AMBITION

Advanced biofuel production with energy system integration

A sustainable advanced biofuels future for Europe

A brief review of the measures in place to support a fossil fuel free Europe

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This brief review of the measures in place to support a fossil fuel free Europe was created by members of the AMBITION project consortium:

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1 Introduction

There are 28 countries in the EU which are all involved in biofuel research and development with enormous investment in people and facilities. The focus is on advanced biofuels in particular, i.e. biofuels produced from biomass other than food/feed crops while meeting the EU sustainability regime under the legislation in force. Each country has its own targets, ambitions and policies and its own infrastructure for research and development into advanced biofuels, while the EU as a whole has parallel policies. In additional there are many supranational organisations exploring biofuel production such as EC, IEA, OECD, UNESCO, etc. The contribution that biofuels can potentially make to the total global annual liquid fuel production of around 35000 million bbl/y is planned to be close to 100% by 2050 for Europe, against a current contribution of less than 5%. However, this will require an unprecedented rate of change from fossil to renewable energy resources with concomitant technology developments and investments. This will require an intensive focus on RD&D in the coming years which is most likely to be successful only through international collaboration. This shows the importance of cooperation in developing and implementing processes for biofuel production which is why an ECRIA (European Common Research and Innovation Agenda) on Advanced Biofuels is so important in enabling Europe to meet these ambitious targets.

The purpose of ECRIA Advanced Biofuels is to develop guiding principles and identify research and innovation priorities for sustainable and cost-effective production of advanced biofuels in the framework of an integrated and sustainable EU-energy system. In such a future integrated sustainable energy system, several energy pillars are integrated horizontally, such that exchange of mass and energy streams across the system maximizes the net energy output from given and limited sustainable sources and limit or remove net-CO_2-emissions[1].

2 Background

The ECRIA call (H2020-LCE-2016-2017, Competitive Low-Carbon-Efficiency, Topic: LCE-33-2016), was created to support the coordination and convergence of national and EU-efforts addressing Research and Innovation Actions (RIA) within the SET-plan[2] and its Implementation plan (Action #8 for advanced biofuels[3]) as background. Priority areas are identified, and a common research agenda is defined to pursue cost efficient development and subsequent industrial implementation of advanced biofuels. The development should be supported by joint research through developing and accumulating a critical mass of research capacity.

ECRIA is just one of many international initiatives to promote and develop low carbon alternatives to fossil fuels and contribute to reduction greenhouse gases. Some of the most significant of the initiatives are summarised below.

[1] Short cycle CO_2-emissions are part of the atmospheric CO_2 – photosynthesis cycle – biomass – transportation fuel - atmospheric-CO_2 which are in a balance; this cycle does not move carbon form one reservoir to another and keep the reservoirs stable; https://earthobservatory.nasa.gov/features/CarbonCycle

[2] The Strategic Energy Technology (SET) Plan – at the heart of energy research and Innovation in Europe, 2007 – 2017, European Commission, https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan, 2017

[3] SET Plan Implementation plan, Action 8: Bioenergy and Renewable Fuels for Sustainable Transport, , European Commission, https://setis.ec.europa.eu/system/files/setplan_bioenergy_implementationplan.pdf, 2018

The recently presented "**European Green Deal**[4]" gives bioenergy and particularly advanced biofuels, a more comprehensive role in the energy transition to a Climate Neutral Europe by 2050. The European Green Deal suggests increasing the EU's emission reductions target to 50 to 55% by 2030[5] with an objective that the EU shall be climate neutral by 2050. For advanced transportation fuels the following objectives are of primary relevance:

- no net emissions of greenhouse gases in 2050
- development of a resource-efficient and competitive economy
- transformation of its economy and society to put it on a more sustainable path
- design of a roadmap of the key policies and measures needed to achieve the European Green Deal

These overall objectives of the European Green Deal are well aligned with the need for large-scale introduction of sustainably produced advanced biofuels into the European Transport market. The transport sector in Europe is responsible for 25% of the EU's GHG-emissions[6] (the second largest sector after energy) and road transport is responsible for approximately 75% of these emissions. The transportation emissions measures to achieve these goals include smart and zero-emission mobility combined with a comprehensive development of new infrastructure and alternative fuels[7]. The sectors covered are road transport[8], marine[9], aviation[10] and improved fuel types[11]. The SET-plan and its implementation are one of the instruments to achieve these targets. The SET-plan transport related targets are strongly interconnected with the development of a circular economy and emission neutral industries, which in turn favours societal changes in the form of job creation, controlled growth and future Investments.

