study conducted under the auspices of IEA Bioenergy Task 43 (Sustainable biomass supply integration for bioenergy within the broader bioeconomy) and Task 45 (Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy), a literature review was performed to identify the main synergies and trade-offs associated with land use for dedicated energy crop production and to identify the context-specific conditions which affect those synergies and trade-offs. The study specifically addresses the trade-offs between SDG 13 (Climate action) and the other SDGs. The review found that the number of synergistic relationships reported in the literature was similar to the number of trade-off relationships between GHG emission reduction and SDGs 2 (Zero hunger), 3 (Good health and well-being), 6 (Clean water and sanitation), 8 (Decent work and economic growth), 13 (Climate action – other indicators), 14 (Life below water), and 15 (Life on land). However, more synergies were found related to SDGs 3, 13, 14 and 15, while more trade-offs were found related to SDGs 2, 6 and 8. Whether synergies or trade-offs occur depends on context-specific factors: they are mainly affected by previous land use and biomass feedstock type and to a lesser extent by climate region, soil type and agricultural management applied.

Figure 3: Land use for dedicated energy crop production results in synergies and trade-offs between SDG 13 and other Sustainable Development Goals.

The use of marginal lands for perennial energy crops potentially maximises synergies between SDG 13 and the other SDGs and minimises the trade-offs, not the least competition with food production. As described above, perennial crops can have advantageous effects on biodiversity and restoration of marginal lands. Furthermore, compared to annual crops they can reduce soil erosion and sequester more carbon in biomass and soils improving soil quality. Perennial crops also generally require less agrochemicals and fertilisers, which is beneficial for water quality. However, the performance (e.g., yield) of perennials on marginal lands is uncertain and production costs can be relatively high. This can potentially result in trade-offs with farmers income and with security of supply. Changes in financial support schemes (e.g., rewarding carbon storage in agricultural land and forests) and policy incentives can help to overcome these challenges.

The study highlights the importance of considering context-specific conditions in evaluating synergies and trade-offs of using land for dedicated energy crops. This is key for informed decision-making and policy development for sustainable bioenergy deployment.

7. Sustainability governance

Governance – here understood as the sum of formal and informal ways that actors and institutions, public and private, manage common affairs – is a continuing process through which diverging interests may be accommodated and cooperative action may be taken. Sustainability governance is concerned with promoting the positive effects of production or development processes whilst avoiding/mitigating their negative impacts, considering environmental, social, and economic aspects of sustainability. Public discourse, stakeholder involvement, and transparent governance structures and procedures at local to global scales are key.

The bioeconomy – and bioenergy as part of it – connects, via international value chains and global trade, raw material-producing countries with those in which intermediate products are manufactured or end products are consumed, i.e., it has global reach. Thus, global governance is necessary for a sustainable bioeconomy, addressing opportunities and risks across borders, both in the geographical sense and in relation to planetary boundaries.

The Sustainable Development Goals (SDGs), agreed upon in 2015 by the United Nations General Assembly, set the ambition for globally sustainable development, to be met in 2030 at the latest [22]. As indicated in Section 6, the use of biomass for energy and other biobased products is linked to many SDGs – both positively and negatively [23]. Thus, the challenge is to implement sustainability governance for the bioeconomy which safeguards against negative impacts while fostering positive options.

As a recent report for IEA Bioenergy Task 45 [24] showed, so far no global institutions have a mandate to govern the sustainability of the use of biomass for energy and biobased products, to create respective rules and monitor their implementation. Yet, a number of UN organisations such as FAO and UNEP deal with aspects of sustainable biomass production with regard to voluntary commitments and standards. The UN environmental conventions (biological diversity, climate, desertification) established certain protective rights. Social regulations such as the International Labour Organisation's Convention on Occupational Safety and Health, on the other hand, are often seen as barriers to trade. The absence of global governance led to intergovernmental partnerships such as the Global Bioenergy Partnership (GBEP) and the Biofuture Platform (BFP). They include many countries and international organisations and are actively working on – again voluntarily – the sustainable management of biomass. These initiatives at least partially provide the basis for global governance.

Voluntary standards for biomass using certification and control measures provide a means to govern biomass sustainability. Such biomass-related sustainability standards have meanwhile been developed in many ways. However, most standards are only related to certain segments of the bioeconomy (e.g., bioenergy; biomaterials, food and feed) and, thus, remain fragmented.

IEA Bioenergy Task 45 is currently completing work on woody biomass certification with a special focus on compliance and verification (C&V), analysing the various approaches of international sustainable biomass certification schemes regarding C&V and will derive perspectives for future governance through certification.

Governing the sustainability of the bioeconomy should be seen as a process which ranges from agenda-setting and framing to the creation and implementation of new policies, and possibly respective institutions (see Figure 4 with a focus on European governance).

Figure 4: EU-focussed governance processes related to the bioeconomy. Taken from Iriarte, Fritsche & van Dam (2021) [24]

For the past several years, discussions in international workshops have called for collaboration to improve sustainability governance of the bioeconomy [e.g. 25], and to fulfil the request of the 2020 Global Bioeconomy Summit to improve on the international sustainability governance [26].

The possible extension of the GBEP Sustainability Indicators for Bioenergy to the broader bioeconomy may be a key opportunity to deliver on that ambition [27] and initiatives such as the Global Bioeconomy Summits could help through exchanging views and supporting alignment between countries.

Given that there is no one-size-fits-all solution, as different cultures and institutional traditions need consideration, the sustainability governance of bioenergy and the broader bioeconomy remains the responsibility of countries, but exchange and co-ordination through international and intergovernmental platforms is necessary. IEA Bioenergy Task 45 will contribute to that through its collaboration with the Biofuture Platform and the GBEP.

8. Way forward

This feature article highlights relationships between bioenergy production and a wide range of sustainability issues. These interactions depend on the bioenergy system and its counterfactual, the system design and management, and the biophysical and socio-economic context. The assessment of these sustainability impacts depends on the definitions, criteria, indicators, and methods applied, and the temporal and spatial scale considered. For these reasons, no general assessment of the sustainability of bioenergy can be given. It is clear that bioenergy deployment can result in both positive and negative sustainability impacts across all three sustainability dimensions. A holistic approach to bioenergy development is therefore important for mitigating negative impacts and promoting co-benefits.

The current heated debate on bioenergy and polarised viewpoints on the sustainability of bioenergy lead to hesitation of decision-makers, while climate change mitigation requires immediate action. By informing the debate with objective transparent quantitative information on impacts and performance of bioenergy systems, the debate should move towards a more constructive discussion on how to do things right. This requires a holistic approach in several dimensions:

- Bioenergy should be considered as part of the whole energy system. Because bioenergy is a dispatchable energy source, it can provide balancing power to give grid stability, supporting the expansion of intermittent renewables, and therefore has a key role to play in energy system transition
- A global perspective is required, due to international supply chains, and as both drivers and impacts occur cross-border.
- Bioenergy feedstock production should be considered as part of the entire land system. The impacts of land use change are the result of the interplay between all land use functions (e.g., provision of food, feed, fibre, and bioenergy). In addition, many production systems produce bioenergy in combination with food, feed, or fibre. Therefore, focussing solely on the sustainability of bioenergy feedstock production can lead to sub-optimal land use solutions at the landscape scale.
- All sustainability impacts should be considered simultaneously, as there are synergies and trade-offs between sustainability impacts of bioenergy. Therefore, the focus on a single (e.g., GHG emissions) or limited set of impacts (e.g., only environmental) is very likely to result in sub-optimal solutions and unintentional trade-offs with other sustainability objectives.

Regarding policy and governance, closer international collaboration is needed to address these challenges, and evidence-based exchanges on practices and examples for positive sustainability contributions from bioenergy should be intensified through multi-stakeholder dialogues. In this, due reflection on the (changing) role of bioenergy within a sustainable bioeconomy is needed. Countries could be encouraged to integrate measures to support deployment of sustainable bioenergy when devising and implementing policy to achieve the SDGs.

As the transformation of the (global) energy system towards sustainability requires significant financial resources [28], future work should also focus on supporting public and private finance institutions in identifying sustainable bioenergy options. For this, practical assessment tools for benchmarking sustainable bioenergy – given its various contexts – are needed, possibly with simplified (proxy) indicators.

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International Energy Agency (IEA)

Mission

The IEA (https://www.iea.org/) works with governments and industry to shape a secure and sustainable energy future for all and is at the heart of global dialogue on energy, providing authoritative analysis, data, policy recommendations, and real-world solutions to help countries provide secure and sustainable energy for all. The IEA was created in 1974 to help co-ordinate a collective response to major disruptions in the supply of oil. While oil security remains a key aspect of its work, the IEA has evolved and expanded significantly since its foundation. Taking an all-fuels, all-technology approach, the IEA recommends policies that enhance the reliability, affordability and sustainability of energy. It examines the full spectrum of issues including renewables, oil, gas and coal supply and demand, energy efficiency, clean energy technologies, electricity systems and markets, access to energy, demand-side management, and much more. Since 2015, the IEA has opened its doors to major emerging countries to expand its global impact, and deepen cooperation in energy security, data and statistics, energy policy analysis, energy efficiency, and the growing use of clean energy technologies.

The areas of work of the IEA are:

- Promoting energy efficiency: advising governments on developing, implementing, and measuring the impact of efficiency policies
- Ensuring energy security: work on energy security ensures that markets remained well supplied, providing information to governments, and helping improve system resilience
- International collaborations: working with a broad range of international organisations and forums to ensure secure, affordable and sustainable energy systems
- Data and statistics: energy data collection and training is at the heart of the IEA's work
- Training: establishing ongoing working relationships with participating countries for continual capacity building
- Technology collaboration: advancing the research, development and commercialisation of energy technologies
- Energy security: ensuring the uninterrupted availability of energy sources at an affordable price
- Global engagement: marking a new era of international energy co-operation
- Industry engagement: sharing insights on how policies shape real-world investments and actions
- Programmes and partnerships: working with governments, organisations and agencies around the world to deliver programmes focused on countries, regions or topics
- Promoting digital demand-driven electricity networks: digital solutions to support power systems in transition

Structure

The IEA is an autonomous body within the OECD framework. The Governing Board is the main decision-making body of the IEA, composed of energy ministers or their senior representatives from each member country. Through the IEA Ministerial Meeting that takes place every two years, the IEA Secretariat develops ideas for existing or new work programmes, which are then discussed with member countries in various IEA committees and ultimately presented to the Governing Board for approval. In addition to the Governing Board, the IEA has several Standing Groups, Committees and Working Parties made up of member country government officials that meet several times a year.

Member Countries

Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, The Netherlands, Turkey, the United Kingdom and the USA. The European Commission also participates in the work of the IEA.

Association Countries

Brazil, China, India, Indonesia, Morocco, Singapore, South Africa and Thailand.

Introducing IEA Bioenergy

Welcome to this Annual Report for 2021 from IEA Bioenergy.

IEA Bioenergy is the short name for the IEA Technology Collaboration Programme (TCP) on Bioenergy formed under the auspices of the International Energy Agency – IEA. A brief description of the IEA is given on the preceding page.

Bioenergy is energy derived from biomass. Biomass is defined as material which is directly or indirectly produced by photosynthesis and which is utilised as a feedstock in the manufacture of fuels and substitutes for petrochemical and other energy intensive products. Organic waste from forestry and agriculture, and municipal solid waste are also included in the collaborative research, as well as broader 'cross-cutting studies' on techno-economic aspects, environmental and economic sustainability, systems analysis, bioenergy trade, fuel standards, greenhouse gas balances, barriers to deployment, and management decision support systems.

The IEA Technology Collaboration Programme (TCP) on Bioenergy, which is the 'umbrella agreement' under which the collaboration takes place, was originally signed in 1978 as IEA Forestry Energy. A handful of countries took part in the collaboration from the beginning. In 1986 it broadened its scope to become IEA Bioenergy and to include non-forestry bioenergy in the scope of the work. The number of participating countries has increased during the years as a result of the steadily increasing interest in bioenergy worldwide. By the end of 2021, 26 parties participated in IEA Bioenergy: Australia, Austria, Belgium, Brazil, Canada, China, Croatia, Denmark, Estonia, Finland, France, Germany, India, Ireland, Italy, Japan, the Republic of Korea, the Netherlands, New Zealand, Norway, South Africa, Sweden, Switzerland, the United Kingdom, the USA, and the European Commission.

IEA Bioenergy is now 44 years old and is a well-established collaborative agreement. All OECD countries with significant national bioenergy programmes are now participating in IEA Bioenergy, with very few exceptions. The IEA Governing Board has decided that the Technology Collaboration Programmes may be open to non-Member Countries, i.e., for countries that are not Members of the OECD. For IEA Bioenergy, this has resulted in a number of enquiries from potential participants, and as a consequence new Members are expected. Five non-Member Countries currently participate in IEA Bioenergy – Brazil, China, Croatia, India and South Africa.

The work within IEA Bioenergy is structured in a number of Tasks, which have well defined objectives, budgets, and time frames. The collaboration which earlier was focused on Research, Development and Demonstration is now increasingly also emphasising Deployment on a large-scale and worldwide. There were 12 ongoing Tasks during 2021:

- Task 32: Biomass Combustion
- Task 33: Gasification of Biomass and Waste
- Task 34: Direct Thermochemical Liquefaction
- Task 36: Materials and Energy valorisation of waste in a Circular Economy
- Task 37: Energy from Biogas
- Task 39: Commercialising of Conventional and Advanced Transport Biofuels from Biomass and Other Renewable Feedstocks
- Task 40: Deployment of biobased value chains
- Task 41: Bioenergy Systems Analysis
- Task 42: Biorefining in a Circular Economy
- Task 43: Sustainable biomass supply integration for bioenergy within the broader bioeconomy
- Task 44: Flexible Bioenergy and System Integration
- Task 45: Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy

Members of IEA Bioenergy are invited to participate in all of the Tasks, but each Member is free to limit its participation to those Tasks which have a programme of special interest. The Task participation during 2021 is shown in Appendix 1.

A progress report for IEA Bioenergy for the year 2021 is given in Sections 1 and 2 of this Annual Report.

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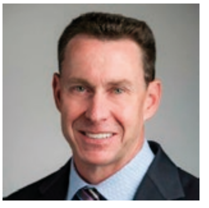

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PROGRESS REPORT

1. THE EXECUTIVE COMMITTEE

Introduction and Meetings

The Executive Committee (ExCo) acts as the 'board of directors' of IEA Bioenergy. The committee plans for the future, appoints persons to do the work, approves the budget, and, through its Members, raises the money to fund the programmes and administer the Technology Collaboration Programme (TCP). The Executive Committee also scrutinises and approves the programmes of work, progress reports, and accounts from the various Tasks within IEA Bioenergy. Other functions of the ExCo include publication of an Annual Report, production of newsletters and webinars, and maintenance of the IEA Bioenergy website. In addition the ExCo produces technical and policy-support documents, and organises workshops and study tours for the Member Country participants.

The COVID-19 pandemic, continued to impede normal business activity n 2021. The disruption to the organisation of in-person gatherings posed ongoing challenges to the delivery of the IEA Bioenergy TCP work programme in this final year of a triennium. However, online platforms continued to be extensively used and, despite the challenges, the Tasks were able to deliver most and in some cases all of their projected outputs.

The 87th ExCo meeting was held as a Virtual meeting in three separate sessions on the 18th and 19th May 2021 with 39-44 participants. The 88th ExCo meeting was held as a Virtual Meeting in three separate sessions on the 11th, 13th and 14th October 2021 and there were 35-39 participants in each session. Kazuhiro Kurumi represented IEA Headquarters at both ExCo87 and ExCo88.

Paul Bennett of SCION chaired both ExCo meetings in 2021 with Dina Bacovsky of BEST – Bioenergy and Sustainable Technologies and Sandra Hermle of the Swiss Federal Office of Energy SFOE in the roles of Vice-chairs. At ExCo88, Paul Bennett was elected as Chair and both Dina Bacovsky and Sandra Hermle were elected as Vice-chairs for 2022.

Secretariat

The ExCo Secretariat has been based in Dublin, Ireland under the Secretary, Pearse Buckley up to the end of 2021. Following an open call for applications for the position of Secretary published on the IEA Bioenergy website in February 2021 the Executive Committee of the IEA Bioenergy TCP interviewed three short listed candidates during the ExCo87 meeting in May 2021. By online secret ballot they selected and approved Andrea Rossi as the new Secretary of the IEA Bioenergy TCP, commencing in the role from the 1st January 2022. Andrea is a bioenergy, bioeconomy and sustainability expert with over 15 years of international experience. From 2009 to 2018, he served as Bioenergy Officer at the Food and Agriculture Organization (FAO) of the UN, where he led the design and management of projects to assess the sustainable bioenergy potential and monitor related impacts in various countries. While at FAO, he also served, from 2014 to 2018, as Programme Officer of the Global Bioenergy Partnership (GBEP) Secretariat, leading activities on capacity development and sustainability. Since March 2019, Andrea has been supporting the IEA Secretariat in the coordination of the Biofuture Platform and of the related CEM Initiative established in 2020

The fund administration for the ExCo Secretariat Fund and Task funds is consolidated with the Secretariat, along with production of ExCo publications and newsletters, and maintenance of the website. From the 1st January 2022 the Secretariat will be based in San Casciano in Val di Pesa, Italy.

The contact details for the Executive Committee can be found in Appendix 7 and for the Secretariat on the inside back cover of this report. The work of the ExCo, with some of the achievements and issues during 2021, is described below.

Implementing Agreement

The current term of the IEA Bioenergy Technology Collaboration Programme (TCP) covers the period 1st March 2020 to 28th February 2025.

Contracting Parties/New Participants

A complete list of the Contracting Parties to IEA Bioenergy is included in Appendix 3.

At ExCo88 Turkey made a presentation to the ExCo and was invited to join the TCP. Following the ExCo88 meeting the formalities were set in train and it is expected that Turkey will join as a contracting party early in 2022, bringing the number of contracting parties in the IEA Bioenergy TCP to 27.

Supervision of Ongoing Tasks, Review and Evaluation

The progress of the work in the Tasks is reported to the Executive Committee twice per year at the ExCo meetings. In order to improve efficiency, the ExCo has decided that in future Task Leaders attend the second meeting in each year so that they can make presentations on the progress in their Task and programme of work personally. Participation by Task Leaders in ExCo meetings has improved the communication between the Tasks and the Executive Committee and has also increased the engagement of the ExCo with the Task programmes. However, as noted earlier, in-person participating was not possible in 2021 due to the impact of COVID-19.

The work within IEA Bioenergy is regularly evaluated by the IEA Committee for Energy Research and Technology (CERT) via its Renewable Energy Working Party (REWP) and is reported to the IEA Governing Board.

Approval of Task and Secretariat Budgets

The budgets for 2021 approved by the Executive Committee for the ExCo Secretariat Fund and for the Tasks are shown in Appendix 2. Total funds invoiced in 2021 were US$2,073,200 comprising US$290,200 of ExCo funds and US$1,783,000 of Task funds. Appendix 2 also shows the financial contributions made by each contracting party and the contributions to each Task. Very substantial 'in-kind' contributions are also a feature of the IEA Bioenergy collaboration but these are not shown because they are more difficult to recognise in financial terms.

Fund Administration

The International Energy Agency Bioenergy Trust Account in Bank of Ireland Global Markets in Dublin has continued to function smoothly. The Trust Account consists of a Call Deposit account and a Fixed Deposit account both of which bear interest. The Call Deposit account is the account used to receive funds from the contracting parties and to distribute funds to the Task Leaders. It can be accessed electronically and transactions can be executed by the Secretary at all times. The Fixed Deposit account is a separate account that attracts a higher level of interest (approximately a factor of 10 higher than the Call deposit account). Funds in this account can only be transferred to the Call Deposit account following a written request from the Secretary and with a delay of several days. Both accounts are denominated in US dollars. The currency for the whole of IEA Bioenergy is US Dollars. Details for making payments are provided with each invoice.

In the 4th quarter of 2021 all of the funds in the Fixed Deposit account were transferred to the Call Deposit account with the former account being subsequently closed. This was done in preparation for the transfer of all funds to the new Secretary based in Italy upon completion of the work of the Secretary based in Dublin.

The main issues faced in fund administration are slow payments from some contracting parties and fluctuations in exchange rates. As of 31 December 2021, there was US$6,700 of contracting parties' contributions outstanding.

At ExCo84, unanimous approval was given to the appointment of KPMG, Dublin as independent auditor for the ExCo Secretariat Fund until 31 December 2021. The audited accounts for the ExCo Secretariat Fund for 2020 were approved at ExCo87.

The Tasks also produce audited accounts. These are prepared according to guidelines specified by the ExCo. The accounts for the Tasks for 2020 were approved at ExCo87.

The audited accounts for the ExCo Secretariat Fund for the period ended 31 December 2021 have been prepared and these will be presented for approval at the ExCo89 Virtual meeting.

Task Administration and Development

Task Participation

In 2021 there were 116 participations in 11 Tasks. Please see Appendix 1 on page 126 for a summary of Task participation.

There was one active project under Task 41 and five Inter-Task projects in 2021. In addition, using surplus Secretariat funds and following a call for tender in April 2021, the ExCo awarded a contract to BEST – Bioenergy and Sustainable Technologies GmbH to develop an update and an expansion of the 2009 IEA Bioenergy report "Bioenergy – a sustainable and reliable energy source[6]". For further details on these see below under '**Strategic Fund/Strategic Outputs**'.

Strategic Planning and Strategic Initiatives

Strategic Plan

The Executive Committee of IEA Bioenergy has adopted a new Strategic Plan for the term 2020-2025. The objectives of the plan are to enable bioenergy to substantially contribute to future global energy demand within a growing global bioeconomy; provide significant greenhouse gas savings across all energy sectors; and contribute to the Sustainable Development Goals. The Plan recognises that bioenergy can and must deliver increasing results in decarbonising transport, heat, power and electricity, including through its capacity to deliver negative emissions by, among many pathways, bioenergy with carbon capture and storage/utilisation (BECCS/BECCUS).

6 https://www.ieabioenergy.com/wp-content/uploads/2013/10/Executive-Summary-Bioenergy-a-sustainable-reliable-energy-source.pdf

Technical Coordinator

In 2021 the Technical Coordinator continued working closely with the Tasks including keeping updated on Tasks' publications, supporting the associated dissemination activity and providing guidance on the completion of the triennium work programmes. He took part in a number of online Tasks' meetings and workshops and coordinated the TCP response to misconceptions on bioenergy being circulated in the media. He was responsible for the development of the programme for the internal workshop that was held in conjunction with ExCo87 in May 2021. The Technical Coordinator directed the organisation and execution of the very successful IEA Bioenergy Conference 2021, which was held online from the 29th November to the 9th December 2021 – see further details under "IEA Bioenergy – Selected Highlights from 2021" at the beginning of this Annual Report. In addition to his key role in the execution of the Communication Strategy (see below), the Technical Coordinator acts as an important link with the IEA Secretariat, other IEA TCPs and international organisations. He provided input to the IEA *Renewables 2021 Report* and the 'Today in the Lab – Tomorrow in Energy' initiative. In 2021 he also participated in the GREET+ Extension project, meetings of the Transport Coordination Group and the Universal TCP meeting. Using IEA data as a basis and with input from ExCo, the Technical Coordinator prepared the *IEA Bioenergy Countries Report – Update 2021* – see https://www.ieabioenergy.com/blog/publications/iea-bioenergy-countries-report-update-2021/.

Communication Strategy

The focus on communications continued in 2021 with ten meetings of the Communications Team, including a kick-off meeting on the Specialist Communications Support project towards the end of the year. The TCP is in the process of engaging the services of a Communications Specialist in 2022 to further improve dissemination of IEA Bioenergy outputs. The use of social media to disseminate outputs from the TCP has expanded with more than 4,000 followers on Twitter and 2,500 followers on LinkedIn. The webinar programme has continued with seven webinars being presented in 2021. The webinars included (i) *Integration of Biogas Systems into the Energy System*, (ii) *Gasification of biomass and waste*, (iii) *Flexible bioenergy in renewable energy systems*, (iv) *Residential wood combustion – towards low emission systems*, (v) *Resilient Biomass Supply Chains in the Post-COVID Recovery*, (vi) *Sustainable Aviation Fuel/Biojet Technologies – Commercialisation Status, Opportunities and Challenges* and (vii) *Sustainable Lignin Valorisation*. The recordings and presentations are available at https://www.ieabioenergy.com/iea-publications/webinars/.

Strategic Fund/Strategic Outputs

At ExCo53 it was agreed that from 2005, 10% of Task budgets would be reserved for ExCo approved work. The idea was that these 'Strategic Funds' would be used to increase the policy-relevant outputs of IEA Bioenergy.

ExCo workshop publications are available at
https://www.ieabioenergy.com/iea-publications/workshops/.

Task 41 Project 11: Renewable Gas – Hydrogen in the grid: This project identified and discussed numerous challenges and hurdles for gradually replacing natural gas by renewable gas, with emphasis on H_2 injection into existing gas grids and on new dedicated H_2 grids. Its core objectives were:

- to bring together the expertise of IEA, IEA Bioenergy and national experts to showcase the role of renewable hydrogen and biomethane in the natural gas grid
- to analyse existing national strategies for greening the gas grid
- to assemble existing knowledge on hydrogen, natural gas and biomethane standards
- to identify possible challenges and hurdles for blending hydrogen and biomethane in natural gas grids.

The main conclusions were presented at the IEA Bioenergy Conference 2021[7]. A synthesis report is due for publication in early 2022.

Inter-Task Project: The role of bioenergy in a WB2/SDG world: In addition to presentations on '*Governing a Sustainable Bioeconomy: Assessment and Monitoring (Experience and Perspective)*' and '*Innovative Landscape Approaches for Sustainable Bioenergy*' at the BBEST 2021-Biofuture Summit II Conference (recorded presentations available here[8]), a virtual workshop on '*How can biomass supply for bioenergy deliver multiple benefits and contribute to sustainable development goals*' was held on 15-16 June 2021. The workshop focused on the relationships between the sustainable development goals (SDGs) and different biomass supply chains and regions, sharing best practice case studies from around the world. The presentations and recorded sessions are available here[9]. A series of publications are available on open access at paper1[10], paper2[11], paper3[12], paper4[13] and paper5[14]. This Inter-Task project also contributed to the IEA Bioenergy Conference 2021.

Inter-Task Project: Renewable gas – deployment, markets and sustainable trade: This project aims to provide state-of-the-art overviews on prospects, opportunities and challenges for mechanisms that could help deploying biogas, biomethane and other renewable gases (RG) in IEA energy markets, and beyond. In looking at the status of regulatory issues for RG, the project builds on work carried out by IEA Bioenergy Task 37 and Task 40 and on current approaches to regulating RG, especially in the European Union. It also looks at RG from non-biomass sources,

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7 https://www.ieabioenergyconference2021.org/

8 https://program2021.bbest-biofuture.org/

9 https://www.ieabioenergy.com/blog/ieaevent/expert-workshop-how-can-biomass-supply-for-bioenergy-deliver-multiple-benefits-and-contribute-to-sustainable-development-goals/

10 https://onlinelibrary.wiley.com/doi/10.1111/gcbb.12844

11 https://onlinelibrary.wiley.com/doi/10.1111/gcbb.12863

12 https://chalmersuniversity.app.box.com/s/ipo4uluynahekyyxak9zle0hrv5zvs6v

13 https://www.mdpi.com/2073-445X/10/2/181

14 https://www.nature.com/articles/s43247-021-00247-y

with a focus on hydrogen and power-to-gas (PtG) production. The sustainable potentials for RG trade between Eastern Europe (Belarus, Ukraine), Russia, the US (via LNG) and the EU is addressed. In addition to work package papers and case studies, an overall synthesis report and webinar are scheduled for the first quarter of 2022.

Inter-Task Project*: *Bioenergy for high temperature heat in industry: Five case studies have been completed and are available here[15]. The policy synthesis report, which is due for publication in early 2022, provides information on market opportunities and potential as well as effective ways to address technical and non-technical barriers to implement bioenergy based process heat. It builds upon the lessons learned in the case studies, but also provides a more generic analysis of the market potential, and how its implementation can be supported. The main conclusions were presented at the IEA Bioenergy Conference 2021[16].

