ETIP Bioenergy
European Technology and Innovation Platform

Report providing input to the update of SRIA

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Cover

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Introduction

Bioenergy and renewable fuels are clean and reliable forms of energy, that provide many benefits. They are an essential part of an integrated energy system towards a climate neutral energy mix, support decentralized and flexible energy production, contribute to energy security, and constitute part of the bioeconomy. Together with electrification and the increased use of low-carbon hydrogen, bioenergy and renewable fuels will support the decarbonization (in the sense of defossilisation) of Europe and in particular its transport system.

Regarding research, innovation and development of processing technologies there are significant potential synergies to be explored between different products and end-use sectors, since often the same technologies are used to produce advanced biofuels, biochemicals, other bioproducts or renewable fuels of non-biological origin (RFNBOs). These products can be used in different end-use applications such as road transport, aviation and shipping, or in the broader bioeconomy. Each end-use sector has its specific requirements and, in the end, a complex array of policy and market forces will decide where products are finally consumed.

From an ETIP Bioenergy standpoint, the best place for renewable fuels (i.e. biofuels and RFNBOs) is in replacing fossil energy consumed by current vehicle/vessel fleets, and in market segments which are not suitable for electrification or the direct use of hydrogen. The transport sector is an enabler of technologies and overall concepts for the use of biomass, residues and wastes, providing a market for fuels in the short to medium term and preparing the ground for a shift to other renewable carbon requiring sectors in the medium to long term. Thus, potential market demand is huge, and we would like to emphasize that promoting renewable fuels does not mean competing against the electrification of transport, but rather supporting the phase-out of fossil fuel consumption, such as gasoline and diesel.

To foster the deployment of bioenergy and renewable fuels, it is essential to ensure fair market competition, clear and consistent sustainability criteria, and a stable policy framework, in particular under a biorefinery perspective. Sustainability criteria are already available for bioenergy under the RED II framework, but need to be further developed to include key aspects such as biodiversity, land use impacts, and social impacts; they should be consistent over all applications of bio-based products.

Bioenergy is needed to replace the massive amount of fossil energy that is currently consumed. Our over-reliance on fossil energy sources has resulted in significant impacts at various levels, most importantly climate change due to the emission of greenhouse gases, and economic and social impacts due to supply insecurity, as the ongoing Ukrainian-Russian conflict has shown.

Being fully based on renewable resources, bioenergy is integrated in the natural carbon cycle, hence with net zero carbon emissions. Further increasing the use of sustainable bioenergy in the EU will have multiple benefits, such as improved energy security, jobs in agricultural and/or sparsely populated areas, reduced GHG emissions, and the establishment of a technology portfolio that leads to increased competitiveness of the European industry.

This Strategic Research and Innovation Agenda (SRIA) aims to identify important activities and focus areas that need to be considered in research and innovation, either fundamental or applied, in order for the value chains to reach their full market potential. RD&D is needed to develop the different value chains and accelerate technology development with the goal of increasing technology readiness levels as well as the societal readiness levels. Technology research and innovation must go hand in hand with sustainable biomass sourcing, societal aspects and the broad policy framework of the transition to a sustainable and clean EU.

1 Deployment

1.1 Status of development and deployment

Biomass is already widely used in the EU for energy applications. It provides more than 10% of EU total primary energy supply, contributing to the block's climate and energy security objectives. Bioenergy alone exceeds the contribution of all other renewables together, such as wind, solar, and hydro. Its primary supply mainly consists of solid wood (mostly residues from forests and wood (waste) processing), followed by liquid biofuels, biogas (from anaerobic digestion of e.g. manure) and the biogenic fraction of municipal solid waste (see Figure 1). Solid biomass is currently mainly used for direct final consumption for heating, and partly for electricity production and centralized heat production for e.g. district heating. Liquid biofuels are mostly applied as transportation fuels, and biogas is partly upgraded to biomethane (and injected into gas grids), partly used for heat and electricity.

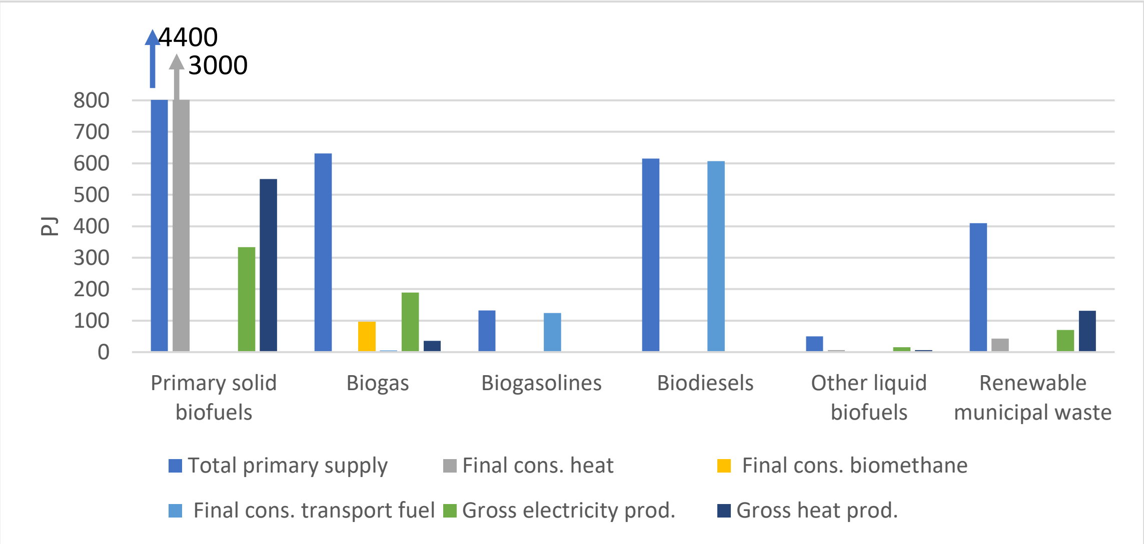

Figure 1 : Primary supply, final uses and gross electricity and heat production from bioenergy resources in the EU in 2021. Source: Eurostat

In general, bioenergy use shows stable growth numbers: overall bioenergy use has grown by almost 15% in the period 2015-2021: Liquid biofuels by ca 25% (see Figure 2); solid biomass fuels by slightly over 10%.

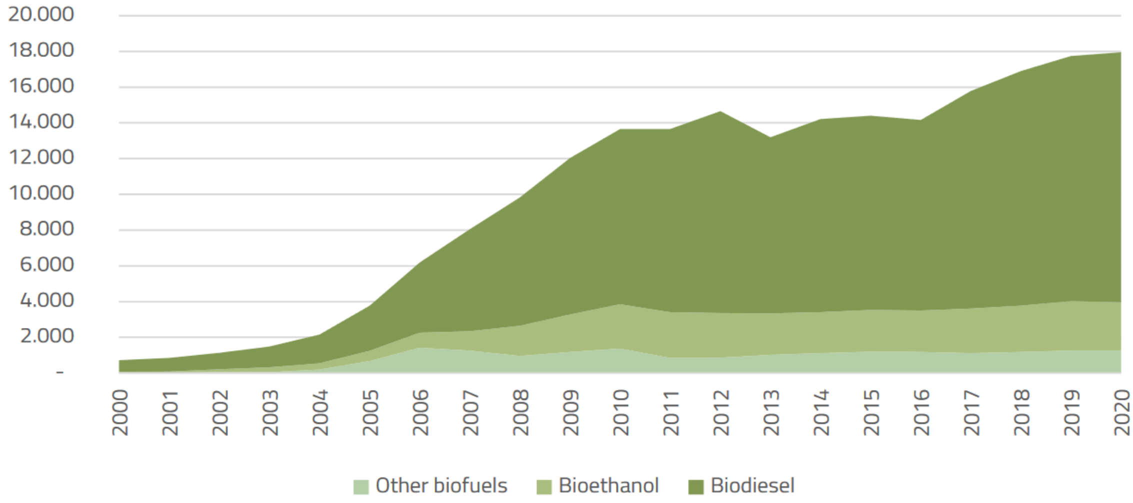

Figure 2 : Evolution of gross inland energy consumption of biofuels in EU27 (in ktoe). Source: Eurostat

1.2 Key R&I challenges for further deployment

For biomass and bioenergy to provide an optimal contribution to a sustainable and decarbonizing (in the sense of defossilising) EU economy, there are several R&I challenges.