2.1 Policy instruments

Cooperation is vital for efficient innovation, therefore **Mission Innovation**[12] was formed. Mission Innovation consists of 24 countries and the EU (represented by the European Commission) which was launched in Sept 2019 at COP21. This recognizes the vital role of innovation to meet long-term climate goals to provide affordable, reliable and secure energy supplies. These innovations are driven by long-term and sustained public investment integrated with business leadership.

The **Innovation Challenge 4** (IC4) intends to develop pathways for production of affordable advanced biofuels for transportation and industrial applications at a substantial scale. Advanced biofuels will have an important role to play in reducing transport emissions via a range of biofuels value chains with the potential to substantially reduce GHG-emissions. IC4 aims to accelerate advanced biofuels research and development, as well as subsequent demonstration, to achieve performance breakthrough and particularly cost reduction. Advanced biofuels are of particular interest in those transportation means where zero-emission electrical systems cannot be implemented practically or

[4] Communication from the Commission to the European Parliament, The European Council, The European Economic and Social Committee and the Committee of the Regions, " The European Green Deal", Dec. 2019
[5] M. Georgiadou, Renewable Fuels and Bioenergy R&I in EU-Update, presented at EERA Bioenergy JP Steering committee meeting, Brussels Nov. 22, 2019
[6] EU Climate Actions; Transport https://ec.europa.eu/clima/policies/international/paris_protocol/transport_en
[7] A European Strategy for low-emission mobility https://ec.europa.eu/clima/policies/transport_en
[8] EU Climate Action; Road Transport: Reducing CO2-emissions from vehicles, https://ec.europa.eu/clima/policies/transport/vehicles_en
[9] EU Climate Actions; Reducing Emissions form the Shipping sector. https://ec.europa.eu/clima/policies/transport/shipping_en
[10] EU Climate Actions; Reducing emissions form Aviation https://ec.europa.eu/clima/policies/transport/aviation_en
[11] EU Climate Actions; Fuel Types https://ec.europa.eu/clima/policies/transport/fuel_en
[12] Mission Innovation, https://www.mission-innovation.net

cost efficiently such as aviation, deep sea shipping and long-haul transport. For these applications, the short and medium-term application of advanced biofuels are the best renewable alternatives to fossil fuels.

In addition to the above initiatives, the ECRIA needs to be seen as an integration of several other international policy documents including:

- Energy Union Package, A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy[13]
- IEA Energy report 2018[14] and 2019[15], Technology Road Maps 2011[16] and 2017[17] as well as Energy Technologies Perspectives 2017[18]
- SET plan[19] and particularly Implementation Plan Action 8[20]
- SIRA from EERA Bioenergy versions from 2019[21]
- RIA form ETIP Bioenergy[22]: short term industrial implementation until 2030
- SIRA from Bio Based Industries Consortium BIC from 2013[23] and 2017[24]

These documents and their integration gives vital guidance on how to face the three energy challenges of Europe:

1. Provide sustainable and secure transportation energy supplies.
2. Maintain a lead in development and implementation of technologies for energy carrier production which efficiently eliminate/limit greenhouse gas emissions.
3. Maintain competitiveness in European energy-reliant economies.