Inter-Task Project*: *BECCUS: Three case studies have been published here[17]. A synthesis report is due for publication in early 2022.

Inter-Task Project*: *Lessons Learned – Biofuels: The project's programme of work comprises six work packages focused on studying national programmes and experiences of leading biofuels producer countries including but not limited to Brazil, Canada, Germany, Sweden and the United States of America. The analysis aims to compare and contrast different producer countries' framework conditions and policy approaches as well as levels and rates of biofuel production growth that these have enabled. Due to COVID-19 related impacts the final project report will be delayed to the end of March 2022.

Bioenergy Review Update: BEST – Bioenergy and Sustainable Technologies GmbH have been contracted by the IEA Bioenergy TCP to develop an update and an expansion of the 2009 report "Bioenergy – a sustainable and reliable energy source[18]". The new report "Bioenergy and its role in a future sustainable energy system" will be a comprehensive, science-based, yet easily accessible document that will serve as an authoritative reference to policy makers, decision makers and the broader scientific community. It will cover all bioenergy value chains, address major issues, and provide an update on recent developments. Its electronic, web-ready format and a series of visualisations, including infographics, will make the content easy to access and serve to inform policy, educate decision makers and serve the broader scientific community alike. The final report will be presented to ExCo89 in May 2022.

15 https://itp-hightemperatureheat.ieabioenergy.com/

16 https://www.ieabioenergyconference2021.org/

17 https://www.ieabioenergy.com/blog/publications/deployment-of-bio-ccs-case-studies/

18 https://www.ieabioenergy.com/wp-content/uploads/2013/10/Executive-Summary-Bioenergy-a-sustainable-reliable-energy-source.pdf

ExCo Workshops

Prior to ExCo87 in May 2021 an internal workshop themed 'Planning for the new triennium' was held. Detailed proposals for programmes of work for the triennium 2022-2024 were presented by Task Leaders. The ExCo also considered a range of potential Inter-Task topics for possible funding from the Strategic Fund. The eleven Tasks for the triennium 2022-2024 were approved by ExCo through written procedure following ExCo88.

There was no internal workshop at ExCo88. The IEA Bioenergy Conference 2021 was held online in a series of sessions between 29 November and 9 December 2021 – see further details under "IEA Bioenergy – Selected Highlights from 2021" at the beginning of this Annual Report.

Seminars, Workshops, and Conference Sessions

Every year a large number of seminars, workshops, and conference sessions are arranged by individual Tasks within IEA Bioenergy. However, in 2021 COVID-19 severely limited normal business activity, with the result that in-person events were few in number. Nonetheless all Tasks made use of online platforms to continue their Task activities and also to engage with stakeholders in e-workshops and e-conferences.

Collaboration with other Technology Collaboration Programmes and International Organisations

The Executive Committee of the IEA Bioenergy TCP continues to place strong emphasis on collaboration with other Technology Collaboration Programmes and International Organisations, including those mentioned in the following.

Advanced Motor Fuels Implementing Agreement

Collaboration with the Advanced Motor Fuels (AMF) Technology Collaboration Programme has continued and included a jointly organised sectoral discussion on e-fuels in conjunction with the IEA Universal TCP meeting in October 2021.

GBEP

IEA Bioenergy continues to collaborate with GBEP on biomass sustainability through IEA Bioenergy Tasks 45 and Task 40. IEA Bioenergy is also involved in GBEP Activity Group 7 on 'Biogas' through IEA Bioenergy Task 37 and in Activity Group 8 on 'Advanced Liquid Biofuels' through IEA Bioenergy Task 39.

FAO

IEA Bioenergy and FAO continue to exchange on areas of cooperation under the MoU between the two organisations.

IRENA

IEA Bioenergy and IRENA continue to review outputs from each other's work programmes, particularly through the Technical Coordinator and to examine areas of potential cooperation.

Biofuture Platform

IEA Bioenergy and the Biofuture Platform have finalised a Memorandum of Understanding (MOU) to facilitate collaboration. The MoU has been approved by the IEA Bioenergy ExCo in the 4th quarter of 2021.

Promotion and Communication

Effective communication of IEA Bioenergy activities to the broader stakeholder community is a priority for the Executive Committee of IEA Bioenergy. The engagement of ETA Florence has been continued. Following the launch of the new TCP brand identity in May 2020 ETA Florence have been updating the IEA Bioenergy Tasks' websites to the new brand.

The 2020 Annual report included the special colour section on "*Technical, ecological and economic assessment of biorefinery cases*". A limited number of printed copies were produced, with substantially increased distribution in electronic format.

The newsletter 'IEA Bioenergy News[19]', which is distributed in June and December each year following ExCo meetings, continues to be widely circulated. Two issues were published in 2021. As a special theme the first issue in 2021 featured a review by the Technical Coordinator of the IEA article "*What does net-zero emissions by 2050 mean for bioenergy and land use?*". The second issue in December 2021 featured a report by the Technical Coordinator on the "*IEA Bioenergy Conference 2021 – wrapping up*". The newsletter is also produced in electronic format and is available from the IEA Bioenergy website. An electronic news bulletin covering recent ExCo and Tasks' activities was also produced and distributed at the end of March 2021. A free subscription to the TCP newsletters is offered to all interested parties and there is wide distribution outside of the normal IEA Bioenergy network.

Two contributions under the banner 'IEA Bioenergy Update' were provided to the journal Biomass and Bioenergy in 2021 bringing the total to 71. This initiative provides excellent access to bioenergy researchers as the journal finds a place in major libraries worldwide.

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19 https://www.ieabioenergy.com/iea-publications/newsletters/

Interaction with IEA Headquarters

Interaction with IEA Headquarters in Paris is of high importance to IEA Bioenergy and has been facilitated in 2021 particularly through the Chair, Vice-chairs, Technical Coordinator, Secretary and a number of Task Leaders at both technical and administrative level. In 2021 the Technical Coordinator provided input to the IEA *Renewables 2021 Report* and the 'Today in the Lab – Tomorrow in Energy' initiative. He participated in the GREET+ Extension project and in meetings of the Transport Coordination Group. The Vice-chairs, together with the Technical Coordinator, participated in the IEA Universal TCP Meeting and organised a sectoral discussion on e-fuels, jointly with the AMF TCP, which was held in conjunction with the IEA Universal TCP Meeting.

The Chair of IEA Bioenergy, Paul Bennett, attended the REWP online meetings in April and September 2021 and presented the IEA Bioenergy Annual Briefing report to the September meeting.

Kazuhiro Kurumi attended both ExCo87 and ExCo88 on behalf of IEA Headquarters and made presentations to the IEA Bioenergy Executive Committee on activities in the IEA. This participation by Headquarters is appreciated by the Members of the ExCo and helps to strengthen linkages between the Technology Collaboration Programme and relevant Headquarters initiatives.

Status reports were prepared by the Secretary and forwarded to the Desk Officer and the REWP following ExCo87 and ExCo88. Status reports were also sent to Carina Alles, Vice Chair of the End Use Working Party (EUWP) for the Transport sector. This forms part of the exchange of information between Technology Collaboration Programmes and the Working Parties.

IEA Bioenergy Website

The IEA Bioenergy website (www.ieabioenergy.com) continues to be updated with the latest outputs from the IEA Bioenergy TCP.

2. PROGRESS IN 2021 IN THE TASKS

TASK 32: Biomass Combustion

Overview of the Task

Task 32 aims to stimulate expansion of biomass combustion for the production of heat and power on a wider scale. The widespread interest in the work of the Task illustrates the relevance of biomass combustion in society and the integration in energy systems with variable renewable energy sources. Combustion applications vary from domestic woodstoves to industrial combustion technologies, co-generation units, dedicated power generation and co-firing with fossil fuels.

Biomass combustion technologies are commercially established with high availability and a multitude of options for integration with existing infrastructure on both large and small-scale levels. Nevertheless, there are still challenges for further market introduction, the importance of which varies over time. The areas covered by the Task through different activities in the 2019-2021 triennium are:

- WP1 – Improvement of small-scale biomass combustion
- WP2 – Biomass combustion in industry
- WP3 – Integration and deployment of efficient and flexible large-scale biomass CHP.

The specific actions of Task 32 involve collecting, analysing, and sharing the policy aspects of results of international and national R&D programmes in the above areas. The results of these actions are disseminated in workshops, webinars and reports and potentially as well via handbooks or databases etc. In addition, specifically designed, strategic actions are carried out by the Task to catalyse this process.

While most of the above areas are of a technical character, Task 32 also addresses non-technical issues on fuel logistics and contracting, environmental constraints and legislation, public acceptance, and financial incentives.

Participating countries: Austria, Canada, Denmark, Germany, Japan, The Netherlands, Norway, Sweden, and Switzerland

Operating Agent: Mr. Mikael Pedersen, Danish Energy Agency, Denmark

Task Leader: Morten Tony Hansen, Ea Energy Analyses, Denmark

Co-Task Leader: Anders Hjörnhede, RI.SE, Sweden

The Task Leader directs and manages the work programme, assisted by the co-Task leader. A national team leader (NTL) from each country is responsible for coordinating the national participation in the Task and of managing each of the projects in the work programme.

For further details on Task 32, please refer to Appendices 2, 4, 5 and 6; the Task website task32.ieabioenergy.com and the IEA Bioenergy website www.ieabioenergy.com under 'Activities: Tasks'.

Progress in R&D

Task Meetings, Webinars and Workshops

In 2021, Task 32 held virtual Task meetings only. Each meeting comprised three sessions, each of two hours, to allow enough time to discuss all necessary topics. Focus was on work programme progress, country reports and planning of the 2022-2024 triennium. Three virtual Task meetings' sessions were held in March to May 2021 and one session was held in December (the two remaining sessions were to be held in January 2022).

Country reports typically include sharing current developments on application of biomass combustion in the member countries of the Task and thereby facilitating learning effects of the meetings. During 2021 the differences already experienced in the public perception of biomass in the member countries have deepened. The Netherlands and Denmark experience resistance, demonstrations and political measures taken against the utilisation of bioenergy; Austria and Germany see biomass as an important means to substitute fossil fuels for heating and electricity generation.

Workshops have been a proven concept to gather and disseminate information in a structured and effective manner. During the pandemic, webinars have become the norm, serving the same purpose and often reaching much higher numbers of participants. It can be discussed whether the outcome is the same as for physical events, but an advantage is that recorded, presentations and debates may be seen multiple times and by an even wider audience.

On 6th of May 2021, Task 32 hosted a webinar "Residential Wood Combustion – Towards Low Emission Systems" on advances within residential wood combustion in collaboration with the IEA Bioenergy communication team from ETA Florence. The webinar comprised a general introduction to emissions and emission reduction measures as well as the two Task 32 reports on improvements of wood combustion (please see below). The webinar can be seen and presentations downloaded here[20].

20 https://www.ieabioenergy.com/blog/publications/iea-bioenergy-webinar-residential-wood-combustion-towards-low-emission-systems/

At the virtual IEA Bioenergy Conference 2021, Task 32 hosted a session "Biomass and renewable heat" on the 7th of December. The topics of the session were biomass for high temperature heat generation in industry and strategies to reduce the impact on air quality from wood combustion. The session can be viewed and presentations downloaded here[21].

The two workshops on combustion experiences in large CHP plants that were planned for the triennium had to be postponed several times due to the pandemic. While there was always a hope to hold the workshops within the triennium – or potentially in the beginning of 2022 – it was decided in December to postpone the workshops and for Task 32 to attempt to create a high-profile event by pooling the two workshops and site visits to new and remarkable combustion units, until the next triennium and to revise the budget accordingly.

Work Programme and Outputs

In 2021, the proposed activities have progressed as described below.

D1.1 Testing methods and real-life performance of pellet stoves (Austria)

The main project activities were carried out in second half of 2019 and the main results were presented at the workshop in Graz in January 2020 while the final results were presented at the webinar on residential wood combustion in May 2021. Reporting had experienced some delay due to the pandemic. The final draft is being edited and the final report is expected to be public in the beginning of 2022.

D1.2 Technical guidelines for design of low emission wood stoves (Denmark)

Preliminary results were presented at the workshop in Graz in January 2020 while the final results were presented at the webinar on residential wood combustion in May 2021. The final draft guideline is being edited and the final report is expected to be public in the beginning of 2022. The guideline focuses on primary measures such as fire chamber design, ignition principles, load, air control and automation while secondary measures such as catalysts and filters (ESP, bag filters, chimney fans) are described in general terms.

D1.3 Internal WS and report: National strategies for reducing the impact on air quality from residential and commercial wood combustion (Germany)

The project aims to gather information from each participating country on strategies to mitigate particulate matter (PM) immision from wood combustion. A comprehensive template has been prepared and country members plus a colleague from Italy have collected and reported national data during 2021. The country reports will form the basis for a main synthesis report. The work was presented in draft at the Task 32 session on biomass and renewable heat at the IEA Bioenergy Conference 2021 on the 7th of December 2021. At the end of 2021, three country reports were pending. They are expected in the first half of 2022 after which the synthesis report will be finalised.

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21 https://www.ieabioenergyconference2021.org/agenda_session/biomass-and-renewable-heat/

D1.4 Workshop: Improved combustion in stoves and small biomass boilers (Austria)

As mentioned above the workshop was held in connection with the Central European Biomass Conference 2020 (CEBC) in January in Graz, Austria. The workshop was a parallel event at the conference on the 23rd of January and benefited from the abstracts sent to the conference on small scale biomass combustion. CEBC proved to be a great opportunity to disseminate news and findings from Task 32 to a wider group. Presentations and a short summary are available on the Task website. A workshop report has been prepared in German and will be translated and published on the website in the beginning of 2022.

D2.5 Biomass for high temperature heat in industry (Inter-Task project, managed by Task 32, Netherlands)

During 2021, the policy report "Decarbonizing industrial process heat: the role of biomass" was finalised by Task 40 and published on the project website: https://itp-hightemperatureheat.ieabioenergy.com/ as well as on the general IEA Bioenergy website. This concluded the Inter-Task project. Task 32 has decided to use the template for four additional case studies related to biomass combustion for generation of process heat. Unspent funding for travel and meeting activities during the triennium has been allocated to fund a part of the case studies. One new case study – from Switzerland – was published on the website next to the existing four cases. The policy report and the Task 32 cases were presented at the Task 32 session on biomass and renewable heat at the IEA Bioenergy Conference 2021 on the 7th of December 2021. In the first half of 2022 the remaining three case studies from Austria, Sweden and Denmark will be published. The total of eight cases will form the beginning of the searchable list of cases that Task 32 will establish during the new triennium as inspiration for interested industry decision makers.

Wood chips and grain residues-fired boiler (KCO Kohlbach) with SNCR (ERC) (left) and electrostatic precipitator (Scheuch) (right) for process heat supply in the largest bakery in Switzerland. Photo by Verenum.

D3.6 Biomass-based CHP for balancing an energy system with a large portion of uncontrollable production (Sweden)

This project is dedicated to feed into the activities in IEA Bioenergy Task 44 on Flexible Bioenergy and System Integration. While Task 32 has contributed with a presentation to Task 44 at the Central European Biomass Conference in January 2020 in Graz, Austria, the primary work has been pending due to the pandemic and other reasons including relatively limited funding compared to the other projects. It was expected that new resources that have been involved in the project and additional funding would enable the contribution to Task 44 in 2021 or in the first part of 2022. However, after having examined potential options, the project lead has towards the end of 2021 regretfully concluded that it will not be possible to contribute to Task 44 as originally expected. Task 32 suggests that the funding is carried over to the 2022-2024 triennium to enable contribution to the new Inter-Task project proposed by Task 44 "Synergies of green hydrogen and bio-based value chains deployment".

D3.7 and D3.8 Workshops: Experiences with combustion of pulverised non-woody solid biofuels (Canada) and with combustion of wood chips for CHP production (Denmark)

The first planning steps had been taken early within the Task as well as with external stakeholders and it was decided to organise the two workshops as one event. The event involved collaboration with Task 40 as well as with members of IEA International Centre for Sustainable Carbon (IEA ICSC – previously Clean Coal Centre) and members of VGB Powertech. Due to the pandemic the two workshops have been postponed multiple times. As uncertainty remained in the beginning of 2021, it was decided to hold the workshops and site visits in Q2 2022 – still as a part of the 2019-2021 triennium which was approved by ExCo. However, as the pandemic continued creating uncertainty for the first half of 2022 it was decided to postpone the event for the 2022-2024 triennium aiming at updating the concept to respond to the potential new focus in industry and holding it in Q3 2022 in Copenhagen. Task 32 suggests that the remaining funding is carried over to the 2022-2024 triennium to fund this event.

Additional project: Study of the Nitrogen Cycle in Biomass Combustion Plants (Phase I)

Due to the pandemic, only a minor part of the triennium budget for travel costs and meeting costs has been spent. This development has enabled Task 32 to already in 2021 initiate new activities that were planned for the 2022-2024 work programme. Task 32 has initiated a study of the nitrogen cycle in biomass combustion plants based on research carried out by BEST Bioenergy and Sustainable Technologies in Austria. The project is led by the representatives from Austria and the Netherlands and aims at quantifying reactive nitrogen flows along the whole biomass combustion cycle. The result of phase I will be a scoping report based on the Austrian study defining the work and data collection to take place in phase II that will be carried out during the 2022-2024 triennium.

Tight emission thresholds in the NL require extensive flue gas cleaning at small scale district heating CHP plant: 2 x SNCR + cyclone + SCR + economiser + bag filter + condenser. Photo by ProBiomass BV.

Website

During the first part of 2021 the Task website has been updated with recent publications. The website has been transferred to another server under which links to publications were compromised. This might have affected the activity level.

The website has been redesigned and re-edited from September 2021 and a list of changes has been implemented in collaboration with ETA Florence. The new site is currently being reviewed and is expected to be put online in the first part of 2022.

Collaboration with other Tasks/organisations/networking

Collaborations have generally become more sluggish due to the pandemic as many ready occasions have not been available.

Task 32 and Task 40 have maintained good communication through the joint organisation of the workshop on experiences with large scale wood chip combustion that has now finally been delayed to the new triennium (Q3 2022) and also within the Inter-Task project on high temperature heat for industry. In the latter, Task 32 has collaborated closely with Task 33, 34 and 36 regarding case studies and with Task 40 concerning the policy report.

Collaboration has also taken place with Task 40 and Task 44 regarding the contribution from Task 32 to the upcoming Inter-Task projects on BECCUS and Synergies with hydrogen/PtX.

During 2021, Task 32 has collaborated with the IEA Renewable Energy Working Party (REWP) to assist with country specific data on investment costs (incl. subsides) and maintenance costs for pellet stoves and pellet boilers and assisting the division with designing and testing their online heat economics calculator that was launched with the Renewable Energy Market Report 2021.

The Task collaborates directly with industry and through industrial networks such as VGB Powertech. Within the IEA family, interaction takes place also with other TCP's such as the International Centre for Sustainable Carbon (previously Clean Coal Centre) and the Combustion TCP. However, also here the pandemic has taken a toll in 2021.

Throughout the year, Task 32 has responded to several inquiries on combustion issues from parties around the world.

Deliverables

The following milestones were achieved in 2021:

- Preparing the annual report for 2020
- Initiating preparations of Task 32 work programme proposal for the 2022-2024 triennium
- Preparing a draft work programme proposal for 2022-2024 and presenting it at the ExCo87 strategy workshop
- Preparing the audited accounts for 2020 and presenting them at the ExCo87 meeting
- Organising and reporting of five virtual Task meeting sessions
- Contributing to the organisation of a webinar on residential wood combustion in May
- Publishing a case study and the policy report in the Inter-Task project on high temperature heat for industry
- Updating and contributing to the redesign of the Task website
- Contributing to the IEA Bioenergy Newsletter
- Preparing the progress report for July 2020 to June 2021 and presenting it at the ExCo88 meeting
- Preparing the updated work programme proposal for 2022-2024 and presenting it at the ExCo88 meeting
- Participating in and contributing to ExCo87 and ExCo88
- Contributing to organising the IEA Bioenergy Conference 2021 as well as moderating and presenting progress at the session on "Biomass and renewable heat"
- Preparing annual report (this report)
- Preparing audited accounts for the ExCo89 meeting.

TASK 33: Gasification of Biomass and Waste

Overview of the Task

The objectives of Task 33 are (1) to promote commercialisation of biomass gasification, including gasification of waste, to produce fuel and synthesis gases that can be subsequently converted to substitutes for fossil fuel based energy products and chemicals, and lay the foundation for secure and sustainable energy supply; (2) to assist IEA Bioenergy Executive Committee activities in developing sustainable bioenergy strategies and policy recommendations by providing technical, economic, and sustainability information for biomass and waste gasification systems.

Participating countries: Austria, Germany, India, Italy, The Netherlands, Sweden, the United Kingdom and the United States of America

Task Leader: Berend Vreugdenhil, TNO, The Netherlands

Task co-leader: Jitka Hrbek, BOKU, Austria

Operating Agent: Kees Kwant, Netherlands Enterprise Agency, The Netherlands

The Task Leader directs and manages the work programme, assisted by sub-task leaders for specific areas. A National Team Leader from each country is responsible for coordinating the national participation in the Task.

For further details on Task 33 please refer to Appendices 2, 4, 5 and 6; the Task website (http://task33.ieabioenergy.com/) and the IEA Bioenergy website (www.ieabioenergy.com) under 'Activities: Tasks'.

Progress in R&D

Task Meetings and Workshops and Webinars

The first Task 33 meeting for 2021 was held on 2nd and 3rd of June online, due to the COVID-19 situation. This was also the reason that no workshop was organised for this meeting. The Task business meeting was held on the first day, with limited time available due to different time zones (13:00-17:00 CET) and on the second day the country updates were given during the same hours. These are available on the website.

The second Task 33 meeting was held again partly online on 1-3 December. There was the possibility for travelling anticipated so for the European members ENEA hosted the meeting in Trisaia. This included also a workshop on "Gasification as a key technology for the Energy Transition and the Circular Economy". It included a very broad set of speakers, dealing with all kinds of applications where gasification plays a key role.

On the 24th of February a webinar was organised with the title "Gasification: A crucial technology for the energy transition. A global perspective". This webinar featured the participants from the Task and speakers from India and China were invited to give their perspective. It was a well attended webinar.

Work Programme and Outputs

The scope of work for the current triennium is built upon the progress made in the previous triennia. In the previous years, information exchange, investigation of selected sub-task studies, promotion of coordinated RD&D among participating countries, selected plant visits, and industrial involvement in technical workshops at Task meetings have been very effective. These remain the basic foundations for developing and implementing a programme of work that addresses the needs of the participating countries.

During 2021 the scope of Task 33 has changed to focus more on the applications of gasification. This is partly to create better visibility to our stakeholders, but also to foster more collaboration within the Task. Additionally, the goal is also to enlarge the core group of Task 33 with countries that have a strong focus on gasification. For the upcoming triennium we have new members from Belgium, Canada, China, France and India on board.

The Task monitors the current status of key operations and R&D efforts relating to biomass and waste gasification, and identifies hurdles to advance further development, operational reliability, and economics of gasification systems. The Task meetings provide a forum to discuss the technological advances and issues critical to scale-up, system integration, and commercial implementation of these processes. These discussions lead to selection of sub-task studies and/or technical workshops that focus on advancing the state-of-the-art technology and identify the options to resolve barriers to technology commercialisation.

The Task has continued the practice of inviting industrial experts to the Task workshops to present their practical experiences and to discuss the options for development of critical process components to advance state-of-the-art biomass and waste gasification systems. The interaction with industry provides the opportunity for the National Team Leaders (NTLs) to evaluate refinements to existing product lines and/or processes. Academic experts are also invited to share information and foster cooperation in order to address and support basic research needs.

Work Program/Sub-task Studies

The current work program includes the following elements:

- Plan and conduct semi-annual Task meetings, where due to COVID-19 at least one workshop was not organised. Also the technical tours that are normally part of the meetings have not taken place. This is a downside to the work programme of 2021. The meeting in Trisaia was in the end only attended by Austria and the UK; due to COVID-19 and personal reasons the other member could not participate face to face.

- Prepare and publish reports on issues relating to gasification of biomass and waste. During 2021 we published 2 reports and 4 case studies. All available online here[22].
  - Report on Emerging gasification technologies for biomass and waste
  - Report on Gasification applications in existing infrastructures for production of sustainable value-added products
  - Case study 1 – Entrained flow biomass gasification in the pulp and paper industry
  - Case study 2 – Gasification for production of biomethanol by coupling with anaerobic digestion
  - Case study 3 – Integration of renewables into existing refineries
  - Case study 4 – Gasification of RDF and integration into an existing naphtha cracker
- Conduct joint studies, conferences, and workshops with related Tasks, Annexes, and other international activities to address issues of common interest to advance biomass and waste gasification technology. The four case studies have been supplied to Task 42 for technical, economic and environmental assessment (TEE), for which they will develop new material.
- Identify research and technology development needs based on the results from the work described above as a part of the workshop reports.
- Publish results of the work programme on the Task website (www.task33.ieabioenergy.com) for information dissemination. Maintain the website with Task updates.
- Maintain Task 33 database on thermal gasification facilities worldwide.

Observations from Workshops:

Workshop organised in Trisaia: Gasification - a key technology in the energy transition and for the circular economy. This workshop (http://task33.ieabioenergy.com/content/workshop_events) provides a good overview of how gasification is being applied in the circular economy, in hydrogen production, in biofuels production and for CHP. It includes a broad overview with speakers from industry actively developing these kinds of projects.

Observations from Webinars:

The webinar organised in March (https://www.ieabioenergy.com/blog/publications/iea-bioenergy-task-33-webinar-gasification-of-biomass-and-waste/) showed clear differences between countries with respect to where technology was being developed. India had a strong focus on CHP while China was going for higher end applications. In Europe and the USA the latter higher end applications is also ongoing with development moving in the direction of fuels, chemicals and hydrogen much more.

22 http://task33.ieabioenergy.com/content/Task%2033%20Projects

Website and database

The Task website (www.task33.ieabioenergy.com) is the most important tool for dissemination of information and results from the Task. Descriptions of the gasification process and a description of the Task including the contact data of national experts are provided. Within two weeks after each Task meeting, all presentations in PDF form (Country Reports, Workshop presentations) can be found on the Task website. The Minutes are posted in the member's area of the website as soon as all Task members provide their feedback. The summaries of the workshops can be found on the website in a Report format.

A Google-map based interactive database of implementations of gasification plants has been incorporated into the Task website. At the moment, there are over 150 gasification facilities, mostly in member countries, registered in the database. The database is interactive, which means that the technology, type, and status of the gasifiers can be chosen to filter all the gasification facilities registered in the database. The possibility to filter also based on the feedstock/raw material was recently added to the database. The database is updated regularly and provides a good overview of gasifiers around the world. During the current triennium, the aim of Task 33 was to extend this triennium report on gasification with relevant countries, who are not yet members and have provided input.

Collaboration with Other Tasks/Organisations/Networking

The collaboration with Task 42 has developed. Task 33 will provide 4 case studies on how gasification can be implemented to convert industrial processes into bio-refineries. The case studies are available since December 2021 and Task 42 will develop techno-economic assessment (TEA) for these case studies which will become available in 2022.

In 2021 we successfully reached out to the IEA Hydrogen TCP to foster collaborations on the production of bio-hydrogen based on gasification. In the upcoming triennium the idea is to provide specific case studies to the IEA Hydrogen TCP on gasification based hydrogen production. Task 33 will also participate with similar activities in the Inter-Task project on hydrogen in the next triennium.

Deliverables

The Task deliverables include planning and conducting two semi-annual Task meetings focused on the workshops selected by the Task participants, involving academic and industrial experts; the preparation and distribution of workshop reports; updating and publishing country reports; conducting joint studies and providing webinars on the content, conferences, and workshops with related Tasks, Annexes, and other international bodies to address mutually beneficial issues; and preparation of periodic progress, financial and annual reports as required by the IEA Bioenergy Executive Committee (ExCo).

TASK 34: Direct Thermochemical Liquefaction (DTL)

Overview of the Task

The objective of Task 34 is to advance the international implementation of bioenergy technology through strategic information analysis and dissemination in the areas of direct thermochemical liquefaction of biomass (including bio-based waste) for bioenergy applications such as heat, power, transportation fuel, and the production of chemicals.