Mobilising so far unused biogenic resources

Further bioenergy development first depends on the availability of resources. There is still significant potential for additional biomass use, see e.g. "Sustainable biomass availability in the EU, to 2050"[1]. Key short-term issues are to substantiate this potential, convince owners to reliably provide their raw materials to bioenergy production, and to efficiently collect the biomass. Existing successful contractual agreements could be shared and used as templates of good practices. For the long term, R&I in agriculture and forestry (e.g. improving net yields) are essential to sustainably increase the resource base.

Further refining of sustainability safeguards

Compared to other applications of biomass, its use for energy already has the most elaborated sustainability standards and safeguarding mechanisms, particularly in the EU. However, sustainability should be considered a verb, not a noun. Monitoring of developments and insights is important, leading to further development of science-based standards and certification systems, sufficiently preventing undesired impacts and keeping administrative burden to acceptable levels.

Using low-quality resources

In order to further increase the resource base and reduce competition issues with other applications, innovations are needed to convert low-quality resources, particularly lignocellulosic materials and other organic residual materials, into high-quality energy carriers such as liquid fuels. Thermal (e.g. gasification) and biochemical (e.g. enzymatic) processes will both play a role here, depending which one is the most

[1] Imperial College London (2021): Sustainable biomass availability in the EU, to 2050. Ref: RED II Annex IX A/B. Ref: RED II Annex IX A/B. Available online at https://www.concawe.eu/wp-content/uploads/Sustainable-Biomass-Availability-in-the-EU-Part-I-and-II-final-version.pdf

adequate on the characteristics of the raw materials, locally available resources, and intended final products.

Improving conversion efficiencies, reducing costs, and de-risking value-chains

For all conversion technologies, lasting R&I attention is needed to further improve efficiencies and otherwise reduce production costs. Next to learning-by-doing, learning-by-searching remains important. Also, de-risking of value chains will be essential to convince investors. Identification of key investors and investment support programs would help to identify cooperative partnerships in value chains. Moreover, the integration of bioenergy production into biorefineries, where other products will be obtained, for example animal feed and high value compounds for various applications, or other production systems will reduce risks as more revenue streams will be available, while increasing bioenergy sustainability by ensuring a more efficient and complete raw materials utilization.

Preparing for a move towards long-term application sectors

Current bioenergy applications are dominated by heat, electricity and liquid fuels for road transport. Given the potentials and limitations of other options for decarbonizing our economy, biomass will also be needed for material and chemical applications, as liquid fuels for aviation and shipping, and as gases for versatile applications (biobased methane and hydrogen). This is confirmed by integrated energy system models, such as the IEA Net Zero by 2050[2]. Technologies required for these alternative applications have already been identified and corresponding R&I is ongoing, but will have to be intensified, e.g. by support for first-of-a-kind commercial plants to de-risk the technologies. Next to GHG efficiency considerations, other aspects that need to be considered are local use, environmental, economic and energy efficiency benefits, priority for hard-to-decarbonize usage and sectors, social aspects (jobs), and societal aspects (energy security, social acceptance).

Developing efficient approaches for infrastructure

While current biomass applications can be well-integrated with existing infrastructure for heat, electricity and (blended) liquid fuels, new applications as platform chemicals and dedicated fuels may also require additional infrastructure or new ways to use existing networks.

Preparing long-term solutions

R&D must also continue to work on longer-term solutions, like algae or solar fuels, to accelerate their time-to-market and contribute, as soon as possible, to the diversification of the future energy landscape.

[2] IEA (2021), Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050, License: CC BY 4.0

2 Making biomass available to supply the growing bioeconomy industry

Biomass is an important, regenerative asset for the development of a robust bioeconomy industry in the European Union and at global level. Biomass feedstocks are versatile, and their circular use can increase supply, without using more land, for food, feed, energy, and bio-based products.

- In the **short-term**, the established use of agricultural, forest and waste streams for bioenergy has and will continue to provide expertise on sustainable biomass sourcing and certification, existing operational facilities, and infrastructure, for the transition to a circular, resource efficient bioeconomy that produces food, feed ingredients, chemicals, materials, fuels, heating, cooling and power in a synergetic way.
- In the **mid-term**, following the progress of light-duty vehicle electrification, bioenergy carriers will strive to decarbonise the hard to abate sectors- (aviation, marine, heavy-duty vehicles, steel, and cement), and there will be increasing biomass flows to the circular biobased industry through efficient cascading and biorefining approaches.
- In the **long-term**, decarbonisation of hard to abate sectors will remain the top priority for advanced bioenergy pathways, including bioenergy with carbon capture (BECCS) in the power and industry sectors. Moreover, the conventional use of wood as a fuel in the tertiary and industrial sectors is expected to decrease and technologies such as heat pumps, heat storage as well as hydrogen will deliver Net Zero energy solutions. For the latter, the industry also places high priority on exploiting biogenic sources of CO2 from wood burning energy plants to be merged with green hydrogen. This is expected to be a strong enabler for the future responsible use of wood-based fuels.

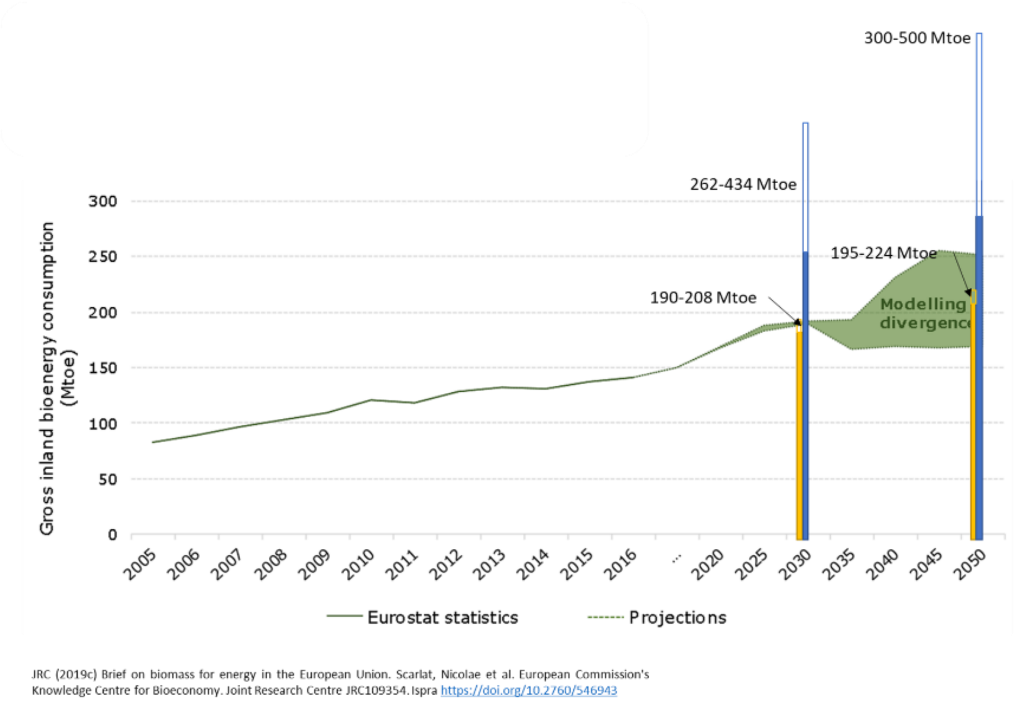

Figure 3 Biomass demand and supply projections in the European Union (yellow bars: low projections for supply, blue bars: high projections for supply)