In order to reach the target of up to 55% reduction in Green House Gas emissions, de-carbonization of the transport sector is mandatory. Currently, alternative fuels (liquid and gaseous biofuels) provide in the order of 5% of the total energy consumption in Europe. These fuels are primarily conventional biofuels[25]. Across Europe, electric cars are gaining momentum, although the current energy mix for electricity only reduces local emissions whereas emissions of electric power production are still substantial.

[13] Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee, the Committee of the Regions and the European Investment Bank A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, COM/2015/080 final; https://eur-lex.europa.eu/resource.html?uri=cellar:1bd46c90-bdd4-11e4-bbe1-01aa75ed71a1.0001.03/DOC_1&format=PDF 2015

[14] IEA World Energy Outlook 2018, https://www.iea.org/reports/world-energy-outlook-2018

[15] IEA World Energy Outlook 2019, https://www.iea.org/reports/world-energy-outlook-2019#

[16] IEA Technology Roadmap – Biofuels for Transport 2011 https://webstore.iea.org/technology-roadmap-biofuels-for-transport

[17] IEA Technology Roadmap – Delivering Sustainable Bioenergy 2017, https://webstore.iea.org/technology-roadmap-delivering-sustainable-bioenergy

[18] IEA Energy Technologies Perspectives 2017 https://www.iea.org/reports/energy-technology-perspectives-2017

[19] The Strategic Energy Technology (SET) Plan – at the heart of energy research and Innovation in Europe, 2007 – 2017, European Commission, 2017

[20] SET Plan Implementation plan, Action 8: Bioenergy and Renewable Fuels for Sustainable Transport, European Commission, 2018

[21] EERA Bioenergy Strategic Innovation and Research Agenda 2018 (SIRA), http://www.eera-bioenergy.eu/wp-content/uploads/pdf/EERABioenergySRIA2020.pdf, 2018

[22] Innovation and Research Agenda, European Technology and Innovation Platform ETIP, http://www.etipbioenergy.eu/images/ETIP_SRIA_2018.pdf

[23] BIC Strategic Innovation and Research Agenda (SIRA) Bio-based and Renewable Industries for Development and Growth in Europe, https://ec.europa.eu/research/participants/data/ref/h2020/other/legal_basis/jtis/bbi/bbi-sira_en.pdf, 2013

[24] BIC Strategic Innovation and Research Agenda (SIRA) https://www.bbi-europe.eu/sites/default/files/sira-2017.pdf

[25] Conventional liquid biofuels such as ethanol and FAME are produced from sugar and starch rich crops and straight vegetable oils. Produced by technologically mature processes proven at commercial scale. Fuels are available, though blending in relatively low concentrations into existing fossil fuels

Today's situation with one dominant energy source, (namely "easy" fossil oil for transportation, fossil coal and gas for stationary energy production) cannot be maintained because of unacceptable net-CO_2-emissions. Conversion of this singular energy supply structure will require simultaneous development and introduction of complementary energy carriers in parallel. These are:

1. Electricity from variable renewable power (VRP) such as solar and wind and more stable hydroelectric systems all integrated with energy storage such as battery and hydrogen,
2. Biobased liquid and gaseous transportation fuels to replace gasoline, diesel and kerosene for marine, aviation and long haul transportation,
3. Bioenergy for heating and cooling.

2.2 Role and challenges of biofuels

The ECRIA Advanced Biofuels projects focus on a sub-set of these sectors: namely the production of advanced liquid biofuels. These projects are dedicated to highly efficient production of advanced liquid biofuels where optimal utilization of the limited feedstock base is needed, together with integration into other energy chains to maximize carbon efficiency and limit CO_2-emissions during fuel production. In parallel, a comprehensive hybridization of internal combustion engines for some transportation means will improve overall efficiency[26]. Currently, a prioritization of a given energy carrier towards a given application is challenging and clearly dominant energy carriers for long-term applications are not "in sight". Biofuels and advanced biofuels will play a vital role in the short and medium-term, while for some applications, such as aviation and deep-sea shipping, advanced biofuels will likely play an important role also in the longer term.