'Direct Thermochemical Liquefaction' is the controlled thermal degradation of biomass in any form to derive valuable energy and chemical products. It includes thermal and catalytic fast pyrolysis, hydrothermal and solvo-thermal liquefaction.

The Task contributes to standardisation efforts of these energy intermediates, the resolution of critical technical areas and disseminating relevant information particularly to industry and policy makers. The scope of the Task is to monitor, review, and contribute to the advancement of issues that will permit more successful and more rapid implementation of biomass liquefaction technology, including identification of opportunities to provide a substantial contribution to bioenergy.

The Task scope includes all steps in a process of liquid fuels production from biomass, extending from reception of biomass in a raw harvested form to delivery of a marketable product as liquid fuel, heat and/or power, chemicals and char by-product. The technology review may focus on the thermal conversion and applications steps, but implementation requires the complete process to be considered. Process components as well as the total process are therefore included in the scope of the Task, which will cover optimisation, alternatives, economics, and market assessment.

The work of the Task aims at concerns and expectations of stakeholders such as:

• Conversion technology developers	• Bio-oil/biocrude application developers
• Equipment manufacturers	• Bio-oil users
• Chemical producers	• Utilities providers
• Policy makers	• Decision makers
• Investors	• Planners
• Researchers	

Industry is actively encouraged to be involved as Task participants, as contributors to Workshops or Seminars, as Consultants, or as technical reviewers of Task outputs to ensure that the orientation and activities of the Task match or meet their requirements.

Participating countries: Canada, Denmark, Finland, Germany, India, The Netherlands, New Zealand, Norway, Sweden, and the United States of America

Task Leader: Dr.-Ing. Axel Funke, Karlsruhe Institute of Technology (KIT), Germany

Operating Agent: Birger Kerckow, Fachagentur Nachwachsende Rohstoffe e.V. (FNR), Germany

The Task Leader directs and manages the work programme, assisted by National Team Leaders (NTL) that are responsible for specific work packages and/or deliverables. An NTL from each country is responsible for coordinating the national participation in the Task.

For further details on Task 34, please refer to Appendices 2, 4, 5 and 6; the Task website (http://task34.ieabioenergy.com/) and the IEA Bioenergy website (www.ieabioenergy.com) under 'Activities: Tasks'.

Progress in R&D

This year the national team leaders worked on a variety of efforts to advance research in thermally liquefied biomass for use as energy carriers, with the additional goal of providing value to Task 34, the international thermal liquefaction research community, as well as the interests of the individual member states. Typically, these efforts are supported by Task meetings held in conjunction with both international and regional bioenergy conferences and workshops. This was not possible in 2021 due to the impact of the ongoing COVID-19 pandemic. This also had direct impacts on planned workshops that are typically organised in conjunction with these meetings. Instead, a series of regular videoconferences was conducted with the primary aim to keep track of Task related work packages and discuss findings/news.

Information dissemination to stakeholders was continued through the PyNe newsletter, journal publications, web resources, and circulation of reports that may have broader use among member countries.

The overview of work efforts in 2021 included:

- A continued series of videoconferences to replace face-to-face meetings
- Continued publication of the bi-annual electronic PyNe newsletter to highlight current research, standards work, collaborations, and successes in bioenergy through direct thermal liquefaction of biomass. Additionally, a third issue was published: the jubilee PyNe celebrating the 50^{th} issue in its 25^{th} year of publication.
- Participation in European R&D projects, specifically regarding co-processing of fast pyrolysis bio-oil in existing refineries. This work will contribute significantly to development of associated analytical standards in Europe. Task 34 provides a platform for the involved researchers to connect and exchange information.

- Reporting and publicising ongoing collaborations and research in bioenergy in the form of country reports by country representatives at Task meetings. These country reports have also been published on the Task's website as separate reports.
- Identification of a success story around the development of new fast pyrolysis bio-oil applications, namely co-feeding in a fossil refinery.
- Contribution to the Inter-Task project (ITP) on 'High temperature heat for industrial application' by providing an in-depth case study on the use of fast pyrolysis bio-oil.
- A report on analytical methods to quantify compounds in fast pyrolysis bio-oil that are relevant for its registration as a chemical commodity in the European Union (REACH).
- Creation of a new web page that provides an overview of Task 34 Round Robin contributions to standardisation.

Task Meetings and workshops

Five videoconferences were conducted in 2021 to replace the originally planned two face-to-face meetings. The main focus was on creating the proposal for the upcoming triennium, discussion of results from work packages, and exchange via country reports. Regular items of these online meetings such as keeping track of work packages, PyNe publication, communication with ExCo/ other TCP Bioenergy Tasks etc are not explained further here. Detailed minutes are available on the Task's website.

Work Programme and Outputs

An overview of techno-economic assessments of DTL technologies was conducted with the aim to assess their suitability to convey reliable information to stakeholders from industry. Based on the data collected it became apparent that there were some issues that require closer evaluation as follow up work. This will be done in 2022, also in conjunction with e.g. IEA Bioenergy Task 42 to prepare a meaningful report.

Country reports have been made available on the Task's website twice: early and late 2021. These reports provide an overview of research activities, demonstration activities and commercial applications of Direct Thermochemical Liquefaction in Canada, Denmark, New Zealand, Norway, and the United States of America.

With demonstration in a full-scale refinery in Sweden, co-feeding of fast pyrolysis has taken the next decisive step towards market implementation. This important project even required the construction and commissioning of a fast pyrolysis unit with dedicated production solely for co-feeding. Task 34 has featured and published this as Success Story.

Trading of all chemicals in the EU, including biofuels, requires prior registration (REACH). Fast pyrolysis is a complex reaction product and as such is represented by a mixture of chemicals with partially unknown and varying composition. REACH registration for fast pyrolysis bio-oil demands keeping certain specifications for maximum tolerated concentrations of certain compounds. Task 34 published a report on analytical methods to quantify some of the more difficult compounds to support establishing fast pyrolysis bio-oil as a tradable commodity.

Newsletter

In 2021 the PyNe newsletter was produced twice to publicise and highlight ongoing research and collaborations in member countries, with particular emphasis on active research and growing commercialisation efforts. A variety of pyrolysis and hydrothermal liquefaction activities was featured in both issues. There is a consistently high audience accessing PyNe newsletters.

Additionally, the 50th PyNe issue in its 25th year of publication was celebrated by publishing a third PyNe issue – the Jubilee PyNe 2021. Several previous members of Task 34 contributed to this PyNe with articles, focussing on the historic development of Task 34 and its origins.

All PyNe newsletters, including previous ones, are accessible on the Task's website:
https://task34.ieabioenergy.com/pyne-archive-1996-2020/

Website/Dissemination

The Task 34 website was updated on a continuous basis regarding events, participants, and the PyNe newsletter. The layout of the website was adjusted to comply with the new brand of the IEA Bioenergy TCP. Most web pages with hard facts concerning DTL have been thoroughly revised in 2021; however, implementation into the new web page layout will be finalised in early 2022.

Task 34 has supported the standardisation of fast pyrolysis bio-oil through conduction of Round Robins with a focus on its special matrix. This work was very successful, and the first standards for its use as a fuel for boilers are in place. A new web page was created to provide an overview of these Round Robins to further disseminate this important contribution.

Website traffic is categorically up and increasing significantly. Most page views are for pyrolysis reactors, followed by biocrude and pyrolysis principles. The increase in views for biocrude, the liquid product from hydrothermal liquefaction (HTL) is particularly noteworthy since it reflects ongoing activities in the field of HTL to achieve demonstration of this technology. Significant traffic from non-member countries to Task 34 still includes China, the United Kingdom, and Brazil suggesting potential areas for outreach.

Collaboration with Other Tasks/Organisations/Networking

Task 34 participates in the IEA Bioenergy ITP 'Bioenergy for High Temperature Heat in Industry' and has finalised its contribution to the report. It also collaborated with Task 44 'Flexible Bioenergy and System Integration' in the course of their report on 'Technologies for Flexible Bioenergy'. Task 34 also contributed to the report of Task 39 on 'Progress towards biofuels for marine shipping'.

Deliverables

Deliverables for 2021 included:

- Review of techno-economic assessments of DTL technologies (D1.1, completed, but follow up work identified prior to publication planned to be finalised by Q3/2022)
- Contribute to co processing bio-oil/biocrudes in petroleum refineries Task 39 report (D 1.2, Draft is out, delayed to Q2/2022)
- Report on Round Robin (D2.1, delayed to Q4/2022)
- Advanced analytical techniques workshop/webinar (D 2.2, cancelled)
- Report on standardisation of bio-oil/biocrude analysis and application (D 3.1, delayed to Q2/2022)
- Technical notes on R&D and commercialisation experiences (D3.2, delayed to Q2/2022)
- Publication of two PyNe newsletter issues (D4.1 e/f, **completed**)
- Website content refresh (D4.3, delayed to Q1/2022)
- Two workshops, seminars, and/or site visits with key stakeholders (D4.4c/d, cancelled due to pandemic induced travel restrictions)
- Success Story (D 4.5, **completed**)
- Country Report (D4.6b, delayed from Q4/2020, **completed**; D4.6c **completed**)
- Process heat in industry (ITP 1, **completed**)
- Validation of methods to determine polar and non-polar components in FP Bio-Oil (DAdd 2.2, **completed)**
- Assessment of MSDS data of fast pyrolysis bio-oil (DAdd3.1, delayed to Q2/2022)
- Material Compatibility (DAdd 3.2, delayed to Q3/2022)
- Electrochemistry & Fast Pyrolysis Bio-Oil (DAdd 3.4, delayed to Q2/2022)
- Anniversary PyNe (Add 4.1, **completed**)
- Round Robin database (DAdd 4.2, **completed**)

TASK 36: Material and Energy valorisation of waste in a Circular Economy

Overview of the Task

In 2012, the World Bank estimated that around 1.3 billion tonnes of municipal solid waste are generated per year globally and that this will grow to 2.2 billion tonnes per year by 2025. They attributed this rise in waste generation to increased urbanisation in developing and emerging economies and the associated increase in per capita generation of waste. This trend is a considerable challenge for many countries that will have to work towards intensive legislative, managerial and institutional changes, including the introduction of strategic direction aimed at decreasing and controlling waste generation; and the development of recycling, reduction and re-use as well as energy technologies to decrease the impact of waste. IEA Bioenergy Task 36 investigates the interface between waste management and energy recovery, and the role of waste-to-energy in a circular economy. Our prime aim is to understand the implications of technical and policy changes in the waste area that impact the integration of energy into solid waste management and their integration in a circular economy; and to provide support by disseminating and exchanging information on these developments.

Waste generation varies markedly across the world, in terms of composition and quantity. Strategies and solutions that are appropriate in one region may not be right elsewhere. The consequence of this is that countries have different approaches to challenges in waste arisings, reflected in different mixtures of treatment and disposal. Nevertheless, there are also common themes. Uppermost in these are concerns relating to the increasing quantities of waste needing to be treated and the impact of landfilling mixed wastes on the environment. In some cases, additional pressure arises from decreasing available landfill void space. This is driving policy makers to examine alternatives to landfill, including reduction and recycling of waste, and recovery of value from waste, commonly encompassed in the 'Waste Hierarchy', which is governed by a set of principles dedicated to minimising the impacts of waste and improving resource use. In some regions, there are calls for 'zero waste to landfill' and for policy to encourage the circular economy or 'smart waste management'. These moves are most advanced in the European Union and other regions where landfill is expensive or scarce. Elsewhere, notably in North America and Australia, countries continue to rely on landfill, but in these countries, there are also increasing pressures to reduce waste production and to recycle or recover where possible, leading to increased interest in recovery of energy from the residual waste. Globally, these policy pressures have led to a proliferation of research work on waste management, including policy development, environmental systems analysis, technology development and economic drivers. Whilst this has assisted in the development of more sophisticated waste management systems, in many cases it has also delayed deployment of energy recovery systems (specifically for residual wastes), in particular due to confused policy making, public awareness (and opposition) and uncertainty over environmental performance and technology performance.

Against this background decision makers continue to require guidance and information on waste and resource management systems that are environmentally and economically sustainable. Task 36 provides a unique opportunity to draw together information on how systems, policies and technologies are being applied in different countries to provide guidance for decision makers on key issues.

Participating countries: Australia, Germany, Ireland Italy, Norway, South Africa, Sweden, and the United States of America.

Task Leader: Mr. Inge Johansson, RISE Research Institutes of Sweden, Sweden

Operating Agent: Mr. Jonas Lindmark, Swedish Energy Agency, Sweden

The Task Leader directs and manages the work programme. A National Team Leader from each country is responsible for coordinating the national participation in the Task.

For further details on Task 36, please refer to the Task website www.task36.ieabioenergy.com and the IEA Bioenergy website www.ieabioenergy.com under 'Activities: Tasks'.

Progress in R&D

Task meetings and workshops

The Task's core work was undertaken as structured Task meetings. Since the pandemic these meetings have been held exclusively online and divided into shorter and more frequent meetings. Workshops have also been an important tool during 2021, where the aim of these workshops is to allow Task members to present work on the nature of the issues concerned within their own country; to invite speakers to present work of relevance and to allow discussion of the issues presented.

Workshop – ***Transitioning towards a decarbonised circular economy – Focus on Waste to Energy, Online, June 2021, as part of SABIA National Biogas conference***

Workshop aim: The workshop was arranged as part of the SABIA (https://sabia.org.za) yearly national biogas conference. It aimed to give an international perspective on waste-to-energy.

Workshop outcomes:

Around 60 people participated in the session where they gained insight into different aspects.

- The emerging Hydrogen economy in Australia was presented by Daniel Roberts, and some inspiration on next generation waste to energy technologies and what role waste and residues can play in that segment.

- Some lessons learned from the development of the US Roadmap for Waste to Energy was presented by Beau Hoffman. One important factor for success in making the roadmap (and later on in the implementation) was the stakeholder engagement.
- Inge Johansson presented the role incentives have played in the implementation of biomass from waste in the Swedish energy system. Different kinds of incentives are often needed, especially at the start. However, when deciding the structure of incentives, close attention to what is in place in other regions or countries must be observed, otherwise there might be unintended negative effects.

Task Meetings and site visits

There were online meetings arranged regularly between January-December 2021.

No site visits were organised due to COVID-19.

Work Programme and Outputs

The work during 2021 has been developed in line with the work programme. In total the normal deliveries around Task meetings and ExCo reporting has been done. From the work programme four reports/case studies have been published. Adaptations have been made both to accommodate shifting budgets from travel and meetings to other content and to cover for unforeseen obstacles with some work items. There is ongoing work that has been delayed and which will not be published until the first or second quarter of 2022 (three case studies and two reports).

Website

The website (http://task36.ieabioenergy.com/) is the key tool used for dissemination of information from the Task. It provides access to the latest publications produced by the Task. The website also provides access to past reports, articles, case studies and presentations at workshops associated with Task meetings. During 2021, the website has been updated with the content of newsletters and four new reports from the Task.

In addition, the website provides a 'members only' forum, to allow rapid access to the latest drafts of documents and to information on Task meetings. Part of this structure has however been replaced by a Microsoft Teams platform. During 2021, the website received almost 3,740 visitors. This corresponds to a 17% increase compared to 2020.

Regarding the origin of the visitors to the website, most hits were received from the United States of America, China, the United Kingdom and South Korea.

Collaboration with Other Tasks/Organisations/Networking

The main collaboration with other IEA Bioenergy Tasks has been the participation in Inter-Task/ common projects. Task 36 is involved in two of those, the first one about BECCS/U and the other one regarding the use of High temperature heat from biomass in industry. There have also been discussions for upcoming Inter-Tasks during 2022-2024 with a number of the other Tasks.

In addition, members from Task 37 have reviewed two of the case studies that are either published or close to publishing.

As mentioned before the workshop during the 2nd quarter of 2021 was arranged together with SABIA (who were the main host).

A presentation concerning Waste-to Energy Technologies[23] was made at the APEC seminar organised out of Indonesia during July 2021.

Deliverables

The deliverables for the Task in 2021 have included minutes from the Task meetings; presentations of several Task members at the IEA Bioenergy Conference 2021 representing the Task in the session Waste and residues valorisation in a circular economy[24]; two newsletters[25] published during 2021, contribution to the IEA Bioenergy Newsletter and four reports. In addition, a new work programme for the period 2022-2024 has been developed. There have also been presentations made on different occasions, nationally and internationally, representing the Task.

23 https://www.apec.org/publications/2022/01/apec-workshop-on-community-based-waste-to-energy-management

24 https://www.ieabioenergyconference2021.org/agenda_session/waste-and-residue-valorisation-in-a-circular-economy/

25 https://task36.ieabioenergy.com/news/newsletter/

TASK 37: Energy from Biogas

Overview of the Task

In 2019-2021 Task 37 proposed work on three broad themes: the role of biogas in energy systems; sustainability of biogas systems and methods to ensure good practice; and integration of biogas into processes.

To mitigate climate change, it is essential to develop integrated and sustainable decarbonised renewable energy systems. Heat and transport together, account for about 80% of final energy consumption. Significant progress has been made in renewable electricity but decarbonisation of transport fuel is problematic. Gaseous renewable energy carriers, such as renewable 'green gas' can have a considerable impact in future energy systems and play a key role in decarbonising heat and transport. Green gas[26] at present is dominated by biomethane, which can be generated from the anaerobic digestion of organic biomass and residues produced in agriculture, food production and waste processing. In 2018, there were 577 biogas-upgrading plants in operation in 15 IEA Bioenergy Task 37 countries. The market for biomethane is still growing. Sweden, the UK, Switzerland, France and the Netherlands have all increased their biomethane production significantly in the last six years. In the short term, the development of green gas projects, including the injection of biomethane into gas networks will be the primary focus of this developing industry. Management of this process and broad scale implementation will require a green gas certificate scheme to ensure sustainability, credible GHG reductions and to allow trade.

Recent policy measures facilitate the development of green gas and hydrogen pathways with progressively increasing obligations on decarbonisation. The share in renewable and low-carbon transport fuels will need to increase rapidly to meet climate targets. Biomethane can provide advanced sustainable biofuel for intercity buses, waste management truck fleets and heavy duty commercial vehicles. The on-going requirement to decarbonise will lead to integration of anaerobic digestion systems in other processes, be they agricultural, food and beverage processing, or other industrial and waste management sectors. Anaerobic digestion is also seen as an integrated element in future innovative biorefineries and circular economy systems.

The approach of Task 37 involves the review and exchange of information and promotion of best practices for all steps of these process chains including anaerobic digestion for the production of biogas as a clean renewable fuel for use either directly in combined heat and power generation or after up-grading to biomethane where it replaces natural gas. In addition, there is growing interest in the use of biogas and biomethane to help stabilise power grids that are increasingly fed from variable sources of generation like wind and solar.

26 Referred to as renewable natural gas (RNG) in North America

The Task also addresses utilisation of the residues of the digestion process, the digestate, and the quality management methods for conversion to high quality organic fertiliser. Only in the past number of years has the environmental performance and greenhouse gas footprint of biogas production and utilisation been assessed in detail. Recent studies have identified key sources of emissions of greenhouse gases at various stages of the biogas production chain. Task 37 has addressed emissions and is directing attention to environmental and carbon sustainability of biogas production and utilisation and is working towards defining best practices for emissions reduction.

Through the work of the Task, communication between RD&D programmes, relevant industrial sectors and governmental bodies is encouraged and stimulated. Continuous education is addressed through dissemination of the Task's publications in workshops, conferences and via the website. Information and data collected by the Task is used increasingly for providing support to all levels of policy making and the drafting of standards in Member Countries.

Participating countries: Australia, Austria, Brazil, Canada, China, Denmark, Estonia, Finland, France, Germany, India, Ireland, Italy, Korea, The Netherlands, Norway, Sweden, Switzerland and the United Kingdom.

Task Leader: Prof Jerry D Murphy, MaREI Centre, Environmental Research Institute, University College Cork, Ireland

Operating Agent: Matthew Clancy, Sustainable Energy Authority of Ireland, Dublin, Ireland

The Task Leader directs and manages the work programme, assisted by sub-task leaders for specific areas. A National Team Leader from each country is responsible for coordinating the national participation in the Task.

For further details on Task 37, please refer to Appendices 2, 4, 5 and 6; the Task website (http://task37.ieabioenergy.com/about-task-37.html) and the IEA Bioenergy website (www.ieabioenergy.com/) under 'Activities: Tasks'.

Progress in R&D

Work Programme and Outputs

In 2021 the work programme consisted of the following Topics:

- Preparation of technical reports;
- Case Stories;
- Country reports;
- Task Meetings and Workshops;
- Website, Videos, Newsletters and Webinars;
- Deliverables of Task 37 in 2021.

Preparation of Technical Reports

Our published reports may be viewed at http://task37.ieabioenergy.com/technical-brochures.html. The reports we have completed and are still working on are described below:

D7 Biomethane as a transport fuel

Target audience: Policy makers, Municipalities or Regional Authorities, Haulage Fleets, Bus services, Distribution services (Light Good Vehicle fleet), Biogas producers/developers, Gas Grid operator, Filling Stations

Champions: Sweden, Ireland, Norway, and the United Kingdom

A significant report of enhanced scale over that proposed (attracting a large budget) was published in December 2021 as below:

Ammenberg J., Gustafsson, M., O'Shea, R., Gray, N., Lyng, K-A., Eklund, M. and Murphy, J.D. (2021). Perspectives on biomethane as a transport fuel within a circular economy, energy, and environmental system. Ammenberg, J; Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2021:12.

Both the report and the two page summary are available for free to download at: http://task37.ieabioenergy.com/technical-brochures.html.

Learning outcomes: *Natural gas systems should be a facilitator of the introduction of biomethane for transport, but the sustainability problems associated with natural gas negatively impact the view of biomethane. This is where arguments amongst the renewable sector actors can hinder progress. Biomethane and (power to methane) can utilise the existing gas grid and accelerate progress to decarbonisation of the overall energy sector beyond just electricity and also to decarbonise chemical (such as ammonia and methanol) and steel production. This should be advantageous especially when realising that more energy is procured from the natural gas grid than the electricity grid in the EU and the US; however, suggestions that biomethane is only greenwashing the natural gas industry, and in doing so extending the lifetime of natural gas, greatly impedes this progress. This report provides exemplars of very good biomethane based transport solutions, with a high technological readiness level for all elements of the chain from production to vehicles. Transport biomethane sits well in the broad circular economy, energy, and environmental system providing services across a range of sectors including reduction in fugitive methane emissions from slurries, treatment of residues, environmental protection, provision of biofertiliser, provision of food grade CO_2 and a fuel readily available for long distance heavy haulage.*

D8. Technical aspects of integration of biogas systems into the energy system:

Target audience: Biogas producers/developers, Grid operators, Energy customers, Municipalities, Policy makers.

Champions: Germany, Switzerland, Ireland

Collaboration: with IEA Bioenergy Task 44 (Flexible bioenergy and system integration)

Report published in August 2020 as below:

Liebetrau, J., Kornatz, P., Baier, U., Wall, D., Murphy, J.D. (2020). Integration of Biogas Systems into the Energy System: Technical aspects of flexible plant operation, Murphy, J.D (Ed.) IEA Bioenergy Task 37, 2020:8

Both the report and the two page summary are available for free to download at: http://task37.ieabioenergy.com/technical-brochures.html

Learning outcomes: *Biogas is a versatile energy carrier which can be used to produce electricity, heat and after upgrading serve all functions of natural gas, including transport. Biogas systems are highly scalable in their energy output according to the demand from the particular energy sector. The flexibility of biogas systems can facilitate electricity production at a dynamic schedule to match an electricity demand profile, while facilitating voltage and grid stability. As a decentralised component of the overall energy system biogas systems can function as an infrastructure hub for local energy consumers in rural areas. Biogas can play an essential role (together with PV and wind) as part of a virtual power plant in local distribution energy grids. Biogas systems can operate as a biological battery in coupling the electricity and gas grids using surplus electricity to produce hydrogen to react with biogenic CO_2 in biogas producing biomethane and increasing the output of biomethane (typically by 70%). Innovation and ingenuity will be required of biogas operators in future energy systems.*

D9. Green gas certification & sustainability criteria:

Target audience: Policy makers, Biogas producers/developers, Gas Industry (Gas Grid Operators, Gas Traders), Gas customers

Champions: Germany, Ireland

Collaboration: Inter-Task project including the European Commission DG Energy, IEA Bioenergy Germany, IEA Bioenergy Sweden, IEA Hydrogen and IEA Bioenergy Tasks 37/40 & 45.

The work includes collaboration on Renewable Gas and a second broader collaboration "Renewable Gas – Hydrogen in the grid" led by Uwe Fritsche.

Both the Task 37 report and the two-page summary are available for free to download at: http://task37.ieabioenergy.com/technical-brochures.html

Report published in November 2021 as below:

Liebetrau, J., Rensberg, N., Maguire, D., Archer, D., Wall, D., Murphy, J.D. (2021) Renewable Gas – discussion on the state of the industry and its future in a decarbonised world, Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2021:11.

Learning outcomes: *The existing natural gas infrastructure is very extensive in many industrialised countries and rather than being viewed as a future redundancy associated with a fossil fuel system, it could instead be seen as offering huge benefits for green renewable gas as a future decarbonised energy carrier. The whole natural gas infrastructure system was put in place at huge cost and includes an extensive transport system of transmission and distribution pipes and connections to industries and homes. Within specific industries, gas boilers, CHP units and associated systems are in place to provide the necessary ingredients and energy provision for end products that range from ammonia to whiskey. Traditional renewable gas technologies (such as biogas and biomethane) can be considered mature. For example Denmark has at times substituted natural gas in the grid with over 25% biomethane. In terms of policy we have devised and put in place trading mechanisms for trade between producer and user of renewable gas, sometimes in different countries. The economic feasibility is questioned, however as this is a green fuel which is being compared to a fossil fuel where the present cost of carbon in no way takes account of the climate emergency. As such, it is preferable to contrast the cost of renewable technologies with the cost of other renewable technologies which are viable in that sector; for example we should not compare the cost of abatement of mature technologies in readily decarbonised sectors (say PV arrays) with that of an advanced transport fuel that can power heavy transport but is at an early stage of development. We need to incentivise technologies at early market maturity and at low technology readiness levels (TRL) that are seen to have great potential for application as fuels of the future for hard to abate sectors such as hydrogen and associated electro-fuels.*

The above work provided content to a synthesis report:

Biomethane – factors for a successful sector development Synthesis Report of WP1 of the IEA Bioenergy Inter-Task project Renewable gas – deployment, markets and sustainable trade Authors: Jan Liebetrau, IEA Bioenergy Task 37 Uwe Fritsche, Hans Werner Gress, IEA Bioenergy Task 40

D10. Drivers for successful biogas schemes and their sustainability: International perspectives:

Target audience: municipalities, academics, practitioners, farmers, agri-food, utlility gas grid operators, stakeholders, policy makers

Champions: Canada

Contributor: All

The report is published and can be referenced as follows:

Wellisch, M., Green, J., McCabe, B., Rasi, S., Siemens, W., Ammenberg, J., Liebetrau, J., Bochmann, G., Murphy, J.D. (2020). ***Drivers for Successful and Sustainable Biogas Projects: International Perspectives – Report of a symposium held on March 26, 2020.*** *Green, J., Wellisch, M., Szlachta, P., Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2020: 5*

Learning outcomes: *The drivers for successful and sustainable anaerobic digestion projects are country and context specific. The challenge that such projects face – in all countries – is how to make anaerobic digestion projects financially viable. We know from countries that have biogas plants, that supportive policies are required in a number of areas, including waste management, renewable energy and climate change mitigation. To make these projects work, financial assistance, such as capital grants and multi-year power purchase agreements with a significant premium, is needed to attract the necessary investment. In this symposium we heard from seven IEA Bioenergy Task 37 Member countries – Australia, Finland, The Netherlands, Sweden, Germany, Austria and Ireland. Collectively they painted a picture of how the right combination of feedstocks, technologies and policies are required for a successful and sustainable project. The solutions are not "one size" fits all, but country specific.*

The report is available for free to download at:
http://task37.ieabioenergy.com/technical-brochures.html

D11. Integration of anaerobic digestion into farming systems:

Target audience: farmers, agricultural stakeholders, policy makers

Champions: Australia, Canada, Italy, and the United Kingdom

The report is published and can be referenced as follows:

McCabe, B., Kroebel, R., Pezzaglia, M., Lukehurst, C., Lalonde, C., Wellisch, M., Murphy, J.D. (2020). ***Integration of Anaerobic Digestion into Farming Systems in Australia, Canada, Italy, and the UK.*** *Lalonde, L., Wellisch, M., Murphy, J.D (Ed.) IEA Bioenergy Task 37, 2020: 8*

Learning outcomes: *The four countries – Australia, Canada, Italy, and United Kingdom – differ with respect to their size, climate, and type of agricultural production. Canada and Australia have the largest landmass but vastly different climates. Anaerobic digestion and biogas production in the agriculture sector is highest in Italy, followed by the UK, Australia, and Canada. The adoption of anaerobic digestion (AD) has grown in all four of these countries over the last decades, albeit at different rates. In all cases, energy and climate change policies have been the dominant drivers that have enabled growth. The environmental sustainability of agriculture has many facets. In this section of the report, each country description provides a different lens on sustainability and the role of anaerobic digestion.*

The report is available for free to download at:
http://task37.ieabioenergy.com/technical-brochures.html

D12. Increasing the range of feedstocks for anaerobic digestion

Champions: Switzerland

Contributors: Austria, Canada, China, Germany, Ireland

Audience: operators of biogas facilities, farmers and agricultural organisations, feedstock suppliers, policy makers and consultants

Expected completion date: Q2, 2022 – TBC

Scope:

- Describe substrate characteristics which define anaerobic degradability;
- Give examples and describe the characteristics, source and potential of recalcitrant feedstocks;
- Give an overview of possibilities and concepts for further treatment of digestate such as thermal conversion;
- Give an overview of technically available pre-treatment technologies for poorly degradable substrates and possibilities to implement them into the anaerobic digestion process;
- Present an overview of technically available concepts to enhance substrate digestibility through AD process alteration such as: multi-stage digestion; inline treatment (such as ultrasonic or maceration) or leaching processes followed by UASB.
- Detail decision making processes for assessing suitability of low-quality feedstocks.
- Provide examples of successful implementation of a range expanding processes for substrate utilisation.