Europe has a diverse domestic biomass base to supply the growing bioeconomy industry and the potential sustainable availability has been confirmed by multiple studies recently [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13]. Still mobilisation rates, especially for agricultural biomass residues and biowastes are low and concerns remain as to how far policy targets can be achieved or they will fall short due to limitations and potential sustainability conflicts of the biomass feedstocks. Methods that can optimise biomass growing (cover crops, intercropping, agroforestry, etc.) and use (e.g., biochar, biogas, etc.) to improve soil quality and make more

[3] Elbersen, I. Startisky, G. Hangeveld, M.-J. Schelhass, Han Naeff Atlas of EU Biomass Potentials. Spatially Detailed Overview of EU Biomass Potential Taking Into Account Main Criteria Determining Biomass Availability From Different Sources, Biomass Futures, Alterra/IIASA (2012). https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/biomassfuturesatlas_of_technical_and_economic_biomass_potential_en.pdf

[4] Fischer, G. – Prieler, S. – van Velthuizen, H. – Lensink, M. – Londo, M. – de Wit, M. (2010a) Biofuel production potentials in Europe: Sustainable use of cultivated land and pas-tures. Part I: Land productivity potentials. Biomass and Bioenergy 34 (2010), pp 159-172.

[5] Fischer, G. – Prieler, S. – van Velthuizen, H. – Lensink, M. – Berndes, G. – Faaij, A. – Londo, M. – de Wit, M. (2010b) Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures. Part II: Land use scenarios. Biomass and Bioener-gy 34 (2010b) pp 173-187.

[6] EC Knowledge Centre for Bioeconomy (2019) Oral presentation 'Food, feed, fibres, fuels. Enough biomass for a sustainable bioeconomy?' https://ec.europa.eu/knowledge4policy/publication/food-feed-fibres-fuels-enough-biomass-sustainable-bioeconomy_en

[7] Rettenmaier, N., Reinhardt, G., Schorb, A., Ko ̈ppen, S., Von Falkenstein, E., 2008. and other BEE partners. Status of Biomass Resource Assessments, BEE Project Deliverable 3.6.

[8] www.s2biom.eu

[9] https://ec.europa.eu/energy/sites/ener/files/documents/biosustain_report_final.pdf

[10] https://publications.europa.eu/en/publication-detail/-/publication/.../language-en

[11] ENSPRESO - an open data, EU-28 wide, transparent and coherent database of wind, solar and biomass energy potentials | EU Science Hub (europa.eu)

[12] https://op.europa.eu/en/publication-detail/-/publication/448fdae2-00bc-11e8-b8f5-01aa75ed71a1

[13] Concawe. 2021. Sustainable biomass availability in the EU to 2050. https://www.fuelseurope.eu/publication/sustainable-biomass-availability-in-the-eu-to-2050/#:~:text=%E2%80%9CSustainable%20biomass%20availability%20in%20the%20EU%2C%20to%202050%E2%80%9D%2C,aviation%2C%20maritime%20and%20a%20share%20of%20road

biomass available for the biobased economy need to be further developed. Moreover, the market development of biomass commodities is especially relevant for advanced lignocellulosic based fuels and chemicals which depend on complicated large-scale systems which cannot depend on local biomass.

Sustainable and reliable supply of biomass feedstocks still is and will continue being critical for the long-term, large-scale deployment of advanced biomass-based technologies. This relates to efforts in ***improving productivity and resource efficiency*** as well as ***efficient low-cost harvesting and logistics***, in developing ***reliable, year- round supply chains*** that broaden the feedstock base, certification issues, and prevention of markets distortions in agriculture and forest and biowaste sectors. ***Complementarity, circularity, and synergy are key to the future of biomass supply***. The prevailing biomass supply challenges are not specific to the bioenergy use of biomass, they apply to all biobased industries and as such they should be addressed in a coherent effort in close collaboration with the relevant stakeholders and initiatives.

Future priorities for Research and Development should target:

- ✓ Improving productivity and resource efficiency
  - Improvements for crop yields, traits, and cropping systems (including cover crops, low tillage, etc.) suitable to both arable and low quality, abandoned and contaminated land, including farming under water scarce conditions.
  - Ecological intensification of agriculture/ forest: matching feedstock production to the ecological and climatic zones, optimising and recycling nutrients and water, new pest and disease control techniques, while considering necessary adaptation to climate change
  - Multifunctional agro-forestry: combining best practices for agriculture and forestry to create diverse, productive, profitable, healthy, and sustainable land-use and forest management systems.
  - Development of strategies and cultivational approaches that provide synergies between increased biomass supply and other societal benefits, such as restoring polluted land, water management, reduced erosion, soil quality improvements and recreational needs
- ✓ Efficient low-cost harvesting and logistics
  - Development of appropriate harvesting and logistics (collection, sorting and handling) of various by-products, residues and waste streams to maximise supply by minimizing costs per unit.
  - Integration of biomass value chains with other value chains (e.g., integrated harvesting of residues & the main product(s), new alternatives for backhauling, multiple-use machines to alleviate seasonal fluctuations)
  - Improvements in harvest technologies to operate in difficult terrains such as steep slopes, peatlands, areas with high wildfire risk etc.
  - Development of primary refinery technologies that can be applied at local level to sustainably pre-process biomass sources into high-quality and high-density bio-commodities for efficient long-distance transport and use in more central secondary refineries for the co-production of bioenergy/biofuels and biobased products.
  - Increased efficiency of logistics over longer distances in the future by developing and testing technology and supply chains.
  - Improvements in data and digital infrastructures to characterise biogenic resides and wastes for further use.
- ✓ Reliable, year- round supply chains

  - Optimisation of land use, energy and economic models for resource efficiency, displacement effects, market interdependencies, etc.
  - Analysis of direct and indirect impacts over employment and economy at regional and national scale from specific value chains and the use/promotion of biofuels
  - Demonstration of value chains (subject to regional ecology and climate) with high potential for sustainable feedstock supply, compatibility with infrastructure and supportive policy.
  - Market development for lignocellulosic biomass commodities to accommodate the large economies of scale necessary for production of advanced biofuels.
  - Supply and demand analysis and impacts for policy and financing (local, regional level).
  - Best practices, mobilisation, benchmarking
- ✓ Place sustainability, smart and efficient use of resources at the heart of industrial, business and social activities.
  - Research on soil carbon dynamics and methods to grow biomass for soil quality improvements.
  - Analysis on the long-term provision of ecosystem services and the need to maintain or even increase carbon sinks and preserve water resources.
- ✓ Informing policy formation and updates at global, European, national, regional, and local level
  - Intensify and systematise collaboration with the upstream sector (forest industry, farmers, processing, and waste collection industry, etc.) to understand their needs and provide guidance and support to ‘make biomass available’.

3 Conversion technologies

3.1 Overview of value chains

There are many different technologies for the production of bioenergy and biofuels, taking numerous different feedstocks and converting them into products for various markets. In order to assess the technology readiness levels, key challenges and research priorities it is thus necessary to cluster conversion pathways into value chains.

ETIP Bioenergy distinguishes between established value chains (such as biomass boilers, anaerobic digestion, FAME biodiesel production, crop-based ethanol production), priority value chains (beyond the research stage but not yet established industrially, see figure below), and emerging technologies. Value chains are described in more detail on the ETIP Bioenergy website. Key challenges as well as recommendations are provided for the priority value chains and a set of emerging technologies on the following pages.

3.2 Liquid transport fuels from gasification

Gasification can utilize a wide range of (dry) feedstocks and produces a syngas that can either be used for power and heat production or further processed into a wide range of liquid and gaseous energy carriers and chemicals. Liquid transport fuels that can be produced through gasification pathways include FT liquids (gasoline, kerosene, diesel, naphta), ethanol and methanol.