However, there is a range of inherent challenges with bioenergy and advanced biofuels in particular. This includes the large variety of biobased feedstock, their (region-dependent) availability, sustainability and how to guarantee this, logistic challenges (e.g., how to commoditise biomass) and the large variety of energy and chemical/material products that can be produced. Which products are most attractive may also be region-dependent. For instance, in Denmark, straw is considered to be an attractive bioenergy feedstock, while in Portugal it is used mainly as cattle feed. The large variety in biomass feedstock in combination with the many possible products gives room for a wide range of conversion technologies best suited for specific value chains. A schematic overview of the various possible value chain (feedstock – conversion technology – product) options is given in Figure 1. Clearly, there is not one general silver bullet: available feedstock and desired product(s) are the main determining factors and there is a strong regional dependence.

2.3 Market perspectives

As of today, the market perspectives for renewable transportation fuels remain challenging with low crude oil prices and unstable national political support. Major challenges for the commercialisation of biofuels produced by both biochemical and thermochemical technologies are:

- **Technical challenges** vary depending on the degree of development of a given technology. For lower TRL technologies, increasing product yields and operational time (time on stream) are major technical challenges. For technologies higher on the TRL-scale, technical challenges are primarily related to long term operation in real industrial environments and feedstock

[26] SET Plan Implementation plan, Action 8: Bioenergy and Renewable Fuels for Sustainable Transport, European Commission, 2018

flexibility; basically, the ability to handle less homogeneous feedstocks or those with higher impurities such as forest residues, crop residues, and regional and seasonal "opportunity" biomass sources.

- **Economic challenges**, e.g. how to reduce production costs. The reduction of both capital expenditures (CAPEX) through better system design and the integration with existing infrastructure (both production and distribution) and operational costs (OPEX) through reduced feedstock costs (ability to process less costly feedstock) and increased product yields or co-production of higher added value products as well as improved quality for specific energy applications should be addressed.
- **Logistic challenges**, concerning making available a broad feedstock range and converting the biomass into commodities (bioenergy carriers), to facilitate handling, transport, storage and conversion, but also facilitate sustainability certification and trade.
- European and national **technology neutral fuel specifications** which regulate the quality and properties of fuels and intermediates, especially the number of standards and guidelines for use of bio-oils and biocrudes is limited. Insufficient characterisation information or relevant standards can slow down the commercial deployment of biofuels.
- **European regulations** which give an enough market size of fuels to be supplied are missing[27]. The current situation can be described by the "public and transportation means provider" wait to adapt new fuels: fuel producers will wait for a sufficiently large market to even initiate the planning processes for large-scale production. Thus, simultaneously there is a limited market and missing production capacity which slows down introduction of renewable fuels.
- Unstable and changing **policies** with regards to biomass/biofuel utilization (e.g. blending mandates, feedstock restrictions) causes uncertainty and potentially prevent commercial investment in this area. Efficient marked introduction is to some extend dependent on changing of policies and priorities. The final version of the European Green New Deal needs to address this topic[Error! Bookmark not defined.].
- Finally, **media coverage** through interest groups which have a strong influence on the public perception of biofuels, their application and environmental benefits. A clear unbiased information (strategy) on the environmental performance of biofuels and the consequences of their production is needed. This information needs to utilize fossil fuel as a benchmark for renewable fuels and high light the environmental performance.

2.4 Contribution of AMBITION

The AMBITION project has addressed a sub-set of possible value chains (see Figure 1) and focused on three key unit operations in the production of next generation liquid biofuels (biomass pre-treatment and fractionation, gasification and syngas fermentation) and on linking of energy systems (grid electricity and biofuels in particular) to improve overall efficiencies. The specific advances achieved in AMBITION can be adapted to existing biofuel production schemes or integrated to enable new considerably improved, environmentally friendly and economically competitive processes. Further, it

[27] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

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was recognised that new and more comprehensive Key Performance indicators need to be developed to evaluate a given technology. Generally, this should involve a combination of key performance indicators which describe the process performance (e.g.: efficiency from feedstock to product), environmental performance (e.g.: LCA) and economic performance (e.g. €kWh).