D14. Integration of anaerobic digestion into industrial bioprocessing:

Champions: Austria

Contributors: Australia, Canada, China, Norway, Finland, Sweden

Audience: operators of biogas facilities, farmers and agricultural organisations, feedstock suppliers, policy makers and consultants

Expected completion date: Q1, 2022 – TBC

The report will focus on food and beverage and pulp and paper industries. A number of examples will be presented including abattoirs, dairies, breweries, distilleries, olive mills, sugar factories, potato industry, wineries, juice factory. The analysis will include feedstock, fermentation, process integration, gas utilisation and energy balances.

Extra Deliverable: Manure potential, economics, government investment, economics

Audience: operators of biogas facilities, farmers and agricultural organisations, feedstock suppliers, policy makers and consultants

Champions: Germany; Australia; Austria; Norway; Canada, Ireland and the United Kingdom

Both the report and the two page summary are available for free to download at: http://task37.ieabioenergy.com/technical-brochures.html

The report was published in June 2021 as follows:

Liebetrau, J., O'Shea, R., Wellisch, M., Lyng, K.A., Bochmann, G., McCabe, B.K., Harris,P.W., Lukehurst, C., Kornatz, P., Murphy, J.D. (2021) Potential and utilization of manure to generate biogas in seven countries, Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2021:6.

Learning outcomes: *Production of biogas from manure at a farm level is the very epitome of a sustainable bioenergy system. The system incorporates a circular economy decentralised production of organic biofertiliser and biogas for use in heat, power or transport fuel, whilst simultaneously reducing fugitive methane emissions from open slurry holding tanks, reducing smells and minimising pollution effects on rivers and wells. Why therefore is the practice of producing biogas from manure not more widespread? The characteristics of manure depend on farm animal source and the method of husbandry, which in turn leads to a wide range of levels of technically available manure resources and costs of biogas produced from manure. To exemplify this, IEA Bioenergy published this report which examines the potential of manure for utilisation in biogas facilities across seven countries: Germany; Australia; Austria; Norway; Canada, Ireland and the United Kingdom. These countries have differing levels of biogas industry, very different farming practices and a range of climates. It is hoped that the country selection should allow the lessons learned from these seven countries to be applied to many countries across the planet.*

D.13. Case Stories

Five case stories were published in 2021 and are available at http://task37.ieabioenergy.com/case-stories.html:

1. Treatment of pigment wastewater and generation of natural gas standard biomethane in Hangzhou, China, December 2021
2. Biogas production from kitchen wastes in Jinhua, China, December 2021
3. Corn straw biogas production in cold northern region of China, December 2021
4. Circular economy system integrating biogas into process to produce high quality products from recycled paper, July 2021
5. Minhe Chicken Manure Biogas Plant: Circular economy management of chicken manure, June 2021

Country Reports

IEA Bioenergy Task 37 – Country Reports Summaries 2019 published in March 2020 available from: http://task37.ieabioenergy.com/country-reports.html

We will publish an update in February 2022

Task Meetings and Workshops

- ***Fifth Virtual Meeting 2019/2021 January 12 & 19th, 2021 (via Teams)***
- ***Sixth Meeting Austria (Virtual) 2019/2021 April 14 to 16, 2021***

Workshop: Biomethane: Timely solutions for successful implementation and use. A virtual workshop hosted by IEA Bioenergy Task 37 and the University of Natural Resources and Life Sciences, IFA Tulln, Austria, April 15, 2021

For a successful energy transition to a climate-friendly supply of primary and secondary energy vectors, biomethane must be produced in a manner which ensures a secure and sustainable process. Biomethane may be a central element of future circular economy systems producing energy on demand. It is possible to use established combustion systems and existing infrastructure, such as the natural gas grid or natural gas storage facilities. Hydrogen may be added to biomethane in existing natural gas infrastructure allowing for renewable and green gases to satisfy hard to abate sectors. Biogas also has a role in electro-fuel systems whereby hydrogen produced from electrolysis of variable renewable electricity may be converted to renewable methane and to liquid fuels such as methanol. Hydrogen may be reacted with CO_2 (preferable concentrated biogenic CO_2 streams such as in biogas) via a microbiological or catalytic process to produce renewable methane. Power to methane (or biomethanation) can be considered an advanced biogas upgrading process employing carbon capture and use; typically, the energy output as methane is increased by c. 70% as compared to the original biogas system.

The IEA Bioenergy (International Energy Agency Bioenergy) workshop "Biomethane", organised by the Austrian representatives in Task 37 of IEA Bioenergy and the University of Natural Resources and Life Sciences Vienna, IFA Tulln, highlighted different aspects of biomethane including: certification; legislation; application examples; and financing. The workshop also presented research and new developments in the field of methanation. In addition to national contributions, there were presentations from Germany, Switzerland, the United Kingdom, Sweden and the USA.

Time	Presenter	Topic	Country	Company
9.00-9.07	Dr G Bochmann	Welcome from Boku	Austria	BOKU
9.07-9.15	Prof JD Murphy	Welcome from IEA Bioenergy Task 37	Ireland	IEA Bioenergy Ta
9.15-9.40	Stefanie Königsberger	Biomethane Registry Austria – Challenges of the European certification system for renew	Austria	AGCS Gas Cleari
9.40-10.05	Johannes Misensky	Biomethane map Austria, gas production and grid injection in Austria	Austria	AGGM
10.05-10.30	Robert Paulnsteiner	H2 injection into the gas grid	Austria	Verbund
10.30-10.55	Florian Marko	National Energy Policies and Incentives for Biomethane Production	Austria	BMK
Break				
11.10-11.35	Jaqueline Daniel-Gromke	Retrofitting of existing biogas plants towards upgrading to biomethane	Germany	DBFZ
11.35-12.00	Urs Baier	Aspects of biomethane production and consumption in Switzerland	Switzerland	ZHAW
12.00-12.25	John Baldwin	UK Update on Biomethane as a Truck Fuel	UK	cng services
12.25-12.50	Jonas Ammenberg	Swedish Biomethane Roadmap	Sweden	Linköping Unive
Break				
14.00-14.25	Stefan Bauer	Geo-Methanation: The Underground Sun Conversion project	Austria	RAG
14.25-14.50	Alexander Kraiete	Methanogenesis Beyond Power to Gas. New Applications	Austria	Kraiete

The presentations were uploaded to: http://task37.ieabioenergy.com/workshops.html

- *Seventh Meeting (Virtual) 2019/2021, July 1, 2021 (via Teams)*
- *Eighth Meeting (Virtual Australia) 2019/2021, November 22 to 24, 2021 (via Teams)*

Bioenergy Australia (BA) Webinar Series

https://www.bioenergyaustralia.org.au/events/117500/

BA Webinar: IEA Bioenergy Task 37 – The role of renewable gas in decarbonisation and current status of biomethane frameworks in IEA Bioenergy member countries

Decarbonisation is about so much more than electricity which only accounts for about 20% of final energy demand. We must make decisions informed by scientists and engineers and implemented through policy as to what technologies and roadmaps will be employed to decarbonise the hard to abate sectors including: heavy transport; high temperature industrial heat; agriculture; fertiliser and chemical production. When it is considered that at present in the EU and the USA the natural gas grid provides more energy than the electricity grid, it cannot be seen as a sensible process to abandon such infrastructure and start again, not with the imminent climate emergency and the need to act fast.

The existing natural gas infrastructure is very extensive in many industrialised countries and rather than be viewed as a future redundancy associated with a fossil fuel system, it could instead be seen as offering huge benefits for green renewable gas as a future decarbonised energy carrier. The whole natural gas infrastructure system was put in place at huge cost and includes an extensive transport system of transmission and distribution pipes and connections to industries and homes. Within specific industries gas boilers, CHP units and associated systems are in place to provide the necessary components and energy provision for end products that range from ammonia to whiskey.

Renewable gas technologies include biogas and biomethane from wet organic material, syn-gas from dry woody material and hydrogen from electricity. Power to gas includes initially hydrogen production via electrolysis but also further processing to renewable methane via the Sabatier Process ($4H_2 + CO_2 = CH_4 + 2H_2O$). The source of the carbon dioxide can be from, for example, the food and beverage industry and include reducing the carbon footprint of industry. Electro-fuels can convert hydrogen to liquid fuels such as methanol (CH_3OH) and fertiliser such as ammonia (NH_3). Production of renewable gases tend to be part of broader circular economy systems which impact not only the energy sector but have a role in environmental protection, waste management, facilitation of intermittent renewable energy systems and act as biological batteries.

The interactive Bioenergy Australia live webinar introduced some of the world's leaders on the potential roles for green gases in decarbonising a range of sectors. The presentations also addressed major highlights of a survey within countries participating in IEA Bioenergy on the current status of biomethane frameworks and provided recommendations for a successful sector development. The technology of biomethane provision is mature given more than 500 applications in Europe alone.

Agenda

Welcome

- Georgina Greenland, National Manager, Industry Development & Advocacy Bioenergy Australia
- Professor Bernadette McCabe, University of Southern Queensland, Australian National Team Leader IEA Bioenergy Task 37

The potential role of renewable gas in decarbonisation

- Dr David Wall University College Cork, Ireland and IEA Bioenergy Task 37 co-lead for Ireland
- Professor Jerry Murphy, University College Cork, Ireland and IEA Bioenergy Task 37 leader

Biomethane – status and framework conditions – results of a survey

- Dr.-Ing Jan Liebetrau, Rytec GmbH Germany and IEA Bioenergy Task 37 lead for Germany

Q&A

Panel session moderated by Professor Bernadette McCabe, University of Southern Queensland, Australian National Team Leader IEA Bioenergy Task 37

Website, Videos, Newsletter and Webinars

Website

The website (www.iea-biogas.net & http://task37.ieabioenergy.com) is updated on a regular basis with: technical reports and corresponding two page summaries; case stories; databases, country report summaries; workshop proceedings; webinars.

Newletters

There were 12 newsletters issued for Task 37 in 2021.

Webinars

The differentiation between workshop and webinar and conference was moot during the COVID pandemic. Our workshops were held on-line and potential audiences grew due to lack of room size constraint.

IEA Bioenergy Conference 2021

Session: State of the art and innovation in Green Gas

Thursday 2 Dec 2021: 7:00-9:00 UTC

https://www.ieabioenergyconference2021.org/#agenda

Green gas or renewable gas includes biogas/biomethane and renewable hydrogen involving different production methods (anaerobic digestion, biomass gasification, electrolysis to hydrogen, power to gas). Green gas can have a considerable impact in future energy systems through sector integration and play a key role in decarbonising heat and transport. This session considered the state of the art of green gas and development opportunities.

Moderator

Jerry Murphy, Director SFI MaREI Centre for Energy, Climate and Marine, Director SFI MaREI Centre for Energy, Climate and Marine, Ireland

Presentations

State of the art in Green Gas

Jerry Murphy, Director SFI MaREI Centre for Energy, Climate and Marine, Director SFI MaREI Centre for Energy, Climate and Marine, Ireland

Integration and flexibilization of biogas systems

Jan Liebetrau, Head of the Department Consulting and Research, Rytec GmbH, Germany

Increasing the green gas resource with gasification technologies

Berend Vreugdenhil, Senior Scientist Specialist Biomass and Circular Technologies, TNO, Netherlands

Green Hydrogen developments – Australia

Amy Philbrook, Future Fuels and Renewables, ATCO Group, Australia

Innovation from an industry perspective

Ole Hvelplund, CEO, Nature Energy, Denmark

IEA Bioenergy Conference 2021

Session: Green Gas Perspectives

Thursday 2 Dec 2021: 14:00-16:00 UTC

https://www.ieabioenergyconference2021.org/#agenda

This session discussed perspectives of biogas and biomethane in different parts of the world – Europe, North America, China and developing countries – and the role of policy frameworks for further deployment. It is important to consider that biogas is not just a renewable energy solution, but provides a strong contribution to the circular and biobased economy, mostly starting from waste and residual flows and, amongst others, circulating nutrient and organic material flows, providing sanitation of treated material and contributing to the development of rural areas. Sustainability of green gas concepts needs to be considered to make sure they positively contribute.

Moderator

Uwe Fritsche, Scientific Director, IINAS, Germany

Presentations

- *Sustainability of green gas*

  David Chiaramonti, Professor of Systems for Energy and Environment and Energy Economics, Polytechnic of Turin, Italy

- *A global perspective on green gas*

  Maria Michela Morese, Executive Secretary, Global Bioenergy Partnership (GBEP), Italy

- *Perspective of China*

  Renjie Dong, Head, Bioenergy and Environment Science & Technology Laboratory/Biomass Stoves Test Laboratory/Carbon-Neutral Agriculture Research Center, China Agricultural University (CAU), China

- *Perspective of the United States*

  Sam Wade, Director of Public Policy, RNG Coalition, United States

- *Perspective of the EU*

  Malcolm McDowell, Team Leader – Methane strategy, European Commission – DG Energy, Belgium

Further Webinars and presentations in 2020

Besides the webinars described above in 2021 these are some of the webinars from 2020.

A webinar was held on the 6th May 2020 with Australia Bioenergy entitled "Decarbonising the gas network-potential, projects and policies" which included 4 presentations as follows:

1. *Decarbonisation of the gas network: an international overarching perspective* – Jerry D Murphy IEA Bioenergy Task 37 Leader
2. *Decarbonisation of the gas network: The quiet revolution of biogas and RNG in Denmark* – Claus Mortensen International Business Developer in Agro Business Park and the Danish Innovation Network for Bioresources.
3. *Potentials in methanation* – Ole Hvelplund CEO at Nature energy
4. *Australia: opportunities, policy options and Future Fuels project* – Joshua Moran Commercial Manager at Jemena

Presentations available at:
https://cdn.revolutionise.com.au/cups/bioenergy/files/iaxdenknz2kvm7sd.pdf

Recording available here: https://www.dropbox.com/s/fxpqrokb7u55fc2/Bioenergy%20Australia%20webinar%206%20May%202020%20-%20recording.mp3?dl=0

An IEA Bioenergy webinar entitled "Integraton of Biogas Systems into the Energy System" presented by Prof Jerry D Murphy and Dr Jan Liebetrau was held on January 21, 2021. The audience included 367 people from 54 countries. The webinar was recorded and is available on line at: https://www.youtube.com/watch?v=uaDKIZoWS6A

Presentations

"Flexible biogas systems" Richard O'Shea, Jan Liebetrau and Jerry D Murphy presented at Central European Biogas Conference Graz Austria at a workshop held by IEA Bioenergy Task 44 on the 24 January, 2020. See: https://www.ieabioenergy.com/blog/ieaevent/task-44-workshop-flexible-bioenergy-and-system-integration/

Deliverables

The deliverables are outlined in the publications list in Appendix 4.

TASK 39: Commercialising Conventional and Advanced Transport Biofuels from Biomass and Other Renewable Feedstocks

Task 39 continued its work to advance the development and deployment of sustainable, lower carbon-intensive transport biofuels during 2021. The Task has an overall goal of facilitating the decarbonisation of the *multi-faceted* transport sector (particularly the long-distance transport sector where electrification will be more challenging, i.e., aviation, marine, trucking and rail) using "conventional" and "advanced" transport biofuels. Four relatively main categories of transport biofuels have been covered by Task 39. They include:

- "Conventional" biofuels
  - Ethanol from sugar/starch (e.g. sugarcane, corn, sugar beet and wheat)
  - Biodiesel from oleochemicals/lipids (Fatty acid methyl ester (FAME))
- "Advanced" biofuels
  - Cellulosic ethanol (1.5G and 2G), oleochemicals/lipids from algae, biomethane/renewable natural gas (RNG), power-to-liquid, green hydrogen, etc.
- "Conventional" drop-in biofuels via oleochemical/lipid feedstocks
  - Hydrotreated esters and fatty acids (HEFA), hydrotreated vegetable oil (HVO), hydrogenation-derived renewable diesel (HDRD), renewable diesel, green diesel, etc., produced from lower carbon intensity feedstocks and waste materials such as used cooking oil (UCO)/tallow/tall oil and higher carbon intensity feedstocks such as vegetable oils
- "Advanced" drop-in biofuels via lignocellulosic biomass feedstocks
  - Production and upgrading of biocrude liquid intermediates from lignocellulosic feedstocks (sometimes algal oils) via standalone biorefineries or by co-processing in existing petroleum refineries
  - Production by upgrading of other bio-feedstock derived intermediates, e.g., Alcohol-to-Jet, Sugar-to-Jet, Gasification-followed-by-Fisher-Tropsch synthesis, etc.

Despite significant obstacles, such as slower-than-anticipated progress in commercialising cellulosic ethanol/other advanced biofuels technologies, ongoing uncertainty around future biofuels policies and, more recently, the COVID-19 pandemic, relatively good progress has been made in the biofuels area during 2021. The long-distance transport sector continues to play a vital role in maintaining the delivery of essential goods and services (e.g., medical supplies, food, energy, etc.). However, the shorter-term economic challenges created by the pandemic will be compounded by the increasing urgency to deal with carbon emissions and climate change. In response, many of the governments that have developed economic recovery packages have included aspects that are focussed on reducing the carbon intensity of their economies.

By focussing on technology, commercialisation, sustainability, policy, markets and implementation, Task 39 was able to assist low carbon transport stakeholders in their efforts to develop and deploy biofuels. The Task coordinated the technical and life cycle assessment of various biofuels and compared-and-contrasted the various policies used (with varying levels of effectiveness) to increase the production and use of biofuels. The success of the Task continues to be a direct result of providing a forum for these types of integrated discussions. The active involvement of participants from industry, government and academia have also been key to the Task's success.

During 2021, Task 39 increased its efforts to assist its member countries and other biofuels stakeholders to develop and deploy sustainable, low carbon intensity biofuels to decarbonise the transport sector, in particular the long-distance (e.g. aviation, marine, etc.) sectors. The Task delivered two research projects that highlighted how low carbon intensive drop in biofuels offer an immediate way of decarbonising the aviation and shipping sectors. Task 39's pilot and demonstration biofuels production plants database was recently updated by Austria's BEST – Bioenergy and Sustainable Technologies GmbH organisation. More information on these internal projects is provided in section "Work Programme and Outputs".

Task 39 participants were also encouraged to publish their work in the peer reviewed literature (to increase access to the Task's work). Two manuscripts were published in peer-reviewed journals and one manuscript has been submitted for review.

As part of its communication strategy, Task 39 also organised twice-per-year business meetings. The minutes of the business meetings are documented and posted on Task 39's website (access to minutes is limited to Task 39 membership and business meeting participants). Task 39 organised and participated in other virtual webinars and conferences on how decarbonisation of the transport sector can contribute to a "green economic recovery". In trying to meet this goal, the Task organised three "IEA Bioenergy Webinars", plus a session on Transport Biofuels in "the BBEST 2021-Biofuture Summit II Conference", and the "IEA Bioenergy Conference 2021[27]". The flyer, recording and presentation slides of some of the joint webinars are posted on the Task 39 website (Events and Conferences[28]).

In addition to publishing reports and organising webinars, Task 39 published several newsletters. The newsletters featured country reports, hyperlinks to recent Task 39-relevant media stories and updates of global progress in the biofuels area. In 2021, Task 39 published two newsletters that summarised Task 39 progress updates with feature articles highlighting technical and policy developments related to biofuel production and use in Ireland (Issue #57 in June) and Norway (#58 in December). The newsletters are distributed to over 2500 biofuels stakeholders.

27 https://www.ieabioenergyconference2021.org/

28 https://task39.ieabioenergy.com/events-conferences/

The Task's website is visited regularly and routinely receives enquires that are typically handled by the Task coordinator and webmaster. Alternatively, the enquiries are referred to experts within Task 39's network. Website statistics are reported in the Progress Reports submitted to the IEA Bioenergy ExCo.

In addition, Task 39 strengthened collaborations with other IEA Bioenergy Tasks (e.g. Inter-Task project with Task 40 and Task 45 and joint workshop with Task 44). We continued our good rapport with other groups such as IEA Headquarters, US DoE, IRENA, the BioFuture Platform and Mission Innovation, the IEA Advanced Motor Fuels TCP, UN FAO and various national programs. It should be emphasised that Task 39 continues to benefit from extensive industry input from companies and institutions at the forefront of biofuels development. This includes, Boeing, Borregaard DSM, ENI, GoodFuels, International Air Transport Association (IATA), IFPEN, ISCC, Haldor Topsoe, LanzaTech, LBST, Licella, Neste, Novozymes, Renewable Energy Group (REG), Roundtable on Sustainable Biomaterials (RSB), $(S\&T)^2$ Consultants, skyNRG, Steeper, UPM, World Wildlife Federation, to mention just a few

Overview of the Task

As mentioned earlier, the primary goal of Task 39 is to facilitate the commercialisation of low carbon-intensive transportation biofuels including conventional and advanced biofuels. These fuels are produced through various technology routes such as oleochemical, biochemical, thermochemical and hybrid conversion technology pathways. The success of the Task continues to be, in large part, a direct result of providing a forum for integrated discussions aided by the active involvement of participants from industry, government and academia. The Task continues to lead and coordinate activities in three main programme areas:

1. Technology and Commercialisation

a) Help develop and commercialise improved, cost-effective processes for the production of sustainable low carbon intensity biofuels, particularly the production and use of "drop-in" biofuels from oleochemicals and lignocellulosic feedstocks (biocrudes) to decarbonise the long-distance transport sector;

b) Work with other IEA Bioenergy Tasks to assess and help develop cost-effective oleochemical, biochemical, thermochemical and hybrid technologies as well as to co-optimise fuel-engine systems to maximise transport performance efficiencies and associated greenhouse gas reduction potentials using advanced biofuels; and

c) Assess and describe advancements and challenges in emerging less developed advanced transport biofuels technologies and processes such as biomass-to-hydrogen, algae-to-biofuels, etc.

2. **Policy, Markets, Implementation and Sustainability** encompasses issues that address policy/legislative/regulatory and infrastructure concerns and needs regarding expanding conventional and advanced transport biofuels. This Task activity also provided information and analyses of policies, markets, and implementation issues that have fostered commercialisation of sustainable low carbon biofuels. The broad goal is to replace non-renewable fossil-based fuels by helping deploy conventional (so-called first generation) biofuels while supporting the development of advanced biofuels and 'future-generation' biofuels. The Task also continues work to better clarify commonalities and the main differences in methodological structures, calculation procedures and assumptions used within leading LCA models (i.e., EU's BIOGRACE, Canada's GHGENIUS, USA's GREET and Brazil's VSB).

3. **A Multifaceted Communication Strategy** was used to facilitate knowledge transfer, information dissemination, outreach to stakeholders and coordination with related groups both within IEA Bioenergy and externally. In 2021, Task 39 organised five virtual business meetings. Task 39 members also organised and participated in several virtual webinars and sessions, as listed below. In addition, the Task published two newsletters that included progress updates on Task 39 activities and featured articles on biofuel production and use, technical and policy developments in Ireland and Norway. The newsletters also highlighted recent news articles and reports of interest to biofuels stakeholders.

- **List of Task 39 Business meetings, Joint workshops & Webinars in 2021**
  - Task 39 business meeting, 19-21 April 2021 (virtual)
  - Participated in BBEST 2021-Biofuture Summit II Conference, May 2021 (virtual)
  - Task 39's presentation for the IEA Bioenergy Webinar entitled, "Sustainable Aviation Fuel/Biojet Technologies – Commercialisation Status, Opportunities and Challenges", June 2021
  - February 2021-through-August 2021: Three virtual Task 39 "brainstorming sessions"
  - Task 39 business meeting (End of Triennium), 23-24 November 2021 (virtual)
  - Organised two sessions in the IEA Bioenergy Conference 2021, 1st December 2021 (virtual)

The Task 39 pilot/demonstration biofuel plant database is an on-going activity, updated at least annually as new information becomes available through conferences, presentations, news articles and Task 39-member updates. This database, which provides information and locations of advanced biofuels production facilities in Task 39-member countries and the rest of the world, can be accessed at: https://demoplants.best-research.eu/

Task 39's demonstration biofuels production plants database is maintained by Austria's BEST – Bioenergy and Sustainable Technologies GmbH organisation. Technologies covered in the database include E-Fuels Biomass Hybrids, Hydrotreatment Facilities, Co-processing plants, Hydrothermal Liquefaction and SAF/Biojet Production Facilities. The database was recently updated, with information on all European facilities (121) verified and updated. There are about 290 active entries, of which 220 are at TRL 6-9.

As part of its outreach to stakeholders, Task 39 is fortunate to have the active participation of many experts from industry, government and universities/research centres. The Task's structure allows participants to work together in a comprehensive manner on prioritised issues and challenges identified across the broad area of transport biofuels.

Participating countries: Australia, Austria, Brazil, Canada, Denmark, European Commission, Germany, India, Ireland, Japan, Korea, The Netherlands, New Zealand, Norway, Sweden and the United States of America (USA)

Task Leader: Jim McMillan, National Renewable Energy Laboratory, USA

Task Co-Leader: Jack Saddler, University of British Columbia, Canada

Operating Agent: Oshada Mendis, Natural Resources Canada, Canada

Task Manager: Mahmood Ebadian, University of British Columbia, Canada

The Task leadership is shared between the National Renewable Energy Laboratory (USA) represented by Jim McMillan, and the University of British Columbia (Canada) represented by Jack Saddler. Both Task Leaders are engaged in all aspects of the Task's operations. The Task leaders are assisted by Mahmood Ebadian (UBC), who serves as the coordinator of Task activities and programmes, Editor of the Task Newsletter as well as Webmaster for the Task's website. Dina Bacovsky (Austria) manages the Task's demonstration plants database. Franziska Müller-Langer is the Task's primary liaison to IEA's AMF TCP. Country Representatives (also known as National Team Leaders) for each Task 39 participating country are responsible for coordinating their respective nation's participation in the Task.

For further details on Task 39, please refer to the Task website (http://task39.ieabioenergy.com/) and the IEA Bioenergy website (www.ieabioenergy.com) under 'Activities: Tasks'.