3.2.1 Latest technological developments

In Nevada, USA, Fulcrum has started up a commercial facility (Sierra Biofuels) for the gasification of landfill waste and production of FT liquids and sustainable aviation fuels in 2022. In France, BioTfueL partners (Avril, Axens, CEA, IFPEN, TotalEnergies, ThyssenKruppUhde) have successfully demonstrated the BioTfueL technology, gasifying 4 different types of torrefied biomass for more than 1000 hours. Elyse energy has announced in 2022 the launch of the BioTjet industrial project with the aim to produce sustainable aviation fuels using this technology. Enerkem´s gasification of post-sorted municipal solid waste and conversion to methanol and from that ethanol is operational since 2014 in Alberta, Canada. Red Rock Biofuels´ erection of a commercial-scale facility for the gasification of forest residues and production of FT liquids and sustainable aviation fuels in Oregon, USA, was stopped in 2022 and assets have been taken over by Lakeview RNG with a prospect of producing biomethane and hydrogen instead. In Austria, a 1 MW fuel input dual fluidized bed gasifier has been started up in 2022 with a reactor design adapted as to allow for the gasification of waste materials.

3.2.2 Key challenges

- Feed pre-treatment / feed flexibility
- Lowering operating (efficiency, low cost feedstock) and capital costs
- Management of risks (technical, market etc.)
- Regulatory issues when using mixed wastes (fossil/biogenic), as the fossil part generates “recycled carbon fuels” of uncertain status
- Regulatory environment, the push from REDII, but also in the other direction a mixed view on biomass from the LUCLUF debate

3.2.3 Strengths and weaknesses

Strengths	Weaknesses
• Feedstock flexibility • High efficiency, converting all biogenic carbon without major by-products • Carbon capture from process possible • Integration of green hydrogen from renewable electricity can further increase carbon efficiency	• Requires fairly large capacity due to economy of scale, leading to large investments and challenges in supply of sufficient feedstock • Lack of reference facilities resulting in higher perceived risk to investors • Front-end pre-treatment, gasification and gas purification not yet proven at scale

3.2.4 Recommendations

- Further improve carbon efficiency and energy efficiency of the processes
- Reduce CAPEX intensity
- Investigate pyrolysis, liquefaction and torrefaction as options to densify feedstocks to address the problem of sourcing sufficient feedstock within reasonable distance
- Establish reference installations to generate operational records and reduce risks to investors
- Develop a dedicated smaller-scale biomass FT technology

3.2.5 Future outlook

Gasification-based technologies need to contribute if we are to meet targets for renewables in the transport sector, and urgent action towards scale-up is needed. We need to find solutions for feedstock logistics, as to enable supply to medium-scale (50-100kt/y of product) gasifiers. Gasification technology has to be adapted to different feedstocks, e.g. waste. Since multiple technologies can utilize syngas from the gasifier, downstream technology should be chosen with respect to the CO:H2 ratio and contaminants in the syngas.

FT synthesis provides a range of hydrocarbons in the naphtha to diesel range, providing clean-burning fuels (diesel and aviation fuel) as well as feedstock for renewable plastics production. FT synthesis could also be coupled to hydrogen from electrolysis and contribute to RFNBO and RFNBO-based SAF and maritime fuel production. The viability of RFNBO production however depends on the price and the availability of renewable electricity for producing the hydrogen close to the specific site of the production plant.

Syngas fermentation is complementary to the FT route, producing ethanol or ethanol-based SAF.

3.3 Power and heat via gasification

Small-scale CHPs (i.e., below 10 MW thermal input equivalent to 2 MW electrical output) primarily use fixed and rotary bed gasification coupled to combustion engines, while fluidised bed gasification is applied at medium to large scale (i.e. up to 100 MW thermal input) and coupled to combustion furnaces, co-firing and gas turbines.

In 2021, more than 1700 small-scale CHP installations based on gasification facilities operated all over Europe, most of them in Germany, Italy and Austria. In addition, the use of large-scale gasification of bark and residues was introduced in the paper and pulp industries as early as in the 1980's for replacing fossil fuels in their lime kilns and still has a sizeable share of the market besides direct firing of saw dust or fines from pellets.

3.3.1 Latest technological developments

Small-scale CHP technology can be increasingly suitable for some new market developments such as energy provider services, prosumers, renewables self-consumption and renewable energy communities. The Innovation fund small-scale call awarded at least two such projects linked to industrial settings (acronyms TFFFTP, LK2BM).

Regarding the medium- to large-scale, technical developments are expected since the industry will try to substitute fossil oil and gas with biomass and waste in applications where the direct use of solid fuels is not feasible for process reasons, e.g. food, wood, ceramics, cement, and paper industries. Such industries will increasingly shift from coal or natural gas, in particular if they generate suitable fuel wastes. Furthermore, the need for dispatchable power may attract a renewed interest in gasification-based, high efficiency power or CHP plants using gas turbine cycles and possibly also fuel cells. Again, these applications are not limited to the EU alone. Some producers of such technologies are Phoenix Biopower and Kew-Tech (but for biofuels) for pressurised fluidised bed gasification and gas turbine; EQTEC for atmospheric and ICE; Cortus Energy for indirectly heated gasification and ICE and many others (see Status report on thermal gasification of biomass and waste 2021 Dr. Jitka Hrbek, IEA Bioenergy).

3.3.2 Key challenges

- Collection, transport and storage of low-cost feedstocks
- Lack of data on regional feedstock availabilities and costs
- Technical issues related to low-cost feedstocks
- Appropriate gas cleaning at reasonable cost
- Gas cleaning for high quality application in fuel cells

3.3.3 Strengths and weaknesses

Strengths	Weaknesses
• Heat and power production from syngas is commercially proven	• Difficulties on applying CHP to different low-cost feedstocks • Depending on the feedstock, complicated pre-treatments and conditioning and cleaning

• Recent price spikes for heat and electricity as well as costs of CO_2 emissions make biomass-based CHPs more attractive • Restrictions for disposal of biogenic residues and waste are tightening • Biomass-based CHPs can provide dispatchable power and serve to balance electricity grids • CO_2 can be captured from the process	systems may be needed, e.g. to remove high levels of organic (tar) and inorganic (e.g. S, Cl) compound contaminants, especially for high efficiency and low emission CHP systems as SOFC

3.3.4 Recommendations

- Develop integrated pre-treatments that enable the use of different feedstocks, since this will facilitate the sourcing of sufficient low-cost feedstock for medium- to large-scale plants
- Develop gas conditioning and cleaning technologies that are reliable and low-cost with high efficiencies and low emissions
- Provide legal incentives such as feed in tariffs, tax exemptions, price on fossil CO_2 emissions etc. to make investments profitable
- Develop markets and related legal framework for selling by-products such as char and chemicals
- Develop CHP grid balancing services via management of electricity production between 0% and 100% for small scale and 25%-100% for medium- to large-scale CHPs

3.3.5 Future outlook

Gasification of biomass and wastes remains important for the production of heat and electricity in CHPs in e.g. local solutions, where further upgrading to biomethane for the grid does not seem feasible. Their market share could increase from currently 28% EU average to about 40%. The electrical and the cogeneration efficiency can be further improved up to 25-30% and 80-90% respectively. CAPEX and OPEX need to be further decreased to profitable levels, e.g. below 4000 €/kWe CAPEX and below 0.05 €/kWh OPEX for small scale CHP.

3.4 Transport fuels via pyrolytic and thermolytic conversion

This value chain includes a number of conversion technologies. (1) Fast pyrolysis turns lignocellulosic biomass and waste materials into fast pyrolysis bio-oil. (2) Hydrothermal liquefaction can use rather wet feedstocks and produces a biocrude. (3) Hydropyrolysis is a catalytic pyrolysis that adds hydrogen to the process. Bio-oils and biocrudes from these processes can be upgraded either within or outside of refineries (quite similar to the processing of vegetable oils for HVO production), or gasified. Products cover the full range of refinery outputs (diesel, kerosene, gasoline, bunker fuel, LPG; base chemicals, lubricants).