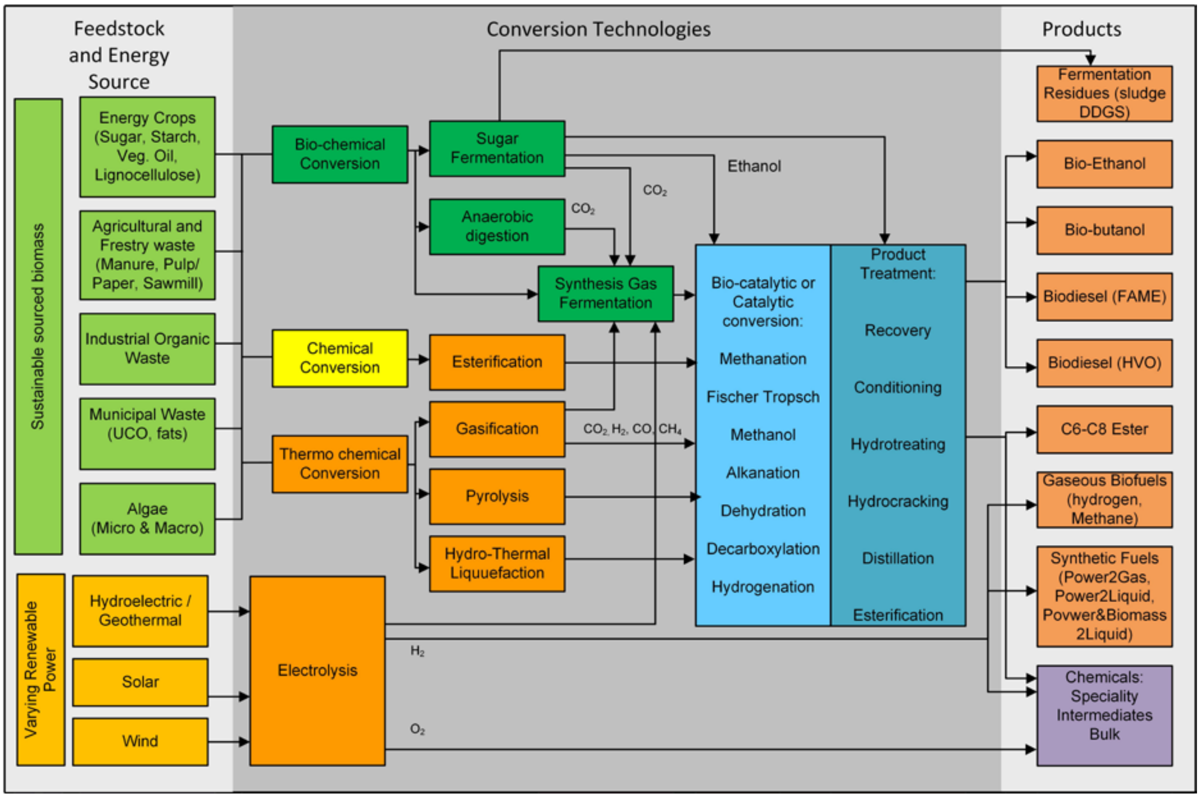

FIGURE 1: BIOFUEL PRODUCTION CHAINS[28]

There is a growing demand for solutions providing integration and flexibility in the European energy system creating a bridge between two forms of energy carriers, i.e. grid electricity and biofuels. This bridge needs to be established since the overall energy and "carbon" efficiency is vital for a future energy system. Provided enough intermittent energy is available to generate hydrogen, CO_2 from current energy systems and industrial production can be utilized as a carbon source as an alternative to sequestration. These integration approaches create flexibility between intermittent electricity and sustainable fuel production, and thus optimise the valorisation of peak renewable electricity and at the same time, enable the production of sustainable biofuels at economically competitive conditions from alternative carbon sources. Finally, this integration will improve the security of supply of renewable electricity and transportation fuels and thus address a key concern in the European energy policy.