Progress in R&D

Task Meetings and Workshops

As part of its organisational/communication strategy, Task 39 typically holds two business meetings per year. These are usually held in conjunction with related conferences and workshops, partially to help justify the travel required by many of the Task 39 members. However, in 2021, the Task held five virtual business meetings (February, April, August and November) due to the coronavirus pandemic which restricted travel and physical meetings. These business meetings included knowledge exchange between participants in the form of country updates and project updates, highlighting industry progress and challenges. Three of the meetings were used to "brainstorm" the scope of the Programme of Work (POW) for the 2022-2024 triennium.

On 2nd February 2021, Task 39 held a virtual brainstorming session to discuss what projects and dissemination activities Task 39 might tackle in the coming triennium. This will span calendar years 2022-2024. The main topics that were discussed included: 1) reviewing the current projects running in the 2019-2021 triennium and that will likely continue in the next triennium; 2) new projects not currently included in Task 39 activities, to be consider for the next triennium; and 3) information dissemination activities. The Task's draft prolongation proposal programme of work was submitted to the IEA Bioenergy Executive Committee (ExCo) in late March 2021 (for their review and comments). Task 39 organised two more virtual brainstorming meetings on August 10th and 25th, 2021, to discuss and refine the projects and dissemination activities. The main meeting agenda was to discuss the **proposed projects** for the next triennium, to confirm the **highest-priority projects** for Task 39 and the **likely champions** that would lead the various projects (recognising the limited budgets and resources available to Task 39). The vast majority of Task members supported continuing many of the Task's ongoing activities. Some Task members expressed interest in participating in new Inter-Task projects, particularly, a) "synergies of green hydrogen and bioenergy deployment" and b) "Biogas as a Transportation Fuel". The Task's final proposed programme of work was submitted to the IEA Bioenergy Executive Committee (ExCo) for review and comment(s) in late August and approved by the ExCo in October 2021.

The Task's first business meeting of 2021 was held virtually on 19-21 April. (The originally planned physical meeting in Denmark was cancelled due to the ongoing global COVID-19 pandemic). The meeting agenda comprised of: a) country updates on biofuels market and policy development in each member country; b) current triennium project updates; c) next meeting/ newsletters; and d) proposed work for the next triennium (2022-2024). To accommodate these agenda items, the Task business meeting was organised into three, 2-hr sessions on Monday 19 April, Tuesday 20 April and Wednesday 21 April. Individual member country updates were presented on the first day and first half of the second day of the meeting. After the country reports, on the second and third days, the project leaders presented progress updates for their respective projects. On the third day, future meetings/newsletters and the "proposed work for the next triennium" were discussed.

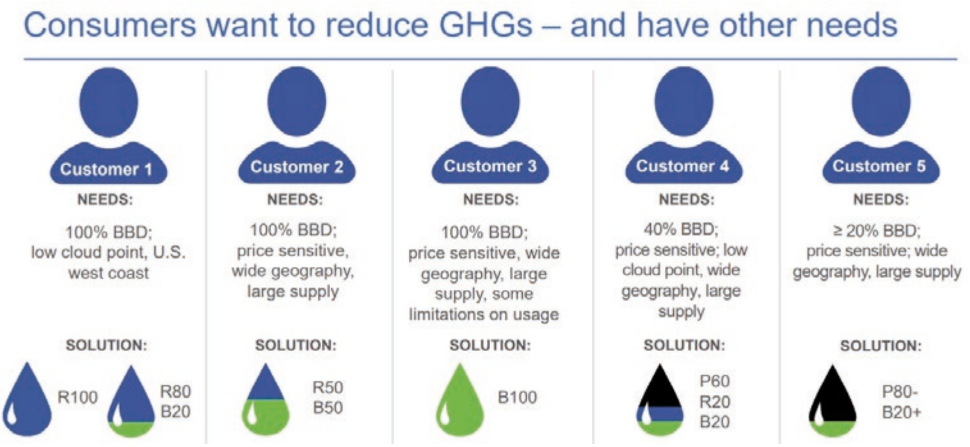
Similar to the previous business meetings in 2020 and 2021, the last Task 39 business meeting of 2021 (and the last meeting of the 2019-2021 triennium) was held virtually, using Zoom. The meeting agenda comprised of: a) current triennium project updates; d) discussions on the Programme of Work approved by the ExCo for the next triennium (2022-2024) and, c) next meeting/newsletters. To accommodate these agenda items, the Task business meeting was organised into two, 2-hr sessions on Monday 8 November and Tuesday 9 November. The project leaders presented progress updates for their respective projects and their plans to finish the projects by the end of the triennium.

Task 39 continues to actively organise and participate in virtual webinars and conferences. The major goal is to share the networks insights on how decarbonisation of the transport sector can contribute to a "green economic recovery". On 24-26 May 2021, Glaucia Mendes Souza, Brazil's representative in Task 39 and her colleagues, Luiz Augusto Horta Nogueira and Renato Godinho co-chaired the BBEST 2021-Biofuture Summit II Conference[29]. The conference was organised by the Brazilian Ministry of Foreign Affairs via the Biofuture Platform, the Bioenergy Research Program, (BIOEN) of the State of São Paulo Science Research Foundation (FAPESP), with support from the APEX-Brazil trade promotion agency and the International Energy Agency (IEA), as well as several other partners. The conference programme covered all aspects of bioenergy, i.e., policy, sustainability, biomass feedstocks, biorefineries, biofuels technologies and biofuels engines and applications and the importance of bioenergy to meeting global "net zero" targets was highlighted. A total of 40 sessions were presented. Task 39 hosted a session on "The commercialization of biofuels".

In June 2021, The Task completed a biojet report entitled "Progress in commercialization of biojet/Sustainable Aviation Fuels (SAF): Technologies, potential and challenges." An IEA Bioenergy webinar was held that summarised the main findings of this report. The recording of the webinar and the presentation slides can be found at the IEA Bioenergy Website: https://www.ieabioenergy.com/blog/publications/iea-bioenergy-webinar-sustainable-aviation-fuel-biojet-technologies-commercialisation-status-opportunities-and-challenges/

29 https://bbest-biofuture.org/

On 22 November 2021, Task 39 co-sponsored a free "virtual" panel discussion on decarbonising the trucking sector. The invited panel members represented some of the key groups that will be needed to decarbonise the long-distance trucking sector (i.e., low carbon fuels suppliers, end users, LCA and policy development advisors). They shared their insights and experience in the various potential pathways that will be needed to decarbonise the trucking sector, with a focus on low carbon intensive drop-in biofuels. The main takeaway message of the webinar was that immediate decarbonisation actions are needed. The speakers confirmed that biofuels, such as biodiesel and renewable diesel, are readily deployable low carbon solutions that can be used to decarbonise the trucking sector. About 100 participants attended the webinar, mainly from North America, South America and Europe. The list of panel members and their short bios as well as the presentation slides and a recording of the panel discussion are available on the Task 39's website (here[30]).



As discussed in the panel discussion, biofuels producers such as the Renewable Energy Group (REG) have been developing various biofuels blending approaches to meet the needs of their customers in the trucking sectors (Source: REG, 2021).

Task 39 also organised and held two virtual conference sessions focused on transport biofuels on 1 December 2021 within the IEA Bioenergy Conference 2021. This virtual conference featured a series of online sessions spread over two weeks between 29 November and 9 December 2021. The central theme of the conference was "the role of biomass in the transition towards a carbon neutral society". Short descriptions of the Task 39 organised sessions and their speakers are available via the following hyperlinks.

Session 1: Emerging biofuels markets and the importance of LCA and certification

Session 2: The potential of drop-in biofuels to decarbonise aviation

30 https://task39.ieabioenergy.com/events-conferences/

The active participation of most country team leaders and other participants at Task 39 meetings is a good indication of the value that Task 39 plays in promoting effective international information exchange.

Work Programme and Outputs

Summary of reports completed or advanced during 2021:

Report: Progress towards biofuels for marine shipping: Status and identification of barriers for utilization of advanced biofuels in the marine sector

Written as a continuation of the 2017 IEA Bioenergy Task 39 report: Biofuels for the marine shipping sector[31], this report highlighted the most significant barriers impeding the commercialisation of biofuels for the marine sector. Interviews were conducted with seven key stakeholders who are involved in the marine freight transportation sector. The interviews confirmed the considerable complexity and the many considerations that relate to decarbonising the marine fuels sector. One major barrier is the lack of economic incentives. Many stakeholders think that the high level of uncertainty related to price of biofuel feedstocks is a major problem. Additional barriers include the sustainability criteria that will be used and the onerous regulatory policies. In contrast, little concern was expressed regarding the technical barriers of scale-up, establishing supply chains, or adopting engine and fuel systems for new biofuels. Encouragingly, a number of the stakeholders highlighted biofuels as the most promising short- to mid-term solution for both reducing carbon emissions and meeting sulphur regulations. Also, with increasing international attention given to sulphur emissions and ship energy efficiency, the price gap between fossil fuels and biofuels is declining.

Report: Progress in commercialization of biojet/Sustainable Aviation Fuels (SAF): technologies, potential and challenges

This report provided an extensive analysis of the current and potential technologies for production of biojet/SAF. The report also summarised the various technologies that are currently being pursued to produce biojet/SAF. It highlighted several commercial-scale facilities that are scheduled to come online over the next few years. As emphasised in the report, some of the biojet/SAF processes have encountered high capital and feedstock costs while others are dealing with technology challenges. The report recognised that, because the price of biojet/SAF fuels is likely to remain significantly higher than conventional jet fuel, the "right" policies will be needed to bridge the price gap. These policies will be needed to incentivise the production and use of biojet fuels. The report emphasised that all of the technologies/pathways to biojet/SAF need to be pursued if we are to deliver the significant fuel volumes required to decarbonise aviation. While ongoing improvements and optimisation of the various processes will continue to reduce the cost of biojet/SAF production and use, meeting the sector's decarbonisation targets will be challenging.

31 https://task39.sites.olt.ubc.ca/files/2013/05/Marine-biofuel-report-final-Oct-2017.pdf

The report's authors presented the report's main findings in an IEA Bioenergy webinar on July 13, 2021. The recording of the webinar and the presentation slides can be accessed at the IEA Bioenergy website[32].

Report: Life Cycle Inventory Data for Brazilian Sugarcane Production

This study developed a life cycle inventory dataset for Brazilian sugarcane production. A unique opportunity arose through the implementation of the RenovaBio programme in Brazil. As part of the RenovaBio certification programme, producers were required to have a third party verify the information that they used to calculate the carbon intensity (CI) of their ethanol production. The data set that was developed represents 153 million tonnes of sugar cane in total plus 138 million tonnes of sugarcane that were produced using all actual values. The RenovaBio calculator uses the input data presented in this report and calculates the carbon intensity of the operations. The calculated emissions can be used as a check on the emissions reported in other models.

The developed dataset is of interest to the public and policy makers and GHG modelers. It was not the goal of this work to investigate the factors that impact the CI of sugarcane ethanol but rather to develop a good dataset that would be of value to LCA modelers.

The draft report was completed and circulated to selected reviewers for comments and feedback in November 2021. The final report was to be prepared in January 2022 after the incorporation of the collected comments and feedbacks from the reviewers.

Updates to demonstration plant database

The Task 39 pilot and demonstration plants database is an on-going activity. It is updated annually, and as new information becomes available. Task 39's demonstration biofuels production plants database is maintained by Austria's BEST – Bioenergy and Sustainable Technologies GmbH organisation. Recent updates include:

- Update with support from Task members: 130 entries updated; 60 newly created (including SAF, HVO, some e-fuels, some older plants)
- Continuous integration of new information
- Website and database maintenance: layout front page and filtering of products (output) possible
- About 280 entries currently active
- Planned activities: (1) Integration of co-processing plants (like OMV, Helpe); (2) Integration of E-Fuels (hybrids with biomass and green hydrogen) and (3) Increase of visibility in next triennium e.g. report on the status of advanced biofuels facilities

32 https://www.ieabioenergy.com/blog/publications/iea-bioenergy-webinar-sustainable-aviation-fuel-biojet-technologies-commercialisation-status-opportunities-and-challenges/

- Technologies covered:
  - gasification
  - fermentation
  - hydrotreatment
  - fast pyrolysis
  - hydrothermal liquefaction
  - lignin depolymerisation

Snapshot of Task 39's online demonstration plants database

This database, which provides information and locations of advanced biofuels production facilities in Task 39 member countries and the rest of the world, can be accessed at: https://demoplants.best-research.eu/

Other ongoing and Inter-Task projects that are led by Task 39 and are planned to be completed by end of Triennium in March 2022 include:

- **Implementation Agendas – compare and contrast policies to develop biofuels, 2020-2021 update**
  - The draft full report was prepared and circulated internally for review in September 2021. Several member countries have already reviewed and provided feedback.
  - The final draft of the full report is completed and will be posted on the Task 39 website in February 2022.

- **Analyse status of biofuels production and use in non-IEA countries/emerging economies**
  - The project lead (Brazil) completed the findings of their life cycle assessment for base case scenarios for four counties under study in the first phase of the project (Brazil, Argentina, Columbia and Guatemala).
  - The project team prepared and submitted a manuscript, entitled "Biofuels in Latin America: Sustainability Assessment of Argentinian, Brazilian, Colombian, and Guatemalan cases" to the journal of Renewable and Sustainable Energy Reviews in December 2021

- **Continuation of Drop-in Biofuels project – Progress in the production of drop-in biofuels/co-processing**
  - A peer-reviewed article has been published in collaboration with the local oil refinery (parkland) in the journal of Fuel in February 2021, entitled "Challenges in determining the renewable content of the final fuels after co-processing biogenic feedstocks in the fluid catalytic cracker (FCC) of a commercial oil refinery" (link[33]).
  - The second peer-review article entitled "Determining the amount of "green" coke when co-processing lipids commercially by fluid catalytic cracking" was submitted to the journal of Biofuels, Bioproducts and Biorefining and was accepted for publication in November 2021.

- **Feedstock-to-biofuel(s) supply chain analysis. Focus on CAPEX and OPEX cost reduction opportunities for advanced biofuels**
  - With contributions from the USA, Canada, Brazil and Germany colleagues, India (project lead) completed their analysis on feedstock availability, supply chains and second-generation ethanol production technologies.

- **Assess successes and lessons learned for conventional/advanced biofuels deployment**
  - This is an Inter-Task project between Task 39 (Project coordinator), Task 40 and Task 45 to evaluate reasons underlying the past and ongoing boom and bust cycles of biofuel technologies development, demonstration, deployment and replication
  - This project is comprised of six work packages (WPs) including WP1 (Status quo biofuel projects), WP2 (Meta-analysis existing studies), WP3 (Case studies technologies), WP4 (Case studies supply chains), WP5 (Synopsis/synthesis of key issues) and WP6 (Project management and dissemination).

33 https://www.sciencedirect.com/science/article/abs/pii/S0016236121004026

- The progress so far: 1) five progress meetings (one or two more meetings are scheduled by the end of the project); 2) three progress report presentations to ExCo with the latest in October 2021; 3) ExCo88 – Inter-Task Lessons learned biofuels 1-page status report; 3) three internal workshops and 4) several project management meetings.

- **Review existing and proposed certifications for oleochemical and lignocellulosic-based biofuels supply chains; identify certification scheme improvement opportunities**
  - The project team prepared a questionnaire and sent it out to Task 39-member countries in July 2021.
  - Several member countries have already filled out and submitted the questionnaire
  - The project team have been cross-checking information in the submitted questionnaires (which will become annexes in the report).

A listing of Task 39's projects for the 2019-2021 triennium and their short descriptions is provided in Task 39 Newsletter #54[34].

Newsletters

In addition to reports, conferences and workshop proceedings, Task 39 disseminates information through its 2-3 times a year newsletters. The newsletters include feature stories highlighting developments in a member country or region of interest while providing hyperlinks to media stories and reports of interest to the biofuel's stakeholder community. The newsletters detail the latest developments in industry and government policies pertaining to transport biofuels. Two newsletters were published in 2021 and distributed to over 2500 recipients. The newsletters featured articles on biofuel production and use and policies in Ireland and Norway. The list of Task newsletter can be found at http://task39.ieabioenergy.com/newsletters/.

Task 39's Newsletter issue #57 published in June 2021, included a feature article on "Biofuels Policies and Market in Ireland". This newsletter also includes a summary of the various topics covered in Task 39's virtual business meetings held in February and April, 2021. The newsletter also included a summary of Task 39 contributions to the BBEST 2021-Biofuture Summit II Conference which was held on 24-26 May 2021.

Task 39's Newsletter issue #58 was published in December 2021 and included a feature article entitled, "Biofuels Policies and Market in Norway". The newsletter also included a summary of the various, recent Task 39 activities including a brief description of brainstorming sessions on the Task's Programme of Work for the 2022-2024 Triennium held on August 10th and 25th, 2021 and End of Triennium Business Meeting on 8-9th November 2021. It also summarised Task 39's

34 https://task39.sites.olt.ubc.ca/files/2020/06/IEA-Bioenergy-Task-39-Newsletter-Issue-54-Final-Draft.pdf

recently published commissioned reports and journal papers that emphasise the important role of low carbon intensity biofuels as an immediate solution to decarbonise transport, especially the difficult-to-electrify long distance aviation and shipping sectors. The Task co-hosted (with the BC SMART Biofuels Consortium[35]) a well-attended webinar entitled, "Decarbonizing the trucking sector using low carbon-intensive fuels", on 22 November 2021, which is also summarised in the newsletter. The newsletter also includes some recent reports, news articles and notice of upcoming meetings, webinars and conferences of interest to biofuels stakeholders.

The country (or regional) specific lead/feature article in each newsletter provides a unique source of information to global biofuel stakeholders. We regularly receive requests for permission to republish these reports in other magazines, e.g., Biofuels Digest, Oi*ls and Fats* and other websites, e.g., Advanced Biofuels USA (https://advancedbiofuelsusa.info/).

Website

The Task continues to increase its influence within the international community that is working on decarbonising transport (using biofuels). The Task's website is well visited and routinely receives enquires that are typically handled by the Task coordinator and webmaster, or referred to experts within Task 39's network. Specific website statistics are reported in the Task's progress reports.

Collaboration with Other Tasks/Organisations/Networking

In the current triennium, Task 39s launched an Inter-Task project, entitled "Assess successes and lessons learned for conventional/advanced biofuels deployment". The IEA Bioenergy project team includes members of Task 39, Task 40 and Task 45.

Task 39 and Task 44 held a joint workshop on 25 November 2020. The workshop's objectives were to provide an overview of the "flexibility" options, gain any insights into concepts for more flexible biofuel and biopower production, discuss the challenges and success factors needed to implement these concepts in energy systems with high shares of renewables, and explore potential Task 39-Task 44 collaborations related to the future role of biofuels-producing biorefineries in grid balancing. A key challenge identified in the workshop was the generally higher capital costs required for biorefinery designs, that enable greater grid flexibility. For example, increased costs are required to install additional feedstock handling, power generation or hydrogen production capacities that will only be used to balance the grid some of the time. Further discussions highlighted the need for further research into compelling schemes as well as the potential for industrial symbiosis-oriented plant designs to mitigate cost barriers, for example by leveraging existing "stranded" capital or co-locating adjacent complementary facilities to help to reduce the otherwise higher capital cost of provisioning biorefineries for increased grid balancing capability.

35 https://www.bc-smart.ca/

Task 39 has continued its good rapport with allied stakeholder groups such as IEA Headquarters, IRENA, FAO, GBEP, other IEA TCP's (e.g., AMF, Hydrogen, etc.) and various national and international programs. Task 39 continues to benefit from extensive industry involvement of companies and institutions at the forefront of biofuels development. These include Boeing, Borregaard DSM, ENI, GoodFuels, International Air Transport Association (IATA), IFPEN, ISCC, Haldor Topsoe, LanzaTech, LBST, Licella, Neste, Novozymes, Renewable Energy Group (REG), Roundtable on Sustainable Biomaterials (RSB), (S&T)2 Consultants, skyNRG, Steeper, UPM, World Wildlife Federation, etc.

Task 39 continued to actively organise virtual webinars and conferences jointly with other organisations such as BC SMART Low Carbon Fuels Consortium with the goal of sharing the networks insights on how decarbonisation of the transport sector can contribute to a "green economic recovery". The flyer, recording and presentation slides of some of the joint webinars are posted on Task 39 website (Events and Conferences[36]).

Deliverables

In summary, the 2021 deliverables for Task 39 include:

1. Organised five virtual Task 39 business meetings;
2. Published two newsletters (issues #57 and 58);
3. Submitted the progress report and audited financial accounts statement;
4. Prepared and submitted the Programme of Work (POW) for the 2022-2024 triennium
5. Maintained and further developed the Task 39 website;
6. Actively organised and participated in several virtual webinars and conferences to share their insights on how decarbonisation of the transport sector can contribute to a "green economic recovery"
7. Updated Task 39's advanced biofuels demonstration plants database;
8. Completed two commissioned projects on marine biofuels and sustainable aviation fuel (SAF)/Biojet, entitled "Progress towards biofuels for marine shipping: Status and identification of barriers for utilization of advanced biofuels in the marine sector" and "Progress in commercialization of biojet/Sustainable Aviation Fuels (SAF): technologies, potential and challenges"
9. Published two manuscripts and submitted one manuscript to peer-reviewed journals.

All of the Task's published reports are available at the Task 39 website[37].

36 https://task39.ieabioenergy.com/events-conferences/

37 https://task39.ieabioenergy.com/

TASK 40: Deployment of biobased value chains

Overview of the Task

The Task 40 objective is to support deploying viable, efficient bioenergy value chains in the context of

- sustainable, national and international markets,
- reflecting on policy developments, and economic aspects, including financing
- international, national and regional trade of biomass,
- recognising the diversity in biomass resources, value chains and competitive applications for bioenergy, biobased materials and products.

The focus of Task 40 in this triennium is on the **development and design of efficient, economically viable and bankable value chains in order to support a larger deployment of sustainable biomass for energy, but also for biobased products and materials, taking into account food, feed and fiber markets.**

In short, the Task works on deploying sustainable biomass for energy in the context of the larger bioeconomy.

Within this scope, international, national and regional biomass trade remains vital. However, Task 40's scope is widened to understanding the functioning and improving the efficiency of entire biomass value chains, taking into account regional supply and use, in a balanced way and avoiding distortions and instability that can threaten investments in biomass production, processing, logistics and infrastructure, and conversion capacity.

It is key to understand biobased value chains and how to sustainably extend them. For this, the barriers and drivers for widespread and sustainable biomass deployment will be identified, and policy developments reflected that could foster biomass uptake in existing and new (emerging) markets.

A **key new** issue to be addressed from a deployment point of view was seen in the **financing aspect of bioenergy projects** (e.g., de-risking, sustainable profitability after initial support), aiming at providing high quality information, analyses, and synthesis to respective decisions for market players and financial institutions, policy makers, international bodies as well as civil society organisations (CSO, e.g., consumer and environmental groups, labor unions). Yet, due to restrictions related to the COVID-19 pandemic it was decided to postpone the work on this issue to the next triennium (2022-2024).

The scope of work has holistically supported the provision and use of sustainable biomass in different national and international markets, with a focus on bioenergy.

Participating countries: Austria, Belgium, Denmark, Germany, Japan, The Netherlands, Sweden, and the United States of America.

Task Leader: Uwe R. Fritsche, IINAS, Germany

Co-Task Leaders: Christine Hennig, DBFZ (Germany) and Olle Olsson, SEI (Sweden)

Secretary: Ms. Nora Lange, DBFZ, Germany

Operating Agent: Birger Kerckow, Fachagentur Nachwachsende Rohstoffe e.V. (FNR), Germany

The Task Leader directs and manages the work programme, together with the Co-Task Leaders (team approach). A National Team Leader from each country is responsible for coordinating the national participation in the Task.

For further details on Task 40, please refer to Appendices 2, 4, 5 and 6; the Task website (http://task40.ieabioenergy.com/) and the IEA Bioenergy website (www.ieabioenergy.com/) under 'Activities: Tasks'.

Progress in R&D

Task Meetings and workshops

In 2021, all planned physical meetings were canceled due to the Corona virus pandemic. Instead, regular virtual meetings (on average: every 6 weeks) took place together with a continuous offline exchange of information through a dedicated **OneNote book**.

Work Programme and Outputs

Task 40 has **three core areas of operation** that all include Inter-Task projects considering the various biobased value chains, markets and applications, as it sees itself as "horizontal" among the IEA Bioenergy Tasks.

WP1: Market developments

- Regional transitions in existing bioenergy markets – **flagship** project of Task 40
- New regional bioenergy markets **–** key actors, policies and regulation, and technological challenges (e.g., future CHP) regarding deployment, and trade – due to the Corona virus pandemic, this issue has been **postponed** to the next triennium.
- Market perspectives and deployment for aviation and marine biofuels – this became part of the "Advanced biofuels: Lessons learned" strategic Inter-Task project
- Globalised sustainable biobased value chains, including market perspectives and synergies between bioenergy and the bioeconomy – this project has started in the 3rd quarter of 2020

WP2: Industrial Heat and Processes

- Task 40 contributes to the Strategic Inter-Task project on Industrial heat
- Task 40 leads the Strategic Inter-Task project on BECCS/U, and its follow-up

WP3: Deployment Strategies

- Deployment guidance regarding technological barriers, economic aspects & financing – due to the corona virus pandemic, this issue has been **postponed** to the next triennium.
- Task 40 leads the Strategic Inter-Task project on Renewable gas – deployment, markets and sustainable trade
- Task 40 leads the Task 41 Special Project on "Renewables Gas – Hydrogen in the grid"
- Task 40 contributes to the WB2/SDG Strategic Inter-Task project

Reports and papers to be finalised until March 2022

- Final report for the Task 41 Special Project on "Renewables Gas – Hydrogen in the grid"
- Synthesis report of the Task 40 "Regional Transitions" project
- Synthesis reports on the Strategic Inter-Task Projects Industrial Heat and Renewable Gas and will contribute to the reports of the Strategic Inter-Task Project "Role of Bioenergy in a well-below 2 °C/SDG world".
- Final report on Work Package 4 Lessons learned in supply chains for the Strategic Inter-Task Project "Assess successes and lessons learned for biofuels deployment"
- Final Report on the Task 40 "Bioeconomy Synergies" project
- Case Study on "Bioethanol" and contribution to case study on "Bio-CCUS and bioenergy flexibility – finding the balance" and contribution to the system study "Carbon accounting across BECCUS supply chains" for the Inter-Task project "Deployment of Bio-CCS/CCU Value Chains

In addition, Task 40 will prepare several scientific articles and conference contributions.

Website

The website http://task40.ieabioenergy.com/ has been officially launched since September 2016 and is under the management of IEA Bioenergy. The Task website is a key tool for dissemination of information. At the beginning of 2019 the website was revised and new members, new projects and the work programme were introduced. Furthermore, the website informs about upcoming events such as webinars or workshops, also from other Tasks of IEA Bioenergy and presents a library of all published reports for download.

Of the total 670 downloads from the website in 2021, the report "*Deployment of BECCS/U value chains Technological pathways, policy options and business model"s* was the most requested document with 21%. The Task 40 February 2021 Newsletter and study "*Margin potential for a long-term sustainable wood pellet supply chain"* followed with about 7-8% of downloads.

Collaboration with Other Tasks/Organisations/Networking

Collaboration with IEA Bioenergy Tasks focused on all Strategic Inter-Task projects (Role of Bioenergy in a well-below 2 °C/SDG world; Renewable Gas; Industrial Heat, BECCS/U and Lessons Learned Biofuels).

Task 40 also contributed to the IEA Bioenergy ExCo online workshops and leads the Task 41 Special Project on "Renewable Gases – Hydrogen in the grid" which started in February 2020 as well as the strategic Inter-Task project Renewable gas deployment, markets and sustainable trade which recommenced in September 2020 and runs in parallel.