3.4.1 Latest technological developments

In the field of fast pyrolysis, Pyrocell is using BTG-BTL technology to produce a fast pyrolysis bio-oil (FPBO) that is being co-fed at Preem refinery for fuel production. If this proves successful, many more refineries could follow this example, creating a huge pull on FPBO.

In the field of hydropyrolysis, Biozin plans to build a commercial plant utilizing the Shell-owned IH2 hydropyrolysis technology and has been awarded funds from the Innovation Fund.

Hydrothermal liquefaction technology has developed quickly over the past few years. In particular the processing of sewage sludge into biocrude has been successfully demonstrated by a number of EU R&D projects, and the Parkland refinery in Canada operates a commercial demonstration. Technology developers include Steeper Energy, PNNL and Licella.

3.4.2 Key challenges

- Treatment of process water (aequeous phase) of HTL, which has high COD
- REACH registration of the products
- Costly upgrading of bio-oils and biocrudes if not done in a refinery
- Scale-up to size requirements of supplying refineries
- Determining the value of products obtained through co-processing in refineries
- Complying with standards that have been developed to fit fossil fuels, since some parameters such as e.g. total acid number are hard to match for biofuels
- Achieving funds for investments, since the risk profile is still high
- Lack of appropriate funding instruments that cover a larger part of the investment than the Innovation Fund does
- Income in the period of building a facility, and commissioning, and demonstrating the technology, and fixing the issues that arise
- Finding the right equipment that works with the feedstocks, intermediates and products at the given temperatures etc. (valves, pumps, fittings, etc.)

3.4.3 Strengths and weaknesses

Strengths	Weaknesses
• Processes can adapt to a wide range of feedstocks, including wastes and wet feedstocks	• Extensive upgrading of intermediates (bio-oil, biocrude) required to produce biofuels

• Smaller, decentral facilities for bio-oil or biocrude production can support centralized gasifiers or upgrading facilities (within or outside of refineries) • Nutrients and rare metals are concentrated in the bio-oil/biocrude/aqueous phase (N, P, etc., Li (if using seaweed) • High carbon efficiency and low energy consumption per GJ of fuel produced • HTL biocrude is relatively stable • Enables CO_2 capture at small scale	• Integration into refineries requires adaptation of refinery upgrading, or dedicated unit within the refinery • Stability of pyrolysis bio-oils for seasonal storage requires attention • Relatively high viscosity of HTL biocrude may require heated transport • Contaminants such a S, N, Cl need to be removed during upgrading, for some of these extra hydrogen is required

3.4.4 Recommendations

- Encourage combinations of small-scale decentral pyrolysis or HTL facilities with central gasification or upgrading (within or outside of refineries)
- Develop standards or technical specifications appropriate for intermediates (bio-oil, biocrude) to be traded as fuel for refineries, gasifiers or upgrading facilities
- Support investments in demonstration plants and first-of-a-kind facilities to enable technological learning
- Further develop continuous processing of FPBO into high-quality liquid biofuels
- Develop refining processes that can produce both transport fuels and bio-chemicals, making full use of the biocrude or bio-oil

3.4.5 Future outlook

Fast pyrolysis can provide advanced biofuels through co-processing of bio-oil in the FCC or hydrotreater of refineries even before 2030. This is currently being validated at large scale in a commercial refinery environment. If successful, this could be ramped up quickly.

Hydrothermal liquefaction could become commercial by 2030, if currently operating demonstration plants prove feasibility. First large-scale plants are expected to start-up in Europe around 2025. The resulting bio-crude needs to be upgraded, e.g. through co-processing in refineries.

SAF pathways based on hydrothermal liquefaction or hydropyrolysis are expected to be certified by 2030-2035.

3.5 Power and heat from intermediate bioenergy carriers

Intermediate bioenergy carriers (IBC) are products that can be traded and transported between facilities. Solid IBCs include densified material such as wood or agro-pellets, torrefied material in the form of pellets, briquettes or powder, and biochar from gasification, pyrolysis or hydrothermal processes. Liquid IBCs include fast pyrolysis bio-oil (FPBO) and biocrude from hydrothermal processes.

3.5.1 Latest technological developments

In the field of solid IBCs, capacities for briquetting of biomass materials have been expanded. Also, first installations are now implementing extrusion densification technologies.

As for liquid IBCs, a number of fast pyrolysis facilities has come online in the past years, most of them located in Northern Europe. First applications of FPBO as well as HTL biocrude are expected to be for heating oil rather than for biofuels.

3.5.2 Key challenges

- Access to sustainably sourced biomass
- Access to finance
- Expanding demand for solid IBCs
- Lack of clearly defined form factors for solid IBCs that enable international trade and efficient densification
- Joint development of final product specifications for different applications, including the use of solid IBCs in metallurgical processes
- Downsizing of boilers to enable small-scale combustion of FPBO
- Development of stand-alone combustion of bio-oils
- Storability of bio-oils in case of seasonal storage

3.5.3 Strengths and weaknesses

Strengths	Weaknesses
• Feedstocks such as residues and wastes with low energy density or otherwise unfavorable quality are treated and made suitable for application in e.g. combustion for heat and power production • These processes produce tradeable commodities that comply with existing standards for energy applications (primarily combustion) • Intermediate bioenergy carriers are storable and hence enable seasonal flexibility of energy supply	• Supply of sustainable biomass is limited unless dedicated supporting schemes or strategies unlock further resources • Large imports of cheap bioenergy carriers constitute barriers for domestic investments • The sustainability of imported bioenergy carriers is harder to prove, increasing the risk of fraud • Licensing of new facilities is complex and often takes long • Fragmented legal framework and financing mechanisms • Costs of treatment/conversion

3.5.4 Recommendations

- Further develop the combustion of bio-oils and biocrudes for heat and electricity production
- Create a market pull for CHP/ process heat which applies sustainability criteria to enable technology open, proper use of available biomass with improved logistic infrastructure, potentially with a support of domestic sources to decrease dependency on imports
- Adapt existing political measures and provide supporting schemes and subsidies that promote the production and conversion of sustainably sourced domestic solid biomass to ensure high level of energy security
- Promote policies that address the entire value chain, from biomass to the finished product, as to also expand the provision of feedstock

3.5.5 Future outlook

Biochar can replace lignite and will become more important, e.g. in steel production or other material use (e.g. fertilizer), and maybe also for graphite production for electromobility.

Bio-oils and biocrudes from pyrolytic and hydrothermal processes will be - next to their use for district heating and heat and power production - used at 5-10% co-processing in refineries.

3.6 Liquid transport fuels from fermentation

There are many different pathways using fermentation to produce liquid transport fuels. The most deployed technology is the production of ethanol from sugar and starch crops, and the efficiency and the GHG emission reductions of such facilities in Europe have increased significantly over the past decade.

Ethanol can also be produced from lignocellulosic biomass after pre-treatment, hydrolysis and fractionation, followed by fermentation, or from syngas, waste gases or flue gases that can be directly fermented by specific microorganisms. Other fermentation pathways lead to acetate, various alcohols, hydrocarbons, terpenes or cycloalkanes, with applications ranging from gasoline substitutes to sustainable aviation fuels. Feedstocks used in such processes include sugars, lignin, glycerol and gases, and microorganisms used include various yeasts and bacteria as well as microalgae.

3.6.1 Latest technological developments

Clariant`s facility in Podari, Romania, has started operation in 2021 with a capacity of 50,000 tons per year of ethanol from wheat and other cereal straw. Lanza Tech is commercializing its technology for the fermentation of gases to ethanol, with a focus on Asia and applications in chemical industry becoming more important. Lanza Jet was founded in 2020 to commercialize the technology of producing Alcohol-to-Jet fuel and currently builds a facility in Georgia, USA. Axens is commercializing the Futurol technology, aiming at producing advanced bioethanol and biobased monomers from lignocellulosic biomass. The Futurol technology has been licensed in 2020 to the Croatian oil and gas company INA. Through combining Futurol technology with the Alcohol-to-Jet Jetanol process, Axens offers a complete pathway for SAF production.