3 Existing SRIA documents and research programmes

Strategic Innovation and research programs relevant for Europe are the SRIA 2020 from EERA Bioenergy[29] and the SRIA from 2018 from ETIP Bioenergy[30] which have a slightly different objective.

[28] Adapted from http://www.etipbioenergy.eu/images/SPM8_Presentations/ETIP_Mueller-Langer_2018-04_new.pdf
[29] http://www.eera-bioenergy.eu/wp-content/uploads/pdf/EERABioenergySRIA2020.pdf
[30] http://www.etipbioenergy.eu/images/ETIP_SRIA_2018.pdf

The document from EERA Bioenergy focusses more on the need for the basic research whereas ETIP Bioenergy is more directed towards advanced research and the implementation of production capacity. Identified research areas are both primary biochemical and thermochemical conversion processes from biomass to advanced biofuels; this also includes the downstream processing and production of intermediate bioenergy carriers.

The governing guiding principles for research for the efficient production of advanced biofuels including jet fuels, and the eventual co-production of other bio-based products in biorefinery approaches are:

- Increase process simplification and integration in order to reduce the CAPEX and OPEX and increase conversion plant availability and reliability.
- Increase feedstock flexibility (e.g. use of low-quality and low-cost feedstocks, such as waste or high- and low-grade biomass) and consider new biomass sources (e.g. algal biomass).
- Maximise the efficient use of resources, which may involve the combined processing of biomass with products from other sources (e.g. renewable hydrogen) or combining biofuels with biobased products.
- Improve process efficiency towards valuable products.
- Create negative GHG emissions by developing alternatives like combining bioenergy with carbon capture and storage (BECCS) and the co-production of biochar.

The research needed can be summarized for thermochemical conversion as:

- Increase feedstock flexibility by utilizing low-cost biobased residues and mixed wastes.
- Improve knowledge and performance of individual process units for gasification, pyrolysis and hydrothermal liquefaction.
- Develop robust and efficient catalysts to improve and stabilize conversion efficiency.
- Develop new and robust thermochemical processes for high-efficiency conversion of waste and residue streams.
- Optimize the properties of intermediates to simplify upgrading and downstream processing.
- Develop innovative conversion and downstream processing schemes for co-production of biofuels, biobased chemicals/materials (and power and heat).
- Develop innovative processes to improve utilization of residues.
- Ensure that all wastes and residues are properly and safely managed.

Similar research needs are identified for biochemical processes but with the addition of:

- Integrated optimization of feedstock pre-treatment and conversion processes.
- Development and engineering of suitable and robust bio-catalysts.
- Improved process, mass and energy integration including efficient product recovery.

All conversion pathways need to reduce capital costs and production costs and ensure a benign environmental performance of not only the processes themselves but the entire value chains. This also includes the sustainable sourcing of feedstocks where agricultural and industrial waste and side streams are prioritized. These innovation targets depend on an integration of process and systems engineering to increase overall efficiency. Further, an increasing role for variable renewable energy (VRE) is identified to integrate with production of advanced biofuels where VRE can be utilized to considerably improve the process performance.

Complementary to the content of the EERA Bioenergy SRIA, the SRIA from ETIP Bioenergy focusses more on implementation of production capacity for advanced biofuels, which also includes the need for coherent national legislation which enables transparent and science-based data and tools for practical implementation of sustainability requirements and create a market place for advanced biofuels. From a technology side, key priorities for commercial feasible advanced biofuel production are improved environmental (such as GHG, energy balance, water, inputs…) and economic performance. Concepts involving biorefinery concepts and bringing flexibility to integrated system are prioritized. Further, conversion technologies which target advanced biofuels for heavy duty road, air, and marine transport deserve priority attention since there is of lack of low fossil carbon alternatives in the foreseeable future and current estimations show an increasing demand. Further, an equalization of incentives for low carbon technologies which ensures a fair appreciation of CO_2 emissions (well-to-wheel approach) is needed, such that vehicles running partly or fully on renewable fuels and electric vehicles are treated using equal criteria.