IEA Bioenergy conference 2021[38]

- Setting up regional biohubs to enhance biomass mobilisation[39]: Ric Hoefnagels "Biomass feedstock supply chains and future markets" and Fabian Schipfer "Biomass supply mobilisation strategies"
- Green Gas perspectives[40]: Uwe Fritsche contributed to and moderated the session
- Biomass and renewable heat[41]: Olle Olsson "Decarbonizing industrial process heat: the role of biomass"
- Bioenergy's contribution to low-carbon energy systems[42]: Christiane Hennig "Bio-CCS and bioenergy flexibility – Finding the balance"

38 https://www.ieabioenergyconference2021.org/

39 https://www.ieabioenergyconference2021.org/agenda_session/setting-up-regional-biohubs-to-enhance-biomass-mobilisation/

40 https://www.ieabioenergyconference2021.org/agenda_session/green-gas-perspectives/

41 https://www.ieabioenergyconference2021.org/agenda_session/biomass-and-renewable-heat/

42 https://www.ieabioenergyconference2021.org/agenda_session/bioenergys-contribution-to-low-carbon-energy-systems/

Deliverables

Task 40 Newsletter February 2021 https://task40.ieabioenergy.com/wp-content/uploads/sites/6/2021/02/Task-40-Newsletter-Feb-2021.pdf

Inter-Task project "Deployment of Bio-CCS/CCU Value Chains"

- Case study – Biomass based combined heat and power (CHP) – HOFOR Amager CHP, Copenhagen, Denmark. Bang, C., May 2021.
- Case Study – Deployment of bio-CCS in the cement sector: an overview of technology options and policy tools, Cavalett, O.; Cherubini, F. & Olle Olsson. December 2021.

Inter-Task project "Industrial Process Heat"

- Report Decarbonizing industrial process heat: the role of biomass, Dec 2021

Task 40 "Regional Transitions" project

- Journal Paper: Strategies for the Mobilization and Deployment of Local Low-Value, Heterogeneous Biomass Resources for a Circular Bioeconomy, Dec 2021

All reports and webinar presentations are available for free download from Task 40 website http://task40.ieabioenergy.com/.

TASK 41: Bioenergy Systems Analysis

Overview of the Task

The objective of the Task is to supply various categories of decision makers with scientifically sound and politically unbiased analyses needed for strategic decisions related to research or policy issues. The target groups are particularly decision makers in Ministries, national or local administrations, deploying agencies, etc. Depending on the character of the projects some deliverables are also expected to be of direct interest to industry stakeholders. Decision makers, both public and private, have to consider many aspects, so the Task needs to cover technical, economic, and environmental data in its work. The Task's activities build upon existing data, information sources, and conclusions. It does not intend to produce new primary scientific data.

The Task differs from the other Tasks in that it does not have networking as one of its prime objectives, nor do the Task's activities have continuous and repeating components, e.g., biannual meetings, country updates, etc. The work programme has a pronounced project emphasis with each project having very specific and closely defined objectives. Because of its special character in terms of participation, financing and cross-cutting orientation, the Task aims to be a valuable resource and instrument to the ExCo serving the ExCo with highly qualified resources to carry out projects, involving several parties (e.g., other Tasks and organisations) as requested by the ExCo. Due to the close contact with the other Tasks, Task 41 is intended to develop into a platform for joint Task work and a catalyst for proposals from the Tasks to the ExCo.

A project leader directs and manages the work of each project. For new projects an appropriate project leader is appointed by the project participants acting through the Executive Committee. The ExCo Member from each participating country acts as the national Team Leader and is responsible for coordinating national input to the projects undertaken.

Progress in R&D

Work Programme

The work programme is comprised of a series of projects. Each project has its own budget, work description, timeframe, and deliverables and is approved by the participants. The focus is on the needs of the participants by way of project outputs. One project was active in 2021 as follows:

Project 11: Renewable Gas – Hydrogen in the grid

The objective of this project was to identify and discuss numerous challenges and hurdles for gradually replacing natural gas by renewable gas, with an emphasis on H_2 injection into existing gas grids and on new dedicated H_2 grids. Its core objectives were:

- to bring together the expertise of IEA, IEA Bioenergy and national experts to showcase the role of renewable hydrogen and biomethane in the natural gas grid
- to analyse existing national strategies for greening the gas grid
- to assemble existing knowledge on hydrogen, natural gas and biomethane standards
- to identify possible challenges and hurdles for blending hydrogen and biomethane in natural gas grids.

Participating countries: European Commission, Germany and Sweden

Status: The final project report is expected to be published in the first quarter of 2022.

TASK 42: Biorefining in a Circular Economy

Overview of the Task

The goal of Task 42 'Biorefining in a Circular Economy' is to facilitate the commercialisation and market deployment of environmentally sound, socially acceptable, and cost-competitive biorefinery systems and technologies, and to advise policy and industrial decision makers accordingly. Task 42 provides an international platform for collaboration and information exchange between industry, SMEs, GOs, NGOs, RTOs and universities concerning biorefinery research, development, demonstration and policy analysis. This includes the development of networks, dissemination of information, and provision of science-based technology analysis, as well as support and advice to policy makers, involvement of industry, and encouragement of membership by countries with a strong biorefinery infrastructure and appropriate policies.

Gaps and barriers to deployment will be addressed to successfully promote sustainable biorefinery systems market implementation. For this 2019-2021 triennium, the focus of the activities is on:

- provision of quantitative, scientifically sound, and understandable data on the technical, economic and environmental added-value of biorefining to co-produce bioenergy and bio-products in a sustainable way (Biorefinery Assessment Platform, Biorefinery Fact Sheets, Reports on sustainable lignin valorisation);
- provision of global implementation status, major deployment barriers and market data (Biorefinery Country Reports, Global Biorefinery Status Report, Report on major non-technical deployment barriers, monitoring of international developments in biobased products certification and standardisation);
- provision of an international platform for cooperation and information exchange (Task 42 website, newsletters, lectures, webinars, thematic workshop on the role of biomass, bioenergy and biorefining in a Circular Economy, national stakeholder events, training).

The real added value of Task 42 'Biorefining in a Circular Economy' is its holistic approach of optimal sustainable use of biomass for a spectrum of non-food applications within the framework of a Circular BioEconomy. Therefore, Task 42 plays a central role in IEA Bioenergy linking the more (single) technology oriented Tasks to the Tasks dealing with biomass supply, climate and sustainability assessment, deployment. Its activities, often performed in cooperation with the other Tasks, provides real added value information for the other Tasks by providing technological, market and stakeholder data to further optimise their biomass conversion technologies to integrated biorefineries optimising their overall sustainable performance.

Participating countries: Australia, Austria, Denmark, Germany, Ireland, Italy, The Netherlands and Sweden

Task Leader: Bert Annevelink, Wageningen Food & Biobased Research, The Netherlands.

Assistant Task Leaders: Ed de Jong, Avantium, The Netherlands & Michael Mandl, tbw Research GesmbH, Austria.

Operating Agent: Kees Kwant, NL Enterprise Agency, Ministry of Economic Affairs, The Netherlands

The Task Leader directs and manages the work programme, assisted by two assistant Task Leaders for specific areas. A National Team Leader from each country is responsible for coordinating the national participation in the Task.

For further details on Task 42, please refer to Appendices 2, 4, 5 and 6; the Task website (http://task42.ieabioenergy.com/) and the IEA Bioenergy website (www.ieabioenergy.com) under 'Activities: Tasks'.

Progress in R&D

Task Meetings, Workshops & Webinars

36th Task Progress Meeting on MS Teams, 28 January 2021

37th Task Progress Meeting on MS Teams, 24 March 2021

IETS Workshop Future Scenarios and Strategic Decision-Making for Industry Transformation: Powered by System Engineering, 6 May 2021

A Task 42 presentation was given by E. Annevelink on 'Technical, Economic and Environmental Assessment (TEE) of biorefinery concepts'

38th Task Progress Meeting on MS Teams, 9 June 2021

Life Cycle Assessment Seminar "Ökobilanzwerkstatt 2021" hosted from Vienna by Wood K plus and supported by IEA Bioenergy Task 42, 22-24 September 2021

39th Task Progress Meeting on MS Teams, 19 October 2021

IEA Bioenergy Webinar on Sustainable Lignin Valorisation – Technical lignin, processes and market development, 4 November 2021

A Task 42 presentation was given by I. de Bari on 'Sustainable Lignin Valorization'

A Task 42 presentation was given by A. Giuliano on 'Simulation tools for lignin valorisation'

IEA Bioenergy End Of Triennium Workshop, Session Industrial symbiosis and biorefineries in a circular economy, 6 December 2021

A Task 42 presentation was given by E. Annevelink, L. Garcia & V. Motola on 'The status of biorefineries in a circular economy'

A Task 42 presentation was given by X. Hilz, T. Stern & F. Hesser on 'Barriers and incentives for the market diffusion of biorefineries in a circular economy'

Planned Meetings/Workshops 2022

The Task 42 Progress Meetings will be virtual on MS Teams in 2022, unless the COVID-19 situation stabilises. In that case meeting number 41 and 43 will be organised as in person meetings. The scheme is:

- 40th Task 42 Progress meeting in March 2022 – Start work plan new Triennium
- 41st Task 42 Progress meeting in May/June 2022 – Regular full progress meeting
- 42nd Task 42 Progress meeting in August/September 2022 – Intermediate progress meeting
- 43rd Task 42 Progress meeting in November 2022 – Regular full progress meeting

Furthermore, Task 42 Workshops and Webinars could be organised on biorefining related subjects depending on the progress of the WPs.

Work Programme and Outputs

WP1. Provide quantitative, scientifically sound, and understandable data on the technical, economic and environmental added value of biorefining to co-produce bioenergy and bio-products in a sustainable way

New TEE assessments started in 2021 and for that purpose several new pathways for assessment were selected. Task 33 (gasification) has made a subtask on TEE where the cooperation with Task 42 has been defined. About four (draft) factsheets have been generated in 2021 in cooperation with Task 33 (EF gasification integrated with Kraft mills). Two rough datasets were supplied by Task 37 (biogas) where further data mining was still necessary. Also some reserve options were available from European projects. So it is expected that about 5-6 factsheets in total will be published in the beginning of 2022.

WP2. Monitor the biorefineries deployment and market potential, incl. non-technical deployment barriers, in the Circular Economy

T2.1) Barriers and Incentives for the Market Diffusion

This activity was continued in 2021. The methodology used is a multi-perspective and multi-stakeholder approach called Importance-Performance-Gap-Analysis that is based on a recently published paper. The activity has identified and analysed specific barriers to and incentives for implementation/commercialisation of biorefineries. An Importance Performance Assessment (IPA) survey was held in 2021 with over 300 invitations, over 70 replies (performance vs. gaps). This includes 39 experts on LCF biorefineries, 25 experts on Green Biorefineries and 6 experts on Algae biorefineries. A scientific publication is being prepared. A slide-deck and short summary report will be made available at the beginning of 2022. Furthermore, the results were already presented at the IEA Bioenergy Conference 2021 in December 2021.

T2.2) Prepare Biorefinery Country Reports

New biorefinery country reports were published in 2021 for Austria, Italy, Australia, Denmark and Germany.

T2.3) Publish a Global Biorefinery Status Report (GBSR)

The report will be an integrated summary of the recent Task 42 deliverables (e.g. the status as mentioned in the country reports, an analysis of the information in the Task 42 data base, the barriers and incentives for market diffusion, etc.). Several meetings were held concerning the database activity in order to obtain the correct biorefinery data for the analysis. The NTLs have been supplying information on the specific situation in their countries, e.g. key-biorefinery examples, country summaries, and they are in the process of describing success stories. Much input was found in the report of the Biorefinery Outlook project. The first results were shown at the IEA Bioenergy Conference 2021 in December 2021. The final report is scheduled at the end of March 2022.

T2.4) Global mapping scheme and database on Biorefineries

Database – The Task 42 biorefinery database has been continuously updated during 2021. Some 915 biorefineries (BRs) are included at the moment and some 15 global BRs were added. Harmonising the data has been an ongoing activity. The new classification of the Biorefinery Outlook project was incorporated. All biorefinery data were taken from public sources, that have been cited appropriately. The biorefinery records of the Task 42 countries were checked by the NTLs. *Global mapping scheme* – A WebGIS application was developed, which enables industry and policy makers to get a visual overview of the distribution of biorefineries in the world. The functionality of this GIS interface was updated according to remarks from the NTLs. The GIS portal and database were officially published in December 2021 (https://task42.ieabioenergy.com/databases/) and announced at the IEA Bioenergy Conference 2021 in December 2021.

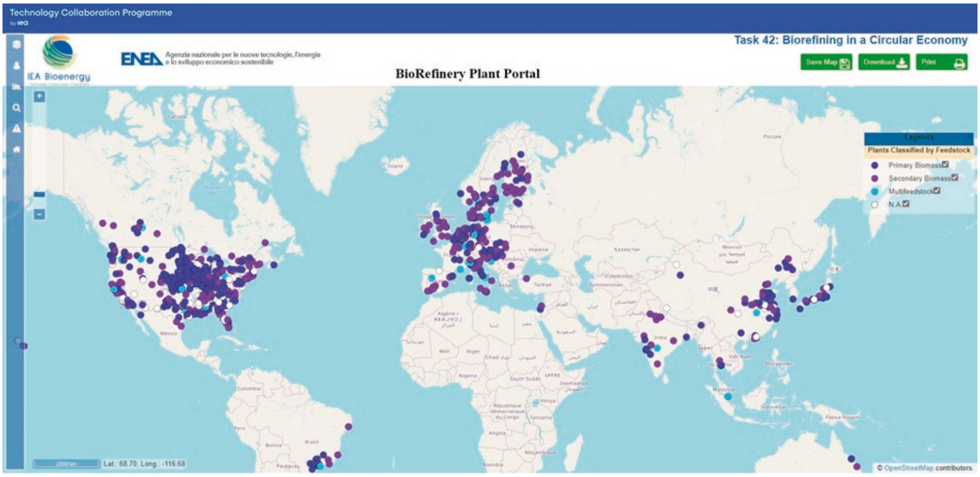


Figure 1. Final version of the Task 42 Biorefinery Plant Portal.

T2.5) Reports on markets for biobased products to get insight in deployment strategies

This activity has delivered the report 'Sustainable Lignin Valorisation – Technical lignin, processes and market development'. It was published together with the EU COST initiative LignoCOST coordinated by Richard Gosselink of Wageningen Food & Biobased Research (WFBR, The Netherlands). The work was also carried out together with the University of Athens from the LignoCOST project. This report was presented at the IEA Bioenergy Webinar 'Sustainable Lignin Valorisation' on the 4th of November 2020.

Figure 2. Announcement of Webinar Sustainable Lignin Valorisation.

Task 2.6) Monitor international developments biobased products standardisation/certification

During the progress meetings an overview was given of CEN issues regarding bio-based products, algae-based products, plant biostimulants, soil improvers, solid biofuels, and biolubricants. Also hydrogen developments might be usefully related to the planned hydrogen Inter-Task project in the next Triennium. However, no specific report was delivered during this Triennium.

WP3. Dissemination & Communication

To involve more relevant stakeholders in Task 42, and to increase its platform role (central international scientifically based platform for information exchange) Task 42's existence was actively communicated to the outside world. This was done by means of operating an up-to-date Task 42 website, lecturing at international conferences (IETS Workshop Future Scenarios and Strategic Decision-Making for Industry Transformation: Powered by System Engineering), organising a Webinar (on the lignin report) and organising a dedicated session at the IEA Bioenergy Conference 2021.

Almost no face-to-face meetings with stakeholders could be organised given the COVID-19 restrictions. This again hindered our dissemination and communication, both internationally and nationally in the member countries. Therefore, our approach in 2021 was to have regular news items on the website. Only an Austrian national meeting was held where the Austrian NTL presented Task 42 results.

Website

The dedicated Task 42 website is located at http://task42.ieabioenergy.com. The Task 42 website layout was updated in 2021. In 2021 there was an increase of about 24% for sessions and 54% for page views compared to the 6 Month period March until August 2020.

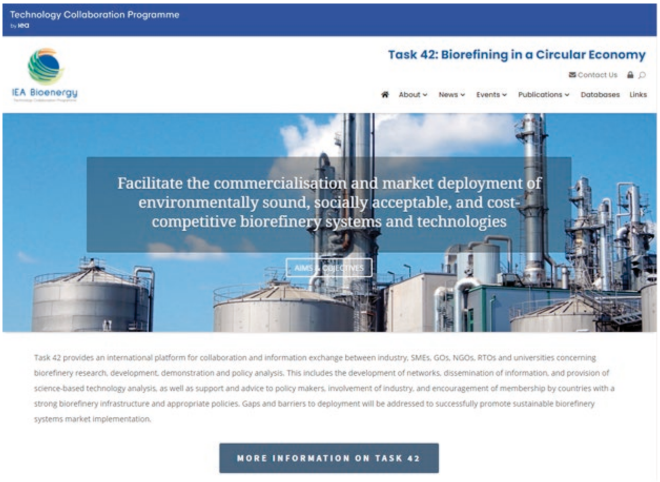


Figure 3. Home page of the Task42 website.

Collaboration with Other Tasks/Organisations/Networking

The cooperation with other tasks and organisations was continued in 2021:

- Another meeting was held with JRC Seville and Ispra on cooperation regarding the JRC database on the bioeconomy (also containing biorefineries) and the IEA Task 42 database. No final decisions have been taken yet.
- The results of the BR Outlook project, that is led by E4Tech, became available in a final report that was published at https://op.europa.eu/en/publication-detail/-/publication/7223cd2e-bf5b-11eb-a925-01aa75ed71a1. These results include data that are valuable for the Task 42 database, but also for the global biorefinery status report. The IEA Bioenergy current and former Task 42 leaders have been participating in that project (as researchers of Wageningen Research) and also FNR and BTG were involved as project partners.
- The cooperation with other IEA Bioenergy Tasks within the Collaborative Inter Task Project (CITP) TEE Technical, Economic and Environmental (TEE) assessment of integrated biorefineries is running smoothly. Task 33 (gasification) has made a subtask on TEE where the cooperation with Task 42 has been defined. There were also contacts with Task 37 (biogas).
- The work on the lignin report was carried out together with the University of Athens from the LignoCOST project.
- IETS Annex XI on Biorefineries is focusing on the system analysis of biorefineries, while Task 42 is also looking more broadly at characterisation of biorefineries (technologies, products, overview of existing biorefineries, global status of BRs etc.). However Task 42 is also working on a TEE tool for analysing biorefineries so this is where we could complement each other by broadening the common tool box. An activity within IETS Annex XI that has recently been started is 'Decision Support Systems (DSS) and Ex-ante Research'. A cooperation possibility for Task 42 is participating in that activity.

Deliverables

- Country report of Austria available at: https://task42.ieabioenergy.com/publications/austria-country-report-2021/
- Country report of Italy available at: https://task42.ieabioenergy.com/publications/italy-country-report-2021/
- Country report of Australia available at: https://task42.ieabioenergy.com/publications/australia-country-report-2021/
- Country report of Denmark available at: https://task42.ieabioenergy.com/publications/denmark-country-report-status-july-2021/
- Country report of Germany available at: https://task42.ieabioenergy.com/publications/germany-country-report-2021/

- Presentation by E. Annevelink on 'Technical, Economic and Environmental Assessment (TEE) of biorefinery concepts' available at: https://task42.ieabioenergy.com/wp-content/uploads/sites/10/2021/04/IETS-workshop-6-May-IEA-Bioenergy-Task-42-TEE-methodology-Annevelink-210506.pdf
- Presentation by I. de Bari on 'Sustainable Lignin Valorization' available at: https://www.ieabioenergy.com/wp-content/uploads/2021/11/Lignin-Webinar-De-Bari.pdf
- Presentation by A. Giuliano on 'Simulation tools for lignin valorisation' available at: https://www.ieabioenergy.com/wp-content/uploads/2021/11/Lignin-Webinar-Giuliano.pdf
- Presentation by E. Annevelink, L. Garcia & V. Motola on 'The status of biorefineries in a circular economy' available at: https://www.ieabioenergyconference2021.org/wp-content/uploads/2021/12/10-02_ANNEVELINK.pdf
- Presentation was given by X. Hilz, T. Stern & F. Hesser on 'Barriers and incentives for the market diffusion of biorefineries in a circular economy' available at: https://www.ieabioenergyconference2021.org/wp-content/uploads/2021/12/10-03_HESSER.pdf
- Report 'Sustainable Lignin Valorisation – Technical lignin, processes and market development' available at: https://task42.ieabioenergy.com/publications/sustainable-lignin-valorization/
- Webinar on 'Sustainable Lignin Valorisation – Technical lignin, processes and market development' available at: https://www.ieabioenergy.com/blog/publications/iea-bioenergy-webinar-sustainable-lignin-valorisation/
- Support of Life Cycle Assessment Seminar "Ökobilanzwerkstatt 2021". More information available at: https://task42.ieabioenergy.com/news/life-cycle-assessment-seminar-okobilanzwerkstatt-2021-hosted-from-vienna-by-wood-k-plus-and-supported-by-iea-bioenergy-task-42/
- GIS portal and database available at: https://task42.ieabioenergy.com/databases/

Figure 3. Report on Sustainable lignin valorization published by Task42 in 2021.

Other Task-related information (brochures, leaflets, newsletters, papers etc.) is available at the Task 42 website: https://task42.ieabioenergy.com.

TASK 43: Sustainable biomass supply integration for bioenergy within the broader bioeconomy

Overview of the Task

The Task will explore technical and economic strategies to increase the quantity of biomass available, improve the quality of the biomass delivered for different energy purposes, and explore strategies to increase the value and foster confidence in biomass supply, for both direct and cascade use of biomass for bioenergy. The Task will work exclusively with terrestrial biomass sources including residues, by-product or co-product production from forest and agricultural production systems; residues, by-products or co-products from bio-based manufacturing industries; cellulosic biomass from post-consumer waste; as well as dedicated biomass crop systems as part of broader land management strategies. The Task focus will be on the production and supply of biomass feedstock for energy leading to value creation within the broader context of the bioeconomy.

Participating countries: Australia, Belgium, Canada, Croatia, Finland, Germany, Sweden, and the United States of America

Task Leader: Mark Brown, USC Australia, Australia

Deputy Task Leader: Ioannis Dimitriou, SLU, Sweden

Work Package leaders: Biljana Kulisič – Work Package 1 Leader, Croatia
Évelyne Thiffault – Work Package 2 Leader, Canada

Task Secretary: Kelly Murphy, USC Australia, Australia

Operating Agent: Mrs Shahana McKenzie, Bioenergy Australia, Australia

The Task leader, together with the Work Package (WP) leaders, manages the work of the Task. A Steering Committee (SC), consisting of the Task Leader, WP leaders and the National Team Leaders (NTLs), is responsible for reviewing progress and making overall priorities. Each NTL forms a national team of experts that support the NTL in making national contributions to the collaboration. Other associated experts are also involved.

For further details on Task 43, please refer to Appendices 2, 4, 5 and 6; the Task website (http://task43.ieabioenergy.com/) and the IEA Bioenergy website (https://www.ieabioenergy.com/) under 'Activities: Tasks'.

Progress in R&D

Task meetings, workshops and webinars since last ExCo meeting

Event (What/Where)	When	Status/Result
Task Leadership Meeting 1/2021 via videoconference	1 March 2021	Minutes available upon request
Task Leadership Meeting 2/2021 via videoconference	28 April 2021	Minutes available upon request
Task Leadership Meeting 3/2021 via videoconference	2 June 2021	Minutes available upon request
IEA Bioenergy Webinar – Resilient Biomass Supply Chains in the Post-COVID Recovery (online)	3 June 2021	https://task43.ieabioenergy.com/ieaevent/iea-bioenergy-webinar-resilient-biomass-supply-chains-in-the-post-covid-recovery/
IEA Bioenergy Workshop on co-benefits of biomass supply (online)	15-16 June 2021	https://task43.ieabioenergy.com/ieaevent/save-the-date-iea-bioenergy-workshop-on-co-benefits-of-biomass-supply/
Task Leadership Meeting 4/2021 via videoconference	11 August 2021	Minutes available upon request
Task Leadership Meeting 5/2021 via videoconference	15 September 2021	Minutes available upon request
Task Leadership Meeting 6/2021 via videoconference	27 November 2021	Minutes available upon request

Targets reached and deliverables

Deliverable (What)	When	Status/Result
Open access publication: Effects of Production of Woody Pellets in the Southeastern United States on the Sustainable Development Goals	January 2021	Available online: https://www.mdpi.com/2071-1050/13/2/821
Summary Series: Woody pellets & Sustainable Development Goals: Southeast United States supply chain case study	May 2021	Available online: https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/05/Kline-et-al-2021-SE-woody-pellets-SDGs_IEA-Bioenergy-Rpt-template-final-07Apr2021.pdf
Summary Series: Contribution of Biomass Supply Chains to the Sustainable Development Goals When Implemented for Bioenergy Production	June 2021	Available online: https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/06/IEA-Bioenergy-2-page-SDG-paper-summary-Final.pdf
Summary Series: Supply chain resilience during a pandemic: Lessons from the Southeast United States wood-pellet supply chain response to COVID-19	August 2021	Available online: https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/08/2021-Resilience-lessons-SE-woody-pellet-supply-chain_IEA-Bioenergy-summary-Aug2021.pdf
Open access publication: Resilience Lessons From the Southeast United States Woody Pellet Supply Chain Response to the COVID-19 Pandemic	August 2021	Available online: https://www.frontiersin.org/articles/10.3389/ffgc.2021.674138/full
Case study: Woody Biomass from the Southeastern United States used for Bioenergy in Europe	August 2021	Available online: https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/08/Case_20_Southeast-US-wood-pellets_Summay-05Nov2020.pdf
Report: Developing a web-based dashboard to merge SWOT analysis results from international biohub and supply chain case studies	October 2021	Available online: https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/10/FINAL-REPORT-Web-based-dashboard-to-merge-SWOT-results.pdf

On-going key activities

The following Task 43 activities are in the final stages of completion and due to be wrapped up prior to the end of the current triennium:

- *Integrated biomass residue management in Sandalwood Plantations* – David Lee
- *Current and future biobased industrial raw material demand and supply* – Dan Bergstrom
- *Bioenergy in remote Indigenous communities* – Sam Van Holsbeeck
- *Innovative ecological pile cover for biomass chip storage* – Robert Prinz and Johanna Routa
- *Development of Techno-economic Model for Assessment of Bio-Hubs in Canada* – Amit Kumar
- *Agrarian bio-hubs* – Biljana Kulisič
- *Assessment of a Bio-hub to facilitate a profitable bioeconomy for the Albany region, Western Australia* – Justine Edwards
- *Integrated land management using small-scale harvesting operations for biomass utilization* – Michael Berry
- *Biohub case study SE QLD* – Michael Berry
- *The benefits of developing biobased commodities to bring biomass to markets* – Wolter Elbersen
- *Improving framework conditions for bioenergy supply chains within bioeconomy – an approach for shaping evidence-based policies* – Biljana Kulisič, Blas Mola, Ioannis Dimitriou and Jorg Schweinle

The following Task 43 activity will not be completed prior to the end of Triennium:

- *Sustainability assessment of biohub archetypes using life cycle assessment* – Rory Monaghan (Inter-Task activity)

Website

The Task website (http://task43.ieabioenergy.com/) has been maintained throughout 2021 and is currently being updated to reflect the new triennium. Information concerning Task 43 work is updated regularly.

Collaboration with Other Tasks/Organisations/Networking

Bruno Gagnon and other members of the Task 43 team have continued to collaborate with Task 45 on the *Biohub in the development and deployment of efficient biomass supply chains* project.

Deliverables

Work Package One

D1 – Strategies to integrate innovated biomass crops to leverage and expand existing residue and co-product supply chains

- Agrarian bio-hubs
    - Final Report – March 2022

D2 – Scale of different biomass crops to economically supply bioenergy production as sole source and as an integrated contribution to residue supply chains

- Integrated land management using small-scale harvesting operations for biomass utilization
    - Final Report – undergoing peer review

- Inventory of LUC and ILUC in tools, instruments and policies
    - Final Report – March 2022

D3 – Quantifying the socioeconomic values of biomass crops as a part of local, regional and national renewable energy strategies.