Yeast biology improvements enable the further development of iso-butanol production from lignocellulosic biomass. ABE production from waste materials has developed from TRL3 to TRL 5-6. Novel fractionation technologies such as the lignin first-approach allow for the development of technologies valorising lignin fractions from fermentation processes that focus on fermenting sugars. Jet fuels are coming into focus.

3.6.2 Key challenges

- Improved exploitation of secondary streams (hemicellulose and lignin) from lignocellulosic ethanol facilities, as to increase profitability of installations
- Development and demonstration of alcohol-to-jet fuel production based on Annex IX-feedstocks
- Feedstock contamination with heavy metals
- Contamination with competing microorganisms through contaminated feedstock
- Robustness of microorganisms towards inhibitors from pre-treatment of lignocellulosic feedstock
- Robustness of microorganism towards inorganic and organic contaminants in syngas used in gas fermentation processes

3.6.3 Strengths and weaknesses

Strengths	Weaknesses
• Biological processes have the advantage of the capability of microorganisms to process many different kinds of feedstocks constituted of carbons sources such as C6 sugars, C5 sugars, or syngas (CO, CO_2 and H2) • Biological processes require milder reaction conditions than thermal processes and have high selectivity for target products • Processes based on biomass fractionation and production of fermentable platform sugars offer the advantage of developing multi-products biorefineries, and this could increase the profitability of the entire process • Processes based on the bioconversion of syngas offer the advantage of increasing the flux of carbon toward the biofuel production, since all biomass components such as cellulose, hemicellulose and lignin can be converted to syngas and fermented to alcohol • Processes based on the bioconversion of syngas could be applied to a broader range of feedstocks, e.g. mixed plastic packaging	• Sensitivity of the processes to inhomogeneous or changing feedstock quality • Fermentation of syngas requires the integration of thermal technologies with biological processes. This means that specifically trained personnel is required, and that the fermentation might be inhibited by contaminants in the syngas • Low productivity of some pathways in terms of space, time and yield

3.6.4 Recommendations

- Increase the availability of lignocellulosic feedstocks locally, as to enable the deployment of related processing facilities, e.g. by including crops cultivated on marginal land, degraded land, or as catch crops in Annex IX of the Renewable Energy Directive. This would make these feedstocks eligible for the production of advanced biofuels
- Provide clarity on how fuels that result from the joint processing of different types of feedstocks (food/feed crops, Annex IX feedstocks, (fossil-based) flue gases) are treated legally

3.6.5 Future outlook

Ethanol from sugar and starch crops is commercially available and has reached very high GHG emission reductions over the past years, but its application is limited in EU due to the cap on food/feed-based biofuels. Advanced ethanol production from non-food crops builds on existing conventional ethanol production and is currently being operated at large scale (although not yet on full capacity). Plant size is limited by feedstock supply. Advanced ethanol production through gas fermentation (CO or CO_2 and H2) is available commercially and expected to grow significantly, since it is relatively feedstock agnostic.

Ethanol is attractive not only for advanced biofuels but also for chemicals and materials (e.g. plastics production). Demand for ethanol for use in the road transport sector in Europe is expected to decline after 2030. Ethanol could be used as a substitute for methanol in dual-fuel engines for shipping. In aviation, the range of feedstocks eligible for SAF production in EU will determine the contribution of ethanol. Renewable ethanol will also be important in the production of chemicals and materials such as ethylene or ethylene-oxide and related downstream products.

3.7 Gaseous transport fuels from biological processes

The production of biogas via anaerobic digestion of biomass is already widely deployed; thousands of small, farm-based biogas plants across Europe produce heat and electricity. Recently, biogas facilities have grown larger, and separating CO_2 from the biogas as to upgrade it to biomethane has come into focus. Some of the upgrading facilities directly facilitate the application of the biomethane as a transport fuel, while others provide their product to industry or inject it into the gas grid.

Further pathways for the production of gaseous transport fuels from biological processes include anaerobic digestion to biogas followed by in-situ or ex-situ biological or catalytical methanation, and the fermentation of sugars to isobutene and further processing into long-chain hydrocarbons.

3.7.1 Latest technological developments

Since the technology of anaerobic digestion is already very well developed, recent developments focused on optimising its integration with other facilities and the standardisation of facilities. While formerly much biogas was produced from cultivated biomass, now there is a trend to the utilisation of crop residues and manure. This has also led to progress in related logistic chains and harvesting equipment for agricultural residues, e.g. for sugar beet leaves.

There is increased interest in upgrading biogas to biomethane, and since this is more economic for larger installations, biogas production facilities have grown larger. While CO_2 separation from the biogas for its upgrading to biomethane is already state-of-the-art, R&D on biological methanation, i.e. the addition of hydrogen (either in-situ or ex-situ) to the biogas to enhance the production of biomethane is ongoing.

3.7.2 Key challenges

- Feedstock supply/availability
  - Utilisation of food/feed crops is capped under RED
  - Residues and wastes are limited in supply
  - Indirect land use change has implications on GHG emissions and other environmental impacts
  - Crops are seasonal, but the facility requires continuous supply of feedstock
- Find buyers who will use biomethane in form of compressed biogas (CBG) or liquefied biogas (LBG), or other gaseous transport fuels
  - Numbers of vehicles that can use gaseous transport fuels is low in Europe
  - Dedicated facilities for providing CBG or LBG to e.g. fleets compete against feeding the biomethane into the gas grid

3.7.3 Strengths and weaknesses

Strengths	Weaknesses
• Anaerobic digestion ○ is a very robust and adaptable technology	• All-year feedstock availability as well as changes in feedstock composition can be an issue

◦ serves to reduce, sanitate and valorise waste ◦ enables the recovery of nutrients from agricultural residues and thus contributes to a circular economy ◦ provides support to rural communities by providing energy, fuel and fertilizer and reducing waste • Capture of CO_2 from anaerobic digestion is easy and the green CO_2 can be used for chemicals production • Biogas and biomethane are storable • Biomethane is a very versatile product that can be used in transport as well as for electricity, heat, lighting and energy for industry	• Volumes of specific feedstocks are often small which make them difficult to utilise economically • Climate change can negatively affect the availability of agricultural residues and manure

3.7.4 Recommendations

- Develop processes that use industrial by-products and residues from e.g. food and beverage industry
- Establish integration with agricultural production systems
- Work on emerging technologies such as microbial electrolysis cell systems
- Standardise the way biogas plants are built, as to reduce the costs
- Support technology transfer and develop capacity in the Global South, so that adapted solutions such as e.g. portable biogas plants can be developed and deployed
- Develop hybrid systems that e.g. couple biogas technologies with photovoltaic and wind energy for the upgrading of biogas by adding hydrogen production from green electricity
- Create level playing field for the biomethane value chain in respect to transportation and energy sector

3.7.5 Future outlook

Biogas and biomethane production through anaerobic digestion is already commercially available and will see strong further deployment, if appropriate incentives for biogas production from residues are in place. Future innovation could include enhanced biomethane production from the CO_2 from biogas production and green hydrogen, either using catalytical or biological methanation. Pre-treatment technologies for co-digestion of lignocellulosic material could enhance biogas yields.

3.8 Emerging technologies

According to IEA analysis[14], about half of the technologies we will be using for energy production in 2050 are not yet fully developed. It is important to continue R&D on emerging technologies, so they can contribute to decarbonising our economy by 2040.