4 Recommendations for Advanced Biofuels

Research towards advanced liquid biofuels is highly diverse, scattered and numerous parallel projects and research initiatives and programs are being performed. Besides specific research needs, generic issues need to be addressed to facilitate efficient and large-scale introduction of advanced liquid biofuels into the market. The most important asset of advanced biofuels for their rapid deployment is their inherent compatibility with the existing fuel distribution infrastructure and engines types. However, the following issues need to be addressed through an adapted policy framework:

- Secure market access for advanced biofuels to stimulate technology development and scale-up.
- Give priority to advanced biofuels for specific end-uses with few alternatives.
- Develop incentives which promote production of the "most" sustainable and “greener” fuels.
- Develop a transparent standardized system to monitor the overall sustainability.

Preferred production technologies for advanced biofuels are generally based on widely available, sustainable feedstocks within a geographical region. Thus, globally promoting one technology over the other is not the way to go. However, integration of value chains should be explored, including:

- Facilitate sustainability certification of the raw biomass and thus facilitate international trade of biomass.
- Development and implementation of technologies for biomass upgrading and commoditization to create a better fit with existing logistics and processing technology.
- Improve feedstock flexibility of the conversion processes.
- Promote decentralised (and smaller scale) biorefinery systems when integrated production of fuels and value-added chemicals are feasible, thereby facilitating maximum feedstock utilization and improve both the overall biomass resources

sustainability and the economic feasibility of processes. Thus, a structured development of biorefinery systems is needed.

- Higher TRL-level (TRL 6/7) technologies have gone through research and operational data are generated in parallel in several pilot plants. Data sharing is limited and does not feed further research. Knowledge is kept inside a given consortium and it is not given that this consortium will proceed to the next stage. Sharing this knowledge i.e. open innovation is vital for rapid development. Higher TRL technologies will still require incremental research and innovation for process optimization.
- The time span for demonstration at industrial scale is often kept to a minimum, because it requires a substantial financial resource base and the products produced are not cost-effective compared to existing fossil products in the market. Long term operation of demonstration plants is urgently needed to facilitate scale-up, identify bottlenecks and the reduction of CAPEX and OPEX. Again, sharing of these experience and data is needed.
- Comprehensive research and innovation is needed for processes at a TRL level below 6. Several technologies might not be environmentally or economical viable for various reasons, though this needs to be proven. Key performance indicators for new innovative concepts and technologies should be applied at an early stage to evaluate new technologies:
  - Resource efficiency defined as carbon from feedstock to carbon in products needs to be improved
  - Feedstock flexibility issues need to be addressed early to broaden sustainable feedstock base, particular industrial/municipal wastes/side streams and marine feedstocks
  - Value chain CO_2-emissions, for this common standard needs to be developed which are both technology and feedstock neutral
  - Continuous validation (TEA and LCA) during the course of development of a technology to understand the environmental potential of a concept and its economic implications. Further, these frequent evaluation/audits will early identify potential bottlenecks in the process and can guide research towards better processes.
  - Promote research to biorefinery concepts which monetarize side and minimize waste streams as integral part of the development
  - Strengthen research for chemical, biochemical and thermochemical technologies for liquid advanced biofuels which can be readily integrated in today's infrastructure either as intermediates as co-feed / drop-in fuels to be up-graded in existing refineries or oxygenated compounds as fuel additives
- Current research on E-fuels (especially Power2Liquid) shows potential provided sustainable CO_2 is available, CO_2 sourced from combustion of fossil fuels will ultimately increase the net-CO_2 emissions. However, the production of E-Fuels should be brought to demonstration scale accompanied by a rigorous environmental and techno-economical evaluation.