- Bioenergy in remote Indigenous communities
    - Findings published – Manuscript has been submitted

- Assessment of a Bio-hub to facilitate a profitable bioeconomy for the Albany region, Western Australia
    - Final Report – March 2022

- Improving framework conditions for bioenergy supply chains within the bioeconomy – an approach for shaping evidence-based policies
    - Final report – March 2022

D4 – Influencing biomass sustainability through strategies to increase volume, value and quality of biomass supply

- Integrated biomass residue management in Sandalwood Plantations
    - Final report – undergoing peer review

- Sustainability assessment of biohub archetypes using life cycle assessment
    - Final Report – December 2022

Work Package Two

D5 – Key biomass quality drivers as they relate to bioenergy technology needs

- Current and future biobased industrial raw material demand and supply
  - Submission of manuscript to scientific journal – March 2022

D6 – Identifying and managing technology bottlenecks in biomass supply chains

D7 – Opportunities to economically extend the range of biomass supply chains through new and emerging biomass technology

- Development of Techno-economic Model for Assessment of Bio-Hubs in Canada
  - Final Report – March 2022

- Biohub case study SE QLD
  - Final Report – undergoing peer review

- The benefits of developing biobased commodities to bring biomass to markets
  - Final Report – undergoing peer review

D8 – Improving biomass quality and value with pre-processing or pre-treatment within the supply chain. Deliverable specifics:

- Innovative ecological pile cover for biomass chip storage
  - Final Report – March 2022

TASK 44: Flexible Bioenergy and System Integration

Overview of the Task

Task 44 contributes to the development and analysis of bioenergy solutions that can provide flexible resources for a low-carbon energy system. The objective is to improve understanding on the types, quality and status of flexible bioenergy, and identification of barriers, framework conditions and future development needs in the context of the entire energy system (power, heat and transport).

Bioenergy has some unique properties that can address many of the problems related to the on-going transition to a low-carbon energy system and provide valuable system services. When sustainably sourced and used, bioenergy can (i) operate as a key element in the coupling of different energy sectors; (ii) provide low-carbon energy to complement wind and solar (residual load and grid stabilisation); (iii) store electricity chemically into fuels to enable more efficient use of wind and solar; (iv) provide sustainable fuels for sectors where other decarbonisation options are not available or exceedingly expensive; (v) provide high temperature heat to industry, and low temperature heat for buildings (and sanitary water) during dark and cold seasons; (vi) co-produce heat, electricity, fuels and other products in a single high-efficiency processing plant; (vii) provide negative emissions through BECCS/U. Achieving these objectives requires a fundamental shift in the way bioenergy is being used, but there is currently a limited understanding on the details of such change.

Task activities in the current triennium are divided into four work packages that together address the main objectives of the task:

- WP1 – Flexible bioenergy concepts for supporting low-carbon energy systems,
- WP2 – Acceleration of implementation,
- WP3 – System requirements for bioenergy concepts, and
- WP4 – Inter-Task projects and collaborative projects.

These actions involve collecting, sharing, and analysing existing information in the above mentioned areas. The results are disseminated through workshops, webinars, reports and databases.

Participating countries: Australia, Austria, Finland, Germany, Ireland, The Netherlands, Sweden, Switzerland and the United States of America

Task Leader: Elina Mäki, VTT Technical Research Centre of Finland Ltd., Finland

Assistant Task Leader: Prof Dr-Ing Daniela Thrän, DBFZ, Germany

Secretary: Nora Lange, DBFZ, Germany

Operating Agent: Jussi Mäkelä, Business Finland, Finland

The Task Leader directs and manages the work programme, assisted by the Assistant Task Leader. A National Team Leader from each country is responsible for coordinating national participation in the Task.

For further details on Task 44, please refer to Appendices 2, 4, 5 and 6; the Task website (http://task44.ieabioenergy.com/) and the IEA Bioenergy website (www.ieabioenergy.com) under 'Activities: Tasks'.

Progress in R&D

Task Meetings and workshops

In 2021, Task 44 organised four Task meetings and additional meetings for preparation of the next triennium's Work Programme. Task meetings were used to initiate, coordinate and monitor progress in different Task activities, plan new activities, and exchange information. All meetings were held as virtual meetings due to the prevailing COVID-19 pandemic. Task 44 led preparation work of a new Inter-Task project 'Synergies of green hydrogen and bio-based value chains' for 2022-2024 and organised several meetings with other Tasks during 2021 to prepare the proposal.

Work Programme and Outputs

Task objectives are advanced through four dedicated work packages and three Inter-Task projects.

WP 1 – Flexible bioenergy concepts for supporting low-carbon energy systems focusses on the assessment and categorisation of flexible bioenergy technologies. Task 44 gathered information on different flexibility concepts together with "technical" Tasks 32, 33, 34 and 39. The final report 'Technologies for Flexible Bioenergy' was published in August 2021 (https://task44.ieabioenergy.com/publications/technologies-for-flexible-bioenergy-2021/).

WP 2 – Acceleration of implementation focusses on policy and market analysis of flexible bioenergy through country cases. Eleven OECD countries (Australia, Austria, Denmark, Finland, Germany, Ireland, Italy, The Netherlands, Sweden, Switzerland and the United States of America) were covered to analyse different approaches for flexible bioenergy, and summarise drivers and barriers. The final report 'Expectation and implementation of flexible bioenergy in different countries' was published in March 2021 (https://task44.ieabioenergy.com/publications/bioenergexpectation-and-implementation-of-flexible-y-in-different-countries-2021/). As a follow-up action Task 44 started collecting Best Practice examples on flexible bioenergy concepts, which are published on the Task 44 website (https://task44.ieabioenergy.com/best-practices/). This action will continue in the next triennium 2022-2024.

A discussion paper 'Five cornerstones to unlock the potential of flexible bioenergy' was published in November 2021 (https://task44.ieabioenergy.com/publications/five-cornerstones-to-unlock-the-potential-of-flexible-bioenergy-2021/). The paper is a summary of Task 44's key outcomes from the current triennium and presents five cornerstones for the successful implementation of flexible bioenergy systems.

WP 3 – System requirements for bioenergy concepts focusses on reaching out to other IEA TCPs to foster discussion on flexible energy system. In 2021, Task 44 established contacts with IEA Hydrogen, IEA AMF and IEA ETSAP TCPs to plan for collaboration in the next triennium.

WP4 – Inter-Task projects and collaborative projects

The Task was involved in the Inter-Task project 'The Role of Bioenergy in a WB2/SDG world' and is currently involved in the Inter-Task projects 'Deployment of BECCUS value chains' and 'Renewable gas'.

Website

The Task website (http://task44.ieabioenergy.com) was redesigned in 2021, and is regularly updated with relevant content.

Collaboration with Other Tasks/Organisations/Networking

Task 44 participated in the Inter-Task project 'Deployment of BECCUS value chains' and focused on potential synergies and trade-offs between flexibility and BECCS/U. A Case Study will be published in 2022.

Task 44 established contacts with IEA Hydrogen, IEA AMF and IEA ETSAP TCPs to initiate collaboration for the next triennium.

Deliverables

The following milestones were achieved in 2021. Task 44 organised four Task meetings and several meetings to plan for the next triennium activities. The Task held a webinar 'Flexible Bioenergy in Renewable Energy Systems' on 19 March 2021. The session 'Bioenergy's contribution to low-carbon energy systems' in IEA Bioenergy Conference 2021 on 7 December 2021 was moderated by Task 44 and three presentations were given by Task members. Furthermore, Task 44 participated in two conferences with a presentation, namely IAEE[43] on 8 June 2021 and IEWT[44] on 8 September 2021. The Task published two reports, one discussion paper and one scientific paper. The Task maintained and updated a LinkedIn group on Flexible Bioenergy and produced a progress report for the ExCo.

43 https://iaee2021online.org/

44 https://iewt2021-eeg-tuwien-ac-at.translate.goog/?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=sc

TASK 45: Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy

Overview of the Task

The Task works on identifying and addressing critical issues related to the climate and other sustainability effects of bioenergy and biobased products and systems. The objective is to promote sound development for bioenergy as an integral component of the overall bioeconomy. One key goal is to increase understanding of the environmental, social and economic impacts of producing and using biomass for bioenergy, within the broader bioeconomy. A central aspect concerns the development and application of science-based methodologies and tools for assessing the effects of biobased systems.

The Task identifies and addresses issues from several points of view (e.g., product/project level; national, regional and global levels; specific sectors or sub-sectors and applications) and considers commercial, near- commercial and emerging/conceptual systems. An important point of departure is that bioenergy systems are commonly components in value chains or production processes that also produce other biobased products (including food, feed and fiber) and they may be shaped to address specific needs such as organic waste management, or water and soil protection.

Three Work Packages (WP) represent the main elements to achieve the Task objectives:

- WP1 – Metrics, methods, and tools for assessing climate change effects of bioenergy
- WP2 – Metrics, methods and tools for assessing sustainability effects of bioenergy (excluding climate change effects)
- WP3 – Sustainability stakeholders and implementation approaches (governance)

The work in the Task is relevant for a broad group of stakeholders including academia, commercial interests and private sector producers, exporters, importers, financing organisations, governments, policymakers, civil society organisations and others such as IRENA[45], GBEP[46] and FAO[47]. The Task also has high ambitions concerning scientific publishing and communication with the scientific community.

45 International Renewable Energy Agency

46 Global Bioenergy Partnership

47 Food and Agriculture Organisation

Participating countries: Australia, Brazil, China, Denmark, Finland, France, Germany, Ireland, The Netherlands, Norway, Sweden, the United Kingdom and the United States of America

Task Leader: Professor Göran Berndes, Chalmers University of Technology, Sweden

Work Package leaders: Annette Cowie, NSW Department of Primary Industries, Australia,

Floor van der Hilst, Copernicus Institute, The Netherlands,

Uwe Fritsche, International Institute for Sustainability Analysis and Strategy (IINAS), Germany

Task Secretary: Gustaf Egnell, Swedish University of Agricultural Sciences, Sweden

Operating Agent: Mr Jonas Lindmark, Swedish Energy Agency (STEM), Sweden

The Task Leader directs and manages the work programme, assisted by sub-task leaders for specific areas. A National Team Leader from each country is responsible for coordinating the national participation in the Task.

For further details on Task 45, please refer to Appendices 2, 4, 5 and 6; the Task website (http://task45.ieabioenergy.com/) and the IEA Bioenergy website (www.ieabioenergy.com) under 'Activities: Tasks'.

Progress in R&D

Task Meetings and workshops

In 2021, Task 45 has carried out monthly remote meetings for Task members, to exchange information, monitor progress of ongoing activities and to plan future activities. Remote meetings were also carried out within Task projects and Inter-Task projects. No face-to-face meetings have taken place due to the pandemic.

Task 45 organised a number of virtual events in 2021:

- Workshop series "RED2 implementation and beyond", together with Task 40, ETIP Bioenergy and Sustainable Biomass Partnership, October 2020 – January 2021:
    - workshop 1: Ongoing developments in EU Member States and the role of REDII (October 5, 2020)
    - workshop 2: Biomass supply from in- and outside the EU (October 19, 2020)
    - workshop 3: How to ensure that using biomass maintains and protects biodiversity (November 9, 2020)
    - workshop 4: Carbon, forests and climate impacts of woody biomass (November 30, 2020)
    - workshop 5: Social impacts of woody biomass (January 20, 2021)

- Workshop: "Forest biomass and climate", together with the European Forest Institute and the Royal Swedish Academy of Agriculture and Forestry (April 15, 2021)
- Conference sessions at BBEST 2021-Biofuture Summit II Conference[48] (May 24-26, 2021)
  - Governing a Sustainable Bioeconomy: Assessment and Monitoring (Experience and Perspective)
  - Innovative Landscape Approaches for Sustainable Bioenergy
- Workshop: How can biomass supply for bioenergy deliver multiple benefits and contribute to sustainable development goals? (June 15-16, 2021)
- Webinar: Climate effects of biomass – true and false, together with ETIP Bioenergy and The Swedish Knowledge Centre for Renewable Transportation Fuels (December 10, 2021)

Task 45 also contributed to the IEA Bioenergy Conference 2021, which consisted of technical sessions and panel sessions, spread between 29 November and 9 December 2021

The international conference on negative CO_2 emissions, co-organised with IEA IETS, IEA GHG and Chalmers University of Technology, was further postponed due to the pandemic and will take place in June 2022.

Work Programme and Outputs

The objective of the Task is to promote sound development for bioenergy as an integral component of the overall bioeconomy. This objective will be achieved by providing analyses that support well-informed decisions by landowners, communities, businesses, governments and others. A central aspect concerns the development and application of science-based methodologies and tools for assessing the effects of biobased systems to contribute to available knowledge and experience. The Task builds on previous work in IEA Bioenergy Tasks and Inter-Task activities in the 2016-18 triennium and previous triennia that have considered issues of sustainability assessment and governance.

The Task works within a dynamic area undergoing rapid change and the work programme is shaped to provide flexibility and capacity to respond constructively to emerging science and policy developments in the countries participating in the Task, as well as international developments. Ad hoc groups are formed within the Task to respond promptly to requests from IEA Bioenergy ExCo or other key international organisations. The ad hoc groups also provide expert scientific and technical review of relevant reports and proposals, as appropriate. This enables the Task to establish a position and provide input to important policy processes as opportunities arise and thereby support policy development concerning topics covered by the Task.

48 https://bbest-biofuture.org/

The Task also seeks to inform and address misconceptions about bioenergy in a wider sense, since public perceptions of bioenergy will determine the future role of the bioenergy industry; unless there is acceptance by academics, NGOs and the general public, policy support for bioenergy will diminish, and the climate-change mitigation potential of bioenergy will not be realised.

The three WPs represent the main elements to achieve the general Task objectives. Specific focus areas and associated work and activities are outlined for each WP:

WP1 builds on the work of Task 38 and its predecessor Tasks, that operate at the science- policy interface, contributing balanced and science-based input to the ongoing debate on the climate effects of bioenergy. These Tasks have contributed to i) the development of methods for reporting and accounting for national greenhouse gas inventories under the UNFCCC and Kyoto Protocol, ii) development of rules for project level accounting for emissions trading and product certification, and iii) national policies on renewable energy.

WP1 aims to build the body of knowledge to equip the community with practice to undertake well-informed studies on the climate effects of bioenergy. We are working to develop, demonstrate, refine and promote metrics, methods and tools to quantify climate effects of bioenergy. Methods applied include a hybrid approach that combines product-focused LCA and integrated assessment modelling (including land use and energy systems) and aims to ensure that each method informs the other. WP1 is also preparing a guide to the many tools, including calculators, models and databases, available to support carbon footprint and LCA assessment. No single approach can provide full understanding; using many different approaches is expected to provide useful and robust insights.

The objective of WP2 is to inform academia, industry, policymakers and other stakeholders on the potential sustainability effects of bioenergy and the possible contribution of bioenergy deployment to the sustainable development goals (SDGs). To this end, WP2 will contribute to, and combine ongoing efforts on, developing and demonstrating metrics, methods and tools to quantify and qualify environmental, social, and economic effects of bioenergy systems, to support multi-stakeholder processes that seek to balance sustainability trade-offs and identify opportunities to realise synergies between several SDGs. While the focus is on bioenergy systems, the work is also relevant for many other types of biobased products. As many of the potential effects of bioenergy are related to land use and LUC, biomass production in managed landscapes is a focus area in this work package.

The role of WP3 relates to the statement in the IEA Bioenergy Roadmap[49] that "*Making the transition to a low-carbon energy system will require massive investment (…) The principal barriers to investment in bioenergy technologies relate to the risks as perceived by potential developers and, in particular, by other investors (…) The additional risks associated with the need to provide for the long-term supply of fuels or feedstock at an affordable cost and which meet appropriate sustainability criteria, are a significant complicating factor for financing bioenergy projects.*"

WP3 aims to create broader support among stakeholders for sustainable bioenergy as an integral part of the broader bioeconomy, as outlined in the IEA Bioenergy Roadmap, through three interrelated lines of activities:

i) identifying perspectives of stakeholders and promoting exchange of views among relevant stakeholders to bridge international and local scales;

ii) suggesting ways to make indicators and tools provided by WP1 and WP2 useful for implementation procedures and instruments (governance);

iii) engaging with identified stakeholders to discuss barriers and risks associated with bioenergy investment, and identifying respective de-risking approaches, and support the implementation of such procedures and instruments.

Key activities in WP3 have been the (continuous) "mapping" of relevant actors and their positions towards bioenergy, and the participation in virtual events related to bioenergy/bioeconomy governance. Among outputs this year, a Technical paper was prepared together with the GBEP Task Force on Sustainability, titled "Sustainability governance of bioenergy and the broader bioeconomy[50]".

Website

The Task website (http://task45.ieabioenergy.com/) primarily targets an external audience and information concerning the Task 45 work is available and updated regularly. Unfortunately, it was not possible to obtain information about web traffic in 2021 because of changes to the website to conform with the new IEA Bioenergy format.

49 https://www.iea.org/reports/technology-roadmap-delivering-sustainable-bioenergy

50 http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/TFS/Bioeconomy/IINAS__2021__Sustainability_governance_of_bioenergy_and_bioeconomy_-_final.pdf

Collaboration with Other Tasks/Organisations/Networking

- Cooperation with Tasks 37, 39, 40, 43 and 44 in Inter-Task projects:
    - Role of Bioenergy in a well-below 2 °C/SDG world
    - Renewable Gas
    - BECCS/U
    - BioHubs

- Cooperation with several organisations in association with workshops: GBEP, Biofuture Platform, ETIP Bioenergy, European Forest Institute, The Swedish Knowledge Centre for Renewable Transportation Fuels, Royal Swedish Academy of Agriculture and Forestry
- Work on Forest Landscape Restoration – Bioenergy (with Task 40, GIZ[51], GBEP, IRENA and UNCCD[52]).
- Cooperation with European Biogas Association (in Renewable Gas Inter-Task project), and Bioenergy Europe for overall Task work.
- Cooperation with IEA-GHG, IEA-IETS and Global Carbon Project related to the International Conference on Negative CO_2 Emissions
- GHG Protocol (WRI[53] & WBCSD[54]): Participation in Technical Working Group and Advisory Committee associated with work to expand the GHG protocol to cover land use issues

Deliverables

The following milestones were achieved in 2021:

- Workshop series, "RED2 implementation and beyond". In total five workshops
- Workshop: "Forest biomass and climate"
- BBEST 2021-Biofuture Summit II Conference events
- Workshop: How can biomass supply for bioenergy deliver multiple benefits and contribute to sustainable development goals?
- Webinar: Climate effects of biomass – true and false
- Information on IEA Bioenergy website on climate effects of woody biomass

51 Deutsche Gesellschaft für Internationale Zusammenarbeit
52 United Nations Convention to Combat Desertification
53 World Resources Institute
54 World Business Council for Sustainable Development

- Sustainability governance of bioenergy and the broader bioeconomy. Technical paper prepared for Task 45 and GBEP Task Force on Sustainability
- How can biomass supply for bioenergy deliver multiple benefits and contribute to sustainable development goals? Report from Joint IEA Bioenergy and GBEP Workshop
- Publications in scientific journals

APPENDIX 1: TASK PARTICIPATION IN 2021

TASK	AUS	AUT	BEL	BRA	CAN	CN	CRO	DEN	EST	FIN	FRA	GER	IND	IRE	ITL	JAP	KOR	NEL	NZE	NOR	SA	SWE	SWI	UK	USA	EC	Total
32		•			•			⊗				•				•		•		•		•	•				**9**
33		•										•	•		•			⊗				•		•	•		**8**
34					•			•		•		⊗	•					•	•	•		•			•		**10**
36	•											•		•	•					•	•	⊗			•		**8**
37	•	•		•	•	•		•	•	•	•	•	•	⊗	•		•	•		•		•	•	•			**19**
39	•	•		•	⊗			•				•	•	•		•	•	•	•	•		•			•	•	**16**
40		•	•					•				⊗				•		•				•			•		**8**
42	•	•						•				•		•	•			⊗				•					**8**
43	⊗		•		•		•			•		•										•			•		**8**
44	•	•								⊗		•		•				•				•	•		•		**9**
45	•			•		•		•		•	•	•		•				•		•		⊗		•	•		**13**
Total	**7**	**7**	**2**	**3**	**5**	**2**	**1**	**7**	**1**	**5**	**2**	**11**	**4**	**6**	**4**	**3**	**2**	**9**	**2**	**6**	**1**	**11**	**3**	**3**	**8**	**1**	**116**

⊗ = Operating Agents • = Participant

APPENDIX 2: BUDGET IN 2021 – SUMMARY TABLES

Budget for 2021 by Member Country (US$)

Contracting Party	ExCo funds	Task funds	Total
Australia	13,700	108,000	121,700
Austria	13,700	106,500	120,200
Belgium	8,700	30,000	38,700
Brazil	9,700	44,000	53,700
Canada	11,700	77,000	88,700
China	8,700	29,000	37,700
Croatia	7,700	15,000	22,700
Denmark	13,700	109,500	123,200
Estonia	7,700	14,000	21,700
Finland	11,700	77,000	88,700
France	8,700	29,000	37,700
Germany	17,700	171,000	188,700
India	10,700	62,000	72,700
Ireland	12,700	93,000	105,700
Italy	10,700	63,000	73,700
Japan	9,700	45,000	54,700
Korea	8,700	29,000	37,700
Netherlands	15,700	139,500	155,200
New Zealand	8,700	33,000	41,700
Norway	12,700	93,500	106,200
South Africa	7,700	16,500	24,200
Sweden	17,700	171,000	188,700
Switzerland	9,700	44,000	53,700
UK	9,700	44,000	53,700
USA	14,700	124,500	139,200
European Commission	7,700	15,000	22,700
Total	**290,200**	**1,783,000**	**2,073,200**

BUDGET IN 2021 – SUMMARY TABLES

Budget for 2021 by Task (US$)

Task	Number of participants	Annual contribution per participant	Total Task funds
Task 32: Biomass Combustion	9	15,000	135,000
Task 33: Gasification of Biomass and Waste	8	15,000	120,000
Task 34: Direct Thermochemical Liquefaction	10	18,000	180,000
Task 36: Material and Energy valorisation of waste in a Circular Economy	8	16,500	132,000
Task 37: Energy from Biogas	19	14,000	266,000
Task 39: Commercialising Conventional and Advanced Transport Biofuels from Biomass and Other Renewable Feedstocks	16	15,000	240,000
Task 40: Deployment of biobased value chains	8	15,000	120,000
Task 41: Bioenergy Systems Analysis	3		
Task 42: Biorefining in a Circular Economy	8	17,500	140,000
Task 43: Sustainable biomass supply integration for bioenergy within the broader bioeconomy	8	15,000	120,000
Task 44: Flexible Bioenergy and System Integration	9	15,000	135,000
Task 45: Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy	13	15,000	195,000
Total			**1,783,000**

APPENDIX 3: CONTRACTING PARTIES

Bioenergy Australia (Forum) Ltd

The Republic of Austria

The Government of Belgium

The National Department of Energy Development of the Ministry of Mines and Energy (Brazil)

Natural Resources Canada

Energy Research Institute ERI (China)

The Energy Institute "Hrvoje Pozar" (Croatia)

The Ministry of Transport and Energy, Danish Energy Authority

The Ministry of Economic Affairs and Communications (Estonia)

Commission of the European Union

Innovation Funding Agency Business Finland

L'Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME) (France)

Federal Ministry of Food and Agriculture (Germany)

Ministry of Petroleum & Natural Gas (India)

The Sustainable Energy Authority of Ireland (SEAI)

Gestore dei Servizi Energetici – GSE (Italy)

The New Energy and Industrial Technology Development Organization (NEDO) (Japan)

Ministry of Knowledge Economy, the Republic of Korea

NL Enterprise Agency (The Netherlands)

SCION (New Zealand)

The Research Council of Norway

South African National Energy Development Institute (SANEDI)

Swedish Energy Agency

Swiss Federal Office of Energy

Department of Business, Energy and Industrial Styrategy (United Kingdom)

The United States Department of Energy

APPENDIX 4: THE EXECUTIVE COMMITTEE

Final Minutes of the ExCo87 Virtual meeting, May 2021.

Final Minutes of the ExCo88 Virtual meeting, October 2021.

IEA Bioenergy Bulletin March 2021

IEA Bioenergy News Volume 33(1), June 2021

IEA Bioenergy News Volume 33(2), December 2021

IEA Bioenergy Update. Number 70. Biomass & Bioenergy, Volume 153C

IEA Bioenergy Update. Number 71. Biomass & Bioenergy, In press

Anon. Contribution of sustainable biomass and bioenergy in industry transitions towards a circular economy. Summary and Conclusions from the IEA Bioenergy ExCo86 e-Workshop. IEA. Bioenergy ExCo:2021:01

Anon. IEA Bioenergy Annual Report 2020. IEA Bioenergy ExCo:2021:02.

All publications listed are available on the IEA Bioenergy website: www.ieabioenergy.com

TASK 32

Task documents List

- Annual report for 2020
- Minutes of the task meeting sessions
- Progress report for ExCo88
- Work programme proposal for 2022-2024
- Annual report 2021 (this report).

Publications List

Please visit the task website, the IEA Bioenergy website and the inter-task project website for case studies, reports and presentations and recordings of the webinar and conference contributions:

- Task website
- Inter-task project on high temperature heat for industry
- Webinar on residential wood combustion
- E-o-T conference session on biomass and renewable heat

Please visit the Task website for the reports and original presentations: https://task32.ieabioenergy.com/

TASK 33

Task documents List

- Minutes of Task online meeting in June
- Business slides of online meeting in June
- Minutes of Task online meeting in December
- Business slides of online meeting in December

Publications List

1. Report on Emerging gasification technologies for biomass and waste
2. Report on Gasification applications in existing infrastructures for production of sustainable value-added products
3. Case study 1 – Entrained flow biomass gasification in the pulp and paper industry
4. Case study 2 – Gasification for production of biomethanol by coupling with anaerobic digestion
5. Case study 3 – Integration of renewables into existing refineries
6. Case study 4 – Gasification of RDF and integration into an existing naphtha cracker

The status update on gasification, with a special focus on R&D needs related to gasification is expected to be finalized in Q3 of 2022.

Please visit the Task website for the reports and original presentations:

http://task33.ieabioenergy.com/

https://itp-hightemperatureheat.ieabioenergy.com

TASK 34

Task documents List

- Minutes from online videoconferences.
- Progress report for IEA TCP Bioenergy ExCo88

Publications List

Country Report 2020 (Canada, New Zealand, United States of America): http://task34.ieabioenergy.com/country-report-2020/

Country Report 2021 (Denmark, Norway): http://task34.ieabioenergy.com/country-report-2021/

Round Robin Archive https://task34.ieabioenergy.com/round-robin-archive-2/

Polar and non-polar components in Fast Pyrolysis Bio-Oil in relation to REACH registration
https://task34.ieabioenergy.com/polar-and-non-polar-components-in-fpbo-in-relation-to-reach-registration/

Please visit the Task website for the reports and original presentations: http://task34.ieabioenergy.com/

TASK 36

Task documents List

- Minutes from four task meetings
- Progress report to ExCO
- New work programme for 2022-2024

Publications List

- Contribution to the IEA Bioenergy Newsletter
- Case Study: Waste-to-Energy and social acceptance. Copenhill WtE plant in Copenhagen, March 2021
- Report: Deployment of bio-CCS: case study on Waste to Energy, May 2021
- Case study: HTC: Valorisation of organic waste and sewage sludge for hydrochar production and biofertilizers, October 2021
- Case study: Decentralised Micro-digesters systems for rural South Africa

Please visit the Task website for the reports and original presentations:
http://task36.ieabioenergy.com/

TASK 37

Task documents List

- Minutes from Fifth Virtual Meeting 2019/2021 January 12 & 19th, 2021 (via Teams)
- Minutes from Sixth Meeting Austria (Virtual) 2019/2021 April 14 to 16, 2021
- Minutes from Seventh Meeting (Virtual) 2019/2021, July 1, 2021 (via Teams)
- Minutes from Eighth Meeting Australia (Virtual) 2019/2021, November 22 to 24, 2021 (via Teams)

Publications List

- Three technical reports

    - *Ammenberg J., Gustafsson, M., O'Shea, R., Gray, N., Lyng, K-A., Eklund, M. and Murphy, J.D. (2021). Perspectives on biomethane as a transport fuel within a circular economy, energy, and environmental system. Ammenberg, J; Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2021:12.*

    - *Liebetrau, J., Rensberg, N., Maguire, D., Archer, D., Wall, D., Murphy, J.D. (2021) Renewable Gas – discussion on the state of the industry and its future in a decarbonised world, Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2021:11.*

    - *Liebetrau, J., O'Shea, R., Wellisch, M., Lyng, K.A., Bochmann, G., McCabe, B.K., Harris, P.W., Lukehurst, C., Kornatz, P., Murphy, J.D. (2021) Potential and utilization of manure to generate biogas in seven countries, Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2021:6.*

- Five case stories

    - *Treatment of pigment wastewater and generation of natural gas standard biomethane in Hangzhou, China, December 2021*

    - *Biogas production from kitchen wastes in Jinhua, China, December 2021*

    - *Corn straw biogas production in cold northern region of China, December 2021*

    - *Circular economy system integrating biogas into process to produce high quality products from recycled paper, July 2021*

    - *Minhe Chicken Manure Biogas Plant: Circular economy management of chicken manure, June 2021*

- Four workshops/webinars/conference sessions

    - Biomethane: Timely solutions for successful implementation and use. A virtual workshop hosted by IEA Bioenergy Task 37 and the University of Natural Resources and Life Sciences, IFA Tulln, Austria, April 15, 2021. See: http://task37.ieabioenergy.com/workshops.html

    - Bioenergy Australia Webinar: IEA Bioenergy Task 37 – The role of renewable gas in decarbonisation and current status of biomethane frameworks in IEA Bioenergy member countries. See: https://www.bioenergyaustralia.org.au/events/117500/

    - IEA Bioenergy ExCo Conference State of the art and innovation in Green Gas Thursday 2 Dec 2021 See: https://www.ieabioenergyconference2021.org/#agenda

    - IEA Bioenergy ExCo Conference Green Gas Perspectives Thursday 2 Dec 2021 See: https://www.ieabioenergyconference2021.org/#agenda

- **Newsletters:** 12 issues in 2021

Please visit the Task website for the reports and original presentations: http://task37.ieabioenergy.com/about-task-37.html

TASK 39

Task documents List

Minutes/Agenda/Presentations from five virtual business meetings

Progress report for ExCo88

Ebadian (Ed.) IEA Bioenergy Task 39 Newsletter Vol. 57, June 2020.