3.8.1 Latest technological developments

Fraunhofer Umsicht is currently working on the development of a combined pyrolysis and cracking technology. KIT is running a lab-scale facility for the production of oxy methyl ether (OME) via synthesis from syngas. Caphenia is piloting the production of synthetic fuels from CO_2 and biogas. Haldor Topsoe is working on technologies for the further upgrading of methanol. IFPEN is innovating on technologies for increasing the BTL yield by the addition of external low carbon hydrogen and combining e-fuels technologies. Regarding advanced ethanol, IFPEN innovations are focusing on the development of improved biocatalyst and diversification of feedstocks.

Various strategies are under investigation to broaden the feedstock basis of anaerobic digestion, including the co-digestion of lignocellulosic residues with different organic wastes, the digestion of steam-exploded wheat straw, or the production of biogas from landfills. Also, the production of biohydrogen through the fermentation of biomass is of interest lately.

3.8.2 Key challenges

While each technology faces its own technological challenges, they also share several non-technical challenges.

- Obtain funding is difficult, the success rate of proposals to Horizon Europe is around 5%, and many countries do not provide funding for bioenergy/biofuel research
- Future market opportunities for biofuels are unclear, since EU wants to ban internal combustion engines and crop-based biofuels might be phased out
- RFNBO production is likely to remain very costly in most parts of Europe

[14] IEA Net Zero by 2050 Roadmap

4 Markets in focus

4.1 Sustainable Aviation Fuels

4.1.1 Latest developments

The International Civil Aviation Organization (ICAO), a United Nations agency, adopted in September 2022 a Long-Term Aspirational Goal of Net Zero Carbon in aviation by 2050, stating drop-in sustainable aviation fuels (SAF) are expected to have the largest impact to reduce greenhouse gas (GHG) emissions from aviation. In parallel, the airlines trade association, the International Air Transport Association (IATA), representing 83 % of the global air traffic, reckons SAF should contribute 65 % of the GHG emission reduction effort at this horizon, with a potential production capacity of 360 million tons per year. Since the first alternative, low-carbon and sustainable aviation fuel pathway was certified in 2009 by ASTM International, with an intention of use in any aircraft, anywhere in the world, R&D efforts have been a permanent and ever-increasing effort for SAF to meet this ambitious objective in less than thirty years. The EU, as one of the three major markets for air transport, with North America and East Asia, representing 20 % of aviation fuel commercial demand, and with its legacy global aerospace manufacturing industry, has the academic, industrial and commercial environments to be a major player in SAF research and innovation, with a local market to distribute such low-carbon industrial products and export innovative technologies to the rest of the world.

Safety being first priority in aviation, a rigorous certification process has been put in place by the sector, under the responsibility of ASTM International, to guarantee a safe and universal use of SAF blends. SAF is a fully fungible hydrocarbon mixture certified according to ASTM D7566 standard, an extension of the aviation fuel ASTM D1655 standard to cater for the feedstocks´ renewable, non-fossil, origin. A similar certification process, named Clearing House, is in development in the EU to de-risk supply and accelerate the approval of SAF production.

The low-carbon component incorporation rate in commercial aviation fuel cannot exceed 50 % today to maintain a full compatibility with existing equipment, like a minimum aromatics content, necessary to allow some circuit seals proper swelling, as SAF is usually mostly paraffinic. Significant work is under way to allow the use of 100 % SAF. Still, the slow fleet renewal rate will not allow the relaxation of the 50 % constraint for many decades: should legislation mandate more than 50 % SAF in aviation fuel (the EU expects 63 % in 2050), the use of renewable aromatics, which production is already certified, will become necessary to maintain the SAF drop-in approach, which is compatible with existing logistics.

So far, 9 production pathways, 2 thereof as coprocessing, have been certified, 6 are under certification, 15 are in the certification pipeline, at lower technology readiness levels. Diversification is key for production efficiency and repartition in diverse regions, pathways cover all major sustainable feedstocks and both thermochemical and biochemical transformation processes.

4.1.2 Recommendations

- Improve the technical, environmental, social and economic performance of SAF
- Develop a better understanding of the chemical impact of SAF on engine emissions and non-CO_2 effects.
- Develop technologies for the conversion of EU RED Annex IX-A feedstocks such as WWT sludge, halophytes, algae, tall oil, low iLUC-grown edible or non-edible oils (e.g. camelina, carinata, jatropha, pongamia) to HEFA.
- Support First-of-a-Kind commercial plants for ATJ production, and make alcohols from cellulosic feedstock or of non-biological origin more available, including methanol that has a dual usage in shipping.
- Make any type of waste eligible as feedstock for gasification-based processes for the production of FT-SPK, and work on increasing SAF yields from the synthesis step.
- Work on increasing the selectivity for kerosene in pyrolysis- or HTL-based SAF production processes.

4.2 Marine Fuels

4.2.1 Latest developments

The International Maritime Organization (IMO), a United Nations agency, with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships, is expected to adopt in 2023 an ambitious “zero emissions” strategy. This strategy includes well-to-wake emissions and aims for zero GHG emissions by 2050, with intermediate steps in 2030 (-40 %) and 2040 (-50 %). This is an improvement to the initial strategy, defined in 2018, to reduce greenhouse gas (GHG) emissions in international shipping, the largest contributor to emissions in the maritime and fluvial transport sector, by 50 % in 2050, compared to 2008, and reduce the carbon intensity by 40 % in 2030, 70 % by 2050. The Marine Environment Protection Committee (MEPC) has been in charge to propose this strategy, which should allow shipping to reduce its present carbon footprint of 3 % of global GHG emissions to a value in line with the ambitions of the Paris Agreement. In the EU, a specific regulation, called ReFuel EU Maritime, is in preparation and expected to be presented in 2023.

An Energy Efficiency Design Index (EEDI) is already in place to enforce improved fuel efficiency for new ships, which has induced considerable activity by engine and ship manufacturers. The use of alternative, low-carbon, fuels in adapted propulsion technologies is expected to contribute 60 % of the decarbonization effort in 2050.

The international shipping sector is concentrated, with the top 5 companies controlling more than 50 % of the activity. Large ships, containers, bulk and liquid carriers, also rely on concentrated logistics for fuelling, in a limited number of large international harbours. As a consequence, bespoke programs to switch from fossil-based marine diesel and heavy fuel oil to alternative fuels with a reduced carbon footprint are already in full action by major actors, like methanol for Maersk, LNG for CMA-CGM, ammonia for MSC.

A large diversity of low-carbon fuels can be used in shipping: Liquefied Natural Gas (LNG), including Synthetic Natural Gas (SNG: low-carbon bio- or e-methane), biomass-based fuels (bio-marine diesel and bio-heavy fuel oil), RFNBOs (hydrogen from renewable electricity, e-methanol, e-ammonia, produced from renewable electricity-based hydrogen and CO_2), electricity (though not considered for transcontinental shipping). On-board safety, GHG emission abatement, adaptability to existing propulsion technology, including in terms of fuel stability and logistics, and Total Cost of Operation (TCO) are key drivers for the selection of the solutions in this global and competitive sector.

Studies and real-life trials in the last ten years have demonstrated that biofuels, i.e. heavy fuel and marine diesel fuel drop-in, fungible, components, can play a significant role in the future. Two outstanding benefits of biofuels are their compatibility with existing engines and the limited investment required in infrastructure. However, these biofuels or the biomass they are produced from can also be used in other sectors looking for low-carbon solutions, such as road and air transport, chemicals, materials, which may limit their availability to the shipping sector.

4.2.2 Recommendations

- Improve the technical, environmental, social and economic performance of alternative shipping fuels
- Facilitate the sourcing of suitable low-carbon feedstocks, the industrial production and the use by shipping companies in a competitive context
- R&D on both biofuels and RFNBO production technologies

5 Outlook for biofuels

Biofuels produced in the European Union include HVO, FAME and ethanol from food and feed crops (often called first generation biofuels); biomethane from the upgrading of biogas; FAME and HVO from UCO and animal fats; and a small portion of advanced biofuels produced from RED Annex IX Part A feedstocks, such as tall oil-based renewable diesel and straw-based ethanol. Depending on which new feedstocks will be included in the upcoming recast of RED Annex IX Part A, the potential of advanced biofuels to contribute to future targets for renewables will further expand. In particular the utilisation of intermediate crops could make important contributions. Innovations could also include the use of sugars for the production of microbial oils.

Advanced biofuels targets for 2030 already require a few hundred new advanced biofuels production plants at average size of 50.000 - 100.000 t/y (beyond HVO production plants), and a multitude of that beyond 2030. As to expand the availability of low-carbon feedstock, we need to explore further feedstocks such as residues and wastes (sewage sludge etc.), (waste) plastics, and CO_2 and electrolysis-based hydrogen for RFNBO production. CO_2 can be separated from bioenergy production facilities and used for the production of RFNBOs; alternatively, such biogenic CO_2 could also be stored for permanent removal from the atmosphere, thus providing negative GHG emissions. While CO_2 capture technologies are fully developed and commercially available today, storage of CO_2 is often still perceived as not yet fully proven and thus risky to invest in and operate[15].

The European Union's recently announced Green New Deal framework calls for a clear regulatory roadmap for the decarbonization of the aviation, the marine and the road sector, to be achieved using a combination of new technology, biofuels, RFNBOs, SAFs, modal shift, and improved efficiency[16]. As part of this effort, the European Commission announced the ReFuelEU aviation initiative (dedicated to SAFs), FuelEU maritime initiative (for low-carbon shipping fuels), and a recast of the Renewable Energy Directive (dedicated provisions for green hydrogen, power and transport). We expect the demand for SAF and maritime fuels through these regulations to be strong and to accelerate the development and deployment of related fuel production technologies. Market signals could deviate fuels away from the road transport sector to the shipping and aviation sectors[17], or – depending on future regulations and consumer preferences – even to biochemicals and biomaterials markets. We expect that future refineries will focus on middle distillates for fuel production, and naphtha for chemicals and materials.

Appropriate design and structure of incentives is important to ensure that investments in production facilities are made in Europe, and they also define the actual climate impact of the fuels produced. EU directives are not uniformly implemented across EU member states, and the result is that the EU market is fragmented into nationally regulated markets[18]. To be effective, any incentive structure must be valid for 10 years or up to 2040, since targets until 2030 are not sufficient to encourage investment in facilities with

[15] See https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/031423-barriers-remain-to-commercial-ccs-rollout-in-europe-despite-high-carbon-prices

[16] (European Parliament, 2020)

[17] Michal Kubicki, Policy officer: https://youtu.be/WPy8GJlnoMY?t=2337

[18] USDA GAIN report Biofuel Mandates in the EU by Member State - July 2023

longer depreciation times; regulations for future eligible feedstocks for biofuels must be discussed now, as to facilitate investment decisions; and incentives must be structured to pay for the price gap between fossil fuels and biofuels/RFNBOs.

Many questions on the future of renewable fuels remain open, including the following that will keep ETIP Bioenergy stakeholders busy for years to come:

- Will biofuels be able to contribute significantly more than the current 5-7%? Why have electricity providers taken up renewables so readily, while fuel providers didn´t?
- How much green energy carriers will Europe import as compared to domestic production?
- Will the refineries in Europe consolidate? Will they use green hydrogen in the future? And what is the future use of naphtha?
- How fast can green hydrogen (linked to the RFNBOs) be deployed, and to which sectors?
- Will green ammonia be used in ships, or only as hydrogen carrier? What is the future role of LNG?

Infobox:E-fuels (RFNBOs)

Renewable fuels of non-biological origin (RFNBO) are synthetic, gaseous or liquid fuels derived from renewable energy and renewable hydrogen, CO_2 or N_2. They can play an important role in ensuring energy supply security and the decarbonization of transport sectors that are difficult to electrify (maritime, aviation), but also, over the next decade, in road transport. The production of RFNBOs will mainly depend on the availability of cheap renewable electricity which is needed for hydrogen production and the operation of direct air capture (DAC) plants.

The investigation by Buffi et al.[19] shows that RFNBO conversion pathways are at early TRLs, and still need technology improvements, demonstration, de-risking and commercial validation in the future. It is essential to provide adequate incentives for the support of the development of RFNBOs for specific transport sectors (e.g. aviation, shipping and high duty vehicles as trucks) which are hard to electrify.

In a transition phase, biomass combustion and biofuel production processes could be important sources of CO_2. Such CO_2 could be used for the production of RFNBOs, or could be stored (as an alternative to the production of fuels) for permanent removal from the atmosphere (BECCS). CO_2 capture technologies from point sources are fully developed and commercially available. Storage of CO_2 however is still perceived by some as not yet fully proven and thus risky to invest in and operate[20].

Infobox:Biomethane

With the ongoing crisis in Ukraine, the interest in biomethane as a replacement of natural gas has increased. The EU communication RePowerEU set the target to 35 bcm biomethane to be produced in 2030, compared to around 3,5 in 2021. The Biomethane Industrial Partnership (BIP) has been formed as a joint effort between the Commission, Member States, Industry and Academia to facilitate meeting the target

Traditionally, biomethane has been produced by upgrading of biogas from anaerobic digestion processes, which in turn are based on waste, residues or other organic material, including agricultural crops. A second pathway is the gasification of biomass, waste, or residues and the subsequent methanation of the synthesis gas.

With rapidly growing production, a number of key elements have been identified as priority areas: setting national policies and targets, accelerating deployment, increasing potential substrate base, improving cost efficiency, and identifying innovation needs.

Innovation needs include:

[19] Buffi, M., Scarlat N., Hurtig O., Motola V., Georgakaki A., Letout S., Mountraki A., Joanny G., Clean Energy Technology Observatory: Renewable Fuels of Non-Biological Origin in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets,Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/76717, JRC130729.

[20] https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/031423-barriers-remain-to-commercial-ccs-rollout-in-europe-despite-high-carbon-prices

- Increasing the feedstock base via pretreatment of residues from agriculture and forestry or new substrates from algae or intermediate crops.
- Improve cost efficiency in thermochemical conversion (gasification) and gas cleaning by upscaling and demonstration.
- Increasing feedstock base with additional renewable electricity for the production of hydrogen to be added to the conversion processes
- Improving methanation technologies, both biological and catalytical, to meet the need for different scales in production
- Improve cost efficiency in liquefaction, grid connection and other means of distribution

Europe is strongly positioned to benefit from the scaling-up of biomethane production and use. The ambitious European timeline to diversify gas supplies brings new prospects, but requires full cooperation among biomethane stakeholders to ensure fast national deployment of the REPowerEU plan. Other broad recommendations to develop these technologies are:

- Improve supply chains and use of sustainable biomass feedstocks
- Diversify process concepts with increased carbon efficiency
- Target industrial-relevant demonstrations
- Highlight the importance of complete value chain approaches

Infobox: Microalgae Cultivation for Bioenergy

Microalgae have gained significant attention as a promising source of bioenergy due to their high photosynthetic efficiency and ability to produce valuable bioactive compounds, such as fish feed, human food, pigments, and pharmaceuticals. They can be cultivated in either open pond systems or photobioreactors, with great potential for high-yield biomass production per area.

However, the industry is facing two major challenges, namely high costs and scaling up of the systems. Therefore, European algal industry focuses on the production of high-value products from microalgae, like feed, food and pharmaceuticals.

At present, microalgae production for biomass or bioenergy use alone is not economically viable, as it is a very energy-intensive process, particularly the cultivation in closed photobioreactors. Yet, the biorefinery concept can enhance the economic feasibility of microalgae-based bioenergy by producing multiple products from a single cultivation system, where the remaining biomass can be used as a feedstock for bioenergy production. Additionally, microalgae can capture CO_2 in water bodies and extract nutrients from wastewater streams, hereby contributing to the management of the carbon cycle and the development of carbon sinks.