Ebadian (Ed.) IEA Bioenergy Task 39 Newsletter Vol. 58, December 2020.

Publications List

Please visit the Task website for the list of published commissioned reports, InterTask project reports and peer-reviewed manuscripts at http://task39.ieabioenergy.com/publications/

TASK 40

Task documents List

- Task 40 Newsletter February 2021 https://task40.ieabioenergy.com/wp-content/uploads/sites/6/2021/02/Task-40-Newsletter-Feb-2021.pdf

Publications List

Please visit the Task website for the list of published commissioned reports, InterTask project reports and peer-reviewed manuscripts at: http://task40.ieabioenergy.com/

TASK 42

Task documents List

- Minutes from the 36th Task 42 progress meeting, MS Teams, 28 January 2021.
- Minutes from the 37th Task 42 progress meeting, MS Teams, 24 March 2021.
- Minutes from the 38th Task 42 progress meeting, MS Teams, 9 June 2021.
- Minutes from the 39th Task 42 progress meeting, MS Teams, 19 October 2021.
- Progress report for ExCo88, MS teams, October 2021.

Publications List

Mastrolitti, S., E. Borsella, A. Giuliano, M.T. Petrone, I. De Bari, R. Gosselink, G. van Erven, E. Annevelink, K.S. Triantafyllidis & H. Stichnothe, 2021. Sustainable Lignin Valorisation – Technical lignin, processes and market development. IEA Bioenergy, Task42 report, 2021:01, 192 pp.

Annevelink, E., 2021. Technical, Economic and Environmental Assessment (TEE) of biorefinery concepts. PowerPoint presentation at online IETS Workshop Future Scenarios and Strategic Decision-Making for Industry Transformation: Powered by System Engineering, 6 May 2021.

Annevelink, E., L. Garcia & V. Motola, 2021. The status of biorefineries in a circular economy. PowerPoint presentation at IEA Bioenergy End Of Triennium Workshop, Session Industrial symbiosis and biorefineries in a circular economy, 6 December 2021.

Bari, I. de, 2021. Sustainable Lignin Valorization. PowerPoint presentation at IEA Bioenergy Webinar on Sustainable Lignin Valorisation – Technical lignin, processes and market development, 4 November 2021.

Bell, G., 2021. Country Report Australia; Status May 2021. IEA Bioenergy, Task42 Power Point.

Giuliano, A., 2021. Simulation tools for lignin valorisation. Power Point presentation at IEA Bioenergy Webinar on Sustainable Lignin Valorisation – Technical lignin, processes and market development, 4 November 2021.

Hilz, X., T. Stern & F. Hesser, 2021. Barriers and incentives for the market diffusion of biorefineries in a circular economy. PowerPoint presentation at IEA Bioenergy End Of Triennium Workshop, Session Industrial symbiosis and biorefineries in a circular economy, 6 December 2021.

Mandl, M., J. Lindorfer & F. Hesser, 2021. Country Report Austria; Status March 2021. IEA Bioenergy, Task42 Power Point.

Mussatto, S.I., 2021. Country Report – Denmark. IEA Bioenergy, Task42 Power Point.

Petrone, M.T & I. De Bari, 2021. Country Report Italy. IEA Bioenergy, Task42 Power Point.

Stichnothe, H., 2021. Country report: Germany 2021; Bioenergy and bio-based products. IEA Bioenergy, Task42 Power Point.

Please visit the Task website for the reports and original presentations:
http://task42.ieabioenergy.com/

TASK 43

Task documents List

- Minutes from the Task meeting, March 2021.
- Minutes from the Task meeting, April 2021.
- Minutes from the Task meeting, June 2021.
- Minutes from the Task meeting, August 2021
- Minutes from the Task meeting, September 2021.
- Minutes from the Task meeting, November 2021.
- Minutes from the Task meeting, January 2022.

Publications List

Effects of Production of Woody Pellets in the Southeastern United States on the Sustainable Development Goals (https://www.mdpi.com/2071-1050/13/2/821)

TR2021-01: Woody pellets & Sustainable Development Goals: Southeast United States supply chain case study (https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/05/Kline-et-al-2021-SE-woody-pellets-SDGs_IEA-Bioenergy-Rpt-template-final-07Apr2021.pdf)

TR2021-02: Contribution of Biomass Supply Chains to the Sustainable Development Goals When Implemented for Bioenergy Production (https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/06/IEA-Bioenergy-2-page-SDG-paper-summary-Final.pdf)

Resilience Lessons From the Southeast United States Woody Pellet Supply Chain Response to the COVID-19 Pandemic (https://protect-au.mimecast.com/s/2jIzCGvmP3tAD8wyikCT5_?domain=links.email.frontiersin.org)

TR2021-03: Woody Biomass from the Southeastern United States used for Bioenergy in Europe (https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/08/Case_20_Southeast-US-wood-pellets_Summay-05Nov2020.pdf)

TR2021-04: Supply chain resilience during a pandemic: Lessons from the Southeast United States wood-pellet supply chain response to Covid-19 (https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/08/2021-Resilience-lessons-SE-woody-pellet-supply-chain_IEA-Bioenergy-summary-Aug2021.pdf)

TR2021-05: Developing a web-based dashboard to merge SWOT analysis results from international biohub and supply chain case studies (https://task43.ieabioenergy.com/wp-content/uploads/sites/11/2021/10/FINAL-REPORT-Web-based-dashboard-to-merge-SWOT-results.pdf)

Please visit the Task website for the reports and original presentations: http://task43.ieabioenergy.com/

TASK 44

Task documents List

- Minutes from the Task meeting, virtual, Mar 2021.
- Presentations and recording from Flexible Bioenergy in Renewable Energy Systems webinar, Mar 2021.
- Minutes from the Task meeting, virtual, May 2021.
- Minutes from the Task meeting, virtual, Sep 2021.
- Presentations and recording from Bioenergy's contribution to low-carbon energy systems session in IEA Bioenergy's triannual conference, virtual, Dec 2021.
- Minutes from the Task meeting, virtual, Dec 2020.
- Progress report for ExCo88, virtual meeting, Oct 2021.

Publications List

Schipfer, F., Mäki, E., Schmider, U. et al. Status of and expectations for flexible bioenergy to support resource efficiency and to accelerate the energy transition. Renew Sustain Energy Rev, 158 (2022), 112094. https://doi.org/10.1016/j.rser.2022.112094

Thrän, D., Anderson, K., Schildhauer, T., Schipfer, F., 2021. Five cornerstones to unlock the potential of flexible bioenergy, Lange, N. (Ed.) IEA Bioenergy Task 44, 2021:11. ISBN: 978-1-910154-99-1. https://task44.ieabioenergy.com/wp-content/uploads/sites/12/2021/11/Five-cornerstones-to-unlock-the-potential-of-flexible-bioenergy.pdf

Schipfer, F., Schildhauer, T., Mäki, E., Thrän, D., Hennig, C., Schmieder, U., Cecilia, H. Valorizing flexible bioenergy. Presentation at IEWT online conference, 8 Sept 2021.

Schildhauer, T., Kroon, P., Höftberger, E., Moioli, E., Reichert, G., Kupelwieser, F., 2021. Technologies for Flexible Bioenergy. IEA Bioenergy Task 44, 2021:8. https://task44.ieabioenergy.com/wp-content/uploads/sites/12/2021/08/IEA-Task-44-report-Technologies-for-Flexible-Bioenergy.pdf

Schipfer, F., Schildhauer, T., Mäki, E., Höftberger, E., Thrän, D., Christiane, H., Rowe, I. A techno-economic catologue for system flexibilization. Presentation at IAEE online conference, 8 Jun 2021.

Thrän, D., Schering, K., Schmieder, U. et al., 2021. Expectation and implementation of flexible bioenergy in different countries. IEA Bioenergy Task 44, 2021:3. https://task44.ieabioenergy.com/wp-content/uploads/sites/12/2021/04/IEA-Task-44-report-Expectation-and-implementation-of-flexible-bioenergy-in-different-countries.pdf

Please visit the Task website for the reports and original presentations:
http://task44.ieabioenergy.com/

TASK 45

Task documents List

Minutes from the Task planning meetings are found on the Task 45 OneNote pages. The Task Secretary provides information about the minutes: please contact Gustaf.Egnell@slu.se.

- Progress report to ExCo88, October 11-14, 2021

Publications List

Please visit the Task website for the reports and original presentations:
http://task45.ieabioenergy.com/

APPENDIX 5: KEY PARTICIPANTS IN EACH TASK

TASK 32 – Biomass Combustion

Operating Agent: Mikael Pedersen, Denmark. For contacts see Appendix 7.

Task Leader: Morten Tony Hansen, Ea Energy Analyses, Denmark. For contacts see Appendix 6.

Assistant Task Leader: Anders Hjörnhede, Research Institutes of Sweden, Sweden. For contacts see Appendix 6.

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below. An up-to-date list can be found on http://task32.ieabioenergy.com

Country	National Team Leader	Institution
Austria	Christoph Schmidl	BEST – Bioenergy and Sustainable Technologies
Canada	Sebnem Madrali	National Resources Canada
Denmark	Morten Tony Hansen	Ea Energy Analyses
Germany	Hans Hartmann	Technologie- und Förderzentrum
Japan	Masayuki Mizuno	New Energy and Industrial Technology Development Organization (NEDO)
The Netherlands	Jaap Koppejan	Pro Biomass BV
Norway	Øyvind Skreiberg	SINTEF
Sweden	Anders Hjörnhede	RI.SE
Switzerland	Thomas Nussbaumer	Verenum

TASK 33 – Gasification of Biomass and Waste

Operating Agent: Kees Kwant, Netherlands Enterprise Agency, The Netherlands. For contacts see Appendix 7.

Task Leader: Berend Vreugdenhil, TNO, The Netherlands. For contacts see Appendix 6.

Assistant Task Leader: Jitka Hrbek, Universität für Bodenkultur (BOKU), Austria. For contacts see Appendix 6.

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below. An up-to-date list can be found on http://task33.ieabioenergy.com/

Country	National Team Leader	Institution
Austria	Jitka Hrbek	University of Natural Resources and Life Sciences
Germany	Thomas Kolb	KIT
India	Rajesh Badhe	Indian Oil
Italy	Donatella Barisano	ENEA
The Netherlands	Berend Vreugdenhil	TNO
Sweden	Joakim Lundgren	Swedish Center for Biomass Gasification (SFC)
UK	Patricia Thornley	Aston University
USA	Robert Baldwin	National Renewable Energy Laboratory (NREL)

TASK 34 – Direct Thermochemical Liquefaction

Operating Agent: Birger Kerckow, Fachagentur Nachwachsende Rohstoffe e.V. (FNR), Germany. For contacts see Appendix 7.

Task Leader: Dr.-Ing. Axel Funke, Karlsruhe Institute of Technology (KIT), Germany. For contacts see Appendix 6.

Assistant Task Leader: Alexandra Böhm, Karlsruhe Institute of Technology (KIT), Germany. For contacts see Appendix 6.

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below, an up-to-date list can be found on http://task34.ieabioenergy.com/

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Canada	Benjamin Bronson	CanmetENERGY, Natural Resources Canada
Denmark	Lasse Rosendahl	Aalborg University
Finland	Christian Lindfors	VTT (Technical Research Centre of Finland Ltd.)
Germany	Axel Funke	Karlsruhe Institute of Technology
India	Pramod Kumar	HP Green R&D Centre
Netherlands	Bert van de Beld	BTG (Biomass Technology Group)
New Zealand	Kirk Torr	Scion
Norway	Kai Toven	RISE PFI
Sweden	Linda Sandström	RISE Energy Technology
USA	Justin Billing	PNNL (Pacific Northwest National Laboratory)

TASK 36 – Material and Energy valorisation of waste in a Circular Economy

Operating Agent: Jonas Lindmark, Swedish Energy Agency (SWEA), Sweden. For contacts see Appendix 7.

Task Leader: Inge Johansson, RISE Research Institutes of Sweden, Sweden. For contacts see Appendix 6.

Assistant Task Leader: Mar Edo, RISE Research Institutes of Sweden, Sweden. For contacts see Appendix 6.

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below, an up-to-date list can be found on http://task36.ieabioenergy.com/

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Australia	Daniel Roberts	CSIRO
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Ireland	Fionnuala Murphy	
	Tom Curran	UCD
Italy	Giovanni Ciceri	RSE
Norway	Michäel Becidan	SINTEF
South Africa	Cristina Trois	University of KwaZulu-Natal
Sweden	Inge Johansson	RISE
USA	Beau Hoffman	Department of Energy- Bioenergy Technology Office U.S

TASK 37 – Energy from Biogas

Operating Agent: Matthew Clancy, Sustainable Energy Authority of Ireland, Dublin, Ireland. For contacts see Appendix 7.

Task Leader: Prof Jerry D Murphy, MaREI Centre, Environmental Research Institute, University College Cork, Ireland. For contacts see Appendix 6.

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below, an up-to-date list can be found on http://task37.ieabioenergy.com/about-task-37.html

Country	National Team Leader	Institution
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Austria	Bernhard Drosg	BOKU University, IFA-Tulln
	Gunther Bochmann	BOKU University, IFA-Tulln
Brazil	Rafael González Felipe Marques Renata Abreu	Centro Internacional de Energias Renováveis – Biogás, Foz do Iguaçu, Brazil
Canada	Maria Welsch	Agriculture and Agrifood Canada
China	Renjie Dong	State International Center for BioEnergy Science and Technology (BEST), Ministry of Science and Technology
Denmark	Teodorita Al Seadi	BIOSANTECH
	Jakon Lorenzen	Dansk Fagcenter for Biogas-DFFB
Estonia	Timo Kikas	Estonia University of Life Sciences
Finland	Saija Rasi	Natural Resources Institute Finland (Luke)
France	Julien Thual	ADEME
Germany	Jan Liebetrau	Rytec, Germany
	Peter Kornatz	DBFZ, Leipzig, Germany
India	Harshad Velankar	Hindustan Petroleum Green Research & Development Centre (HPGRDC), Bangalore, India
Ireland	Jerry D Murphy	MaREI centre, University College Cork
	David Wall	MaREI centre, University College Cork
Italy	Marco Pezzahlia	Italian Biogas Consortium
Korea	Soon Chul Park	Korea Institute of Energy Research
Netherlands	Bert van Asselt	Netherlands Energy Agency
Norway	Kari-Anne Lyng	Norwegian Institute for Sustainable Research
Sweden	Jonas Ammenberg	Linkoping University
	Mats Eklund	Linkoping University
Switzerland	Urs Baier Hajo Nagele	ZHAW Zürcher Hochschule für Angewandte Wissenschaften
United Kingdom	Clare Lukehurst	Probiogas UK

TASK 39 – Commercialising Conventional and Advanced Transport Biofuels from Biomass and Other Renewable Feedstocks

Operating Agent: Oshada Mendis, Natural Resources Canada, Canada. For contacts see Appendix 7.

Task Leader: Jim McMillan, NREL, USA. For contacts see Appendix 6.

Associate Task Leader: Jack Saddler, University of British Columbia, Canada. For contacts see Appendix 6.

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below, and an up-to-date list can be found at http://task39.ieabioenergy.com/about/experts/.

Country	National Team Leader	Institution
Australia	Steve Rogers	Licella
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Brazil	Glaucia Mendes Souza	University of São Paulo and FAPESP Bioenergy Program BIOEN
Canada	Jack Saddler	University of British Columbia
	Mahmood Ebadian	University of British Columbia
Denmark	Sune Tjalfe Thomsen	University of Copenhagen
	Michael Persson	Danish Bioenergy Association
European Commission	Nicolae Scarlet Marco Buffi	Joint Research Centre, European Commission
Germany	Franziska Mueller-Langer	Deutsches Biomasseforschungszentrum (DBFZ)
	Nicolaus Dahmen	Karlsruhe Institute of Technology
India	Ravi P. Gupta	Bioenergy Research Centre at the Indian Oil Corporation
Ireland	Stephen Dooley	University of Dublin
Japan	Yuta Shibahara	New Energy and Industry Technology Development Organization
The Netherlands	Paul Sinnige	Netherlands Enterprise Agency
	Johan van Doessum	DSM
New Zealand	Paul Bennett	Scion
Norway	Duncan Akporiaye	SINTEF Industry
South Korea	Jin Suk Lee	Korean Institute of Energy Research
Sweden	Tomas Ekbom	Swedish Bioenergy Association
	Leif Jonsson	Umea University
USA	Jim McMillan	NREL

TASK 40 – Deployment of biobased value chains

Operating Agent: Birger Kerckow, Fachagentur Nachwachsende Rohstoffe e.V. (FNR), Germany. For contacts see Appendix 7.

Task Leader: Uwe R. Fritsche, IINAS, Germany. For contacts see Appendix 6.

Co-Task Leader: Christiane Hennig, DBFZ (Germany), Olle Olsson, SEI (Sweden). For contacts see Appendix 6.

Task Secretary: Nora Lange, DBFZ, Germany.

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below, and an up-to-date list can be found at http://task40.ieabioenergy.com/

Country	Name	Org	Role
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AT	Fabian Schipfer	TU Vienna	NTL
AT	Michael Wild	Wild&Partner/International Biomass Torrefaction Council	industry
BE	Ruben Guisson	VITO	NTL
DK	Christian Bang	EA Energy Analyses	NTL
DE	Christiane Hennig	DBFZ	NTL & WP3 Lead
DE	Nora Lange	DBFZ	Task Secretary
DE	Daniela Thrän	DBFZ/UFZ	Alternate NTL
DE	Uwe R. Fritsche	IINAS	TL
DE	Birger Kerckow	FNR	Operating Agent
JP	Shintaro Uda	NEDO	NTL
JP	Yusuke Kawame	NEDO	Alternate NTL
NL	Ric Hoefnagels	Utrecht University, Copernicus Institute	NTL
NL	Ronald Zwart	RWE	industry
SE	Olle Olsson	SEI	NTL & WP2 Lead
US	Richard Hess	INL	NTL
US	Chenlin Li	USDOE	Alternate NTL

TASK 42 – Biorefining in a Circular Economy

Operating Agent: Kees Kwant, NL Enterprise Agency, Ministry of Economic Affairs, The Netherlands. For contacts see Appendix 7.

Task Leader: Bert Annevelink, Wageningen Food & Bio-based Research, The Netherlands. For contacts see Appendix 6.

Assistant Task Leader: Ed de Jong, Avantium Technologies B.V., The Netherlands. For contacts see Appendix 6.

Michael Mandl, tbw Research GesmbH, Austria. For contacts see Appendix 6.

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The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below, an up-to-date list can be found on http://task42.ieabioenergy.com/

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Australia	Geoff Bell	Microbiogen Pty Ltd
Austria	Michael Mandl	tbw Research GesmbH
	Johannes Lindorfer	Energie Institut an der Johannes Kepler Universität Linz
	Franziska Hesser	WoodKplus
Denmark	Solange I. Mussatto	DTU Bioengineering
Germany	Heinz Stichnothe	Thünen-Institute of Agricultural Technology
Ireland	J.J. Leahy	University of Limerick
Italy	Isabella de Bari	ENEA C.R. TRISAIA
	Vincenzo Motola	ENEA C.R. ISPRA
	Aristide Giuliano	ENEA C.R. TRISAIA
Netherlands	Bert Annevelink	Wageningen Food & Biobased Research (WFBR)
	Ed de Jong	Avantium B.V.
	René van Ree	Wageningen Food & Biobased Research (WFBR)
Sweden	Johanna Mossberg	RISE Research Institutes of Sweden (RISE Innventia AB)

TASK 43 – Sustainable biomass supply integration for bioenergy within the broader bioeconomy

Operating Agent: Shahana McKenzie, Bioenergy Australia, Australia. For contacts see Appendix 7.

Task Leader: Professor Mark Brown, University of the Sunshine Coast, Australia. For contacts see Appendix 6.

Deputy Task Leader: Ioannis Dimitriou, SLU, Sweden. For contacts see Appendix 6.

Work Package Leaders: Biljana Kulišić – Work Package 1 Leader, Croatia.
Évelyne Thiffault – Work Package 2 Leader, Canada.

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below, an up-to-date list can be found on http://task43.ieabioenergy.com/

Country	National Team Leader	Institution
Australia	Mark Brown	University of the Sunshine Coast
Belgium	Lucas Gossiaux	ValBiom
Canada	Bruno Gagnon and Daniel Mazerolle (alternate)	Natural Resources Canada
Croatia	Biljana Kulisič	Energy Institute Hrvoje Pozar
Finland	Johanna Routa	Natural Resources Institute Finland
Germany	Jörg Schweinle	Thünen Institute of International Forestry and Forest Economics
Sweden	Ioannis Dimitriou and Dan Bergström (alternate)	Swedish University of Agricultural Sciences
USA	Tomas Schuler	USDA Forest Service

TASK 44 – Flexible Bioenergy and System Integration

Operating Agent: Jussi Mäkelä, Business Finland, Finland. For contacts see Appendix 7.

Task Leader: Ms Elina Mäki, VTT Technical Research Centre of Finland Ltd., Finland. For contacts see Appendix 6.

Assistant Task Leader: Prof Dr-Ing Daniela Thrän, Deutsches Biomasse Forschungszentrum (DBFZ), Germany. For contacts see Appendix 6.

Task Secretary: Nora Lange, Deutsches Biomasse Forschungszentrum (DBFZ), Germany

Work Package Leaders: Tilman Schildhauer (Switzerland)
Daniela Thrän (Germany)
Elina Mäki (Finland)

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below, an up-to-date list can be found on http://task44.ieabioenergy.com/

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Australia	Amy Philbrook	ATCO
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	Fabian Schipfer	TU Wien
Finland	Elina Mäki	VTT
Germany	Daniela Thrän	DBFZ
Ireland	Emer Dennehy	SEAI
The Netherlands	Jaap Kiel	TNO
Sweden	Kjell Andersson	Svebio
Switzerland	Tilman Schildhauer	PSI
USA	Ian Rowe	USDOE

TASK 45 – Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy

Operating Agent: Mr Jonas Lindmark, Swedish Energy Agency (STEM), Sweden. For contacts see Appendix 7.

Task Leader: Professor Göran Berndes, Chalmers University of Technology, Sweden. For contacts see Appendix 6.

Work Package Leaders: Annette Cowie (Australia) For contacts see Appendix 6.
Floor van der Hilst (The Netherlands) For contacts see Appendix 6.
Uwe Fritsche (Germany) For contacts see Appendix 6.

The Task is organised with 'National Teams' in the participating countries. The contact persons for 2021 (National Team Leader) in each country are listed below, an up-to-date list can be found on http://task45.ieabioenergy.com/

Country	**National Team Leader**	**Institution**
Australia	Annette Cowie	NSW Department of Primary Industries
Brazil	Glaucia Souza	University of Sao Paulo
China	Dou Kejun	China National Renewable Energy Centre
Denmark	Niclas Scott Bentsen	University of Copenhagen
Finland	Kati Koponen	VTT
France	Miriam Buitrago	ADEME
Germany	Stefan Majer	DBFZ
Ireland	David Styles	University of Limerick
The Netherlands	Peter-Paul Schouwenberg	RWE
Norway	Francesco Cherubini	NTNU
Sweden	Gustaf Egnell	Swedish University of Agricultural Sciences
United Kingdom	Zoe M. Harris	Imperial College London
USA	Daniel B. Fishman	US DOE

APPENDIX 6: OPERATING AGENTS AND TASK LEADERS

Operating Agent Task 32: Denmark

(duration 1 January 2019-31 December 2021)

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Operating Agent Task 33: The Netherlands

(duration 1 January 2019-31 December 2021)

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Operating Agent Task 34: Germany
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Operating Agent Task 36: Sweden
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(duration 1 January 2019-31 December 2021)

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Operating Agent of Task 40: Germany

(duration 1 January 2019-31 December 2021)

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Operating Agent Task 43: Australia

(duration 1 January 2019-31 December 2021

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(duration 1 January 2019-31 December 2021)

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APPENDIX 7: EXCO MEMBERS AND ALTERNATES IN 2021

Current ExCo Members and Alternates are listed at
https://www.ieabioenergy.com/directory/executive-committee/

	Member	Alternate Member
AUSTRALIA	**Professor Mark Brown** Director of the Forest Industries Research Group Forest Industries Research Group (ML16) Locked Bag 4 University of the Sunshine Coast Maroochydore DC, QLD 4558 Phone: +61 (0) 488 123 155 Fax: +61 7 5456 5544 Email: mbrown2@usc.edu.au	**Mrs Shahana McKenzie** Chief Executive Officer Bioenergy Australia P.O. Box 127 Civic Square ACT 2608 Phone: +61 (0) 439 555 764 Email: shahana@bioenergyaustralia.org.au
AUSTRIA	**Mr Hannes Bauer** Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology Radetzkystrasse 2 1030 WIEN Phone: +43 1 711 62 652924 Email: hannes.bauer@bmk.gv.at	**Mrs Dipl.-Ing Dina Bacovsky** BEST – Bioenergy and Sustainable Technologies GmbH Inffeldgasse 21b 8010 GRAZ Phone: +43 7416 52238 35 Email: dina.bacovsky@best-research.eu
BELGIUM	**Dr Thibaut Masy** Centre wallon de Recherches agronomiques Bâtiment Francini Chaussée de Namur 146 5030 Gembloux Phone: +32 81 87 53 24 Email: t.masy@cra.wallonie.be	**Mr. Ruben Guisson** Project manager biobased economy VITO NV Boeretang 200 MOL, BE-2400 Phone: +32 14 33 58 49 Fax: +32 14 32 11 85 Email: ruben.guisson@vito.be
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	Member	Alternate Member
GERMANY	**Mr Birger Kerckow** Fachagentur Nachwachsende Rohstoffe e.V. (FNR) Hofplatz 1 GÜLZOW-PRÜZEN, 18276 Phone: +49 3843 693 0125 Fax: +49 3843 693 0102 Email: B.Kerckow@fnr.de	**Dr Volker Niendieker** Federal Ministry of Food and Agriculture (BMEL) Wilhelmstraße 54 10117 Berlin Phone: +49 30 18 529 3140 Fax: +49 30 18 529 553140 Email: volker.niendieker@bmel.bund.de
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