In addition to the individual development of the technologies, integration of technologies in a plant and or at a higher level into an energy system require further consideration. This includes:

- Horizontal integration of biochemical and thermochemical processes with efficient heat/energy and material flow integration where the side-streams of one process are utilized as feed stream in a different value chain.
- Horizontal integration of advanced biofuels into a renewable energy system where three pillars are integrated including:
    - Sustainable biomass to advanced biofuel
    - Hydrogen from renewable and intermittent power
    - E-fuels from renewable power

It is essential that the time scale for development of processes for advanced biofuels are shortened. For the fuels needed in Europe, it is estimated that 175 to 250 plants need to be built by 2030; and by 2050 around 1000 plants will be needed in total with perhaps 10-20 different feedstock agnostic technologies. However, it is not clear currently which conversion technology is "the golden star". Several technologies which produce drop-in fuels have reached demonstration scale, either for complete replacement (such as Fischer Tropsch diesel), co-feed into refineries (such as pyrolysis oils from lignocellulosic or organic waste streams) or alcohols which can be mixed up to a given amount into gasoline or upgraded to hydrocarbons. There are other potential processes that can deliver compatible hydrocarbon based fuels.

Given that several technologies are at demonstration level, a ramp-up of production is dependent on a sufficient market size over a long enough time scale. A stable and predictable framework is needed to initiate building of substantial capacity. However, the political framework needs to be a combination of blending mandates (generate enough market size) and either economic incentives or financial risk mitigation for building/construction of plants at an industrial scale.

5 Conclusions

5.1 Framework

The purpose of the European Common Research and Innovation Agenda (ECRIA) is to develop guiding principles and identify research priorities for sustainable and cost-efficient production of advanced biofuels for the future. The ECRIA is an instrument which is designed to play a vital role in the design of an integrated EU-energy system. Where several energy pillars are integrated horizontally, such that exchange of mass and energy streams across the systems maximize the net energy output from given and limited sustainable sources and limited or remove net-CO_2-emissions.

The ECRIA call (H2020-LCE-2016-2017, Competitive Low-Carbon-Efficiency, Topic: LCE-33-2016), was created to support the coordination and convergence of national and EU-efforts addressing Research and Innovation Actions (RIA) within the SET-plan and its Implementation plan as background. Priority areas are identified, and a common research agenda is defined to pursue cost efficient development and subsequent industrial implementation of advanced biofuels. The development should be supported by joint research through developing and accumulating a critical mass of research capacity.

5.2 Challenges which set the scene for Research and Innovation

In the current singular energy system primarily based on fossil fuels, renewable energy gain momentum, especially variable renewable electricity is increasingly part of the energy system.

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However, transportation applications on land, sea and air are still dominated by fossil fuels. Given the recent Paris Agreement, comprehensive reductions in transportation emissions are needed, nevertheless two major emission sources: aviation and marine applications are not regulated, this is partly because access to adequate fuels is more complicated compared to land-based applications, and changes in fuel infrastructure and a forced transition to biofuels require international treaties with ambitious commitments compared to national regulations. For other transportation types combustion engines dominate and "blending walls" set by engine manufactures are impeding the increased amount of biofuels blended into transportation fuels.

Even though the SET-plan and recent European Green deal promote renewable fuels and in particular advanced biofuels, market introduction at a sufficient scale by 2030 is still challenging. Targets are set for specific costs and conversion efficiencies. However, current tank-to-wheel efficiencies could be extended to cover the net-CO_2-emissions and energy consumption of an entire value chain, from feedstock to passenger-kilometre, which would improve the comparability of the several technologies.

Advanced biofuels cannot currently compete with fossil fuels economically. Therefore, a system needs to be developed which prioritize advanced biofuels into the market through long-term incentives (such as substantial blending mandates or energy tax reductions), while for industrial production financial risk mitigation is needed.

Besides the commercial production and sale of biofuels, sufficient quantities of sustainable feedstocks are needed. These will require more flexible technologies to convert different feedstocks efficiently into advanced biofuels, where feedstocks include waste and side streams from agriculture or industrial production.

An improved framework encompassing both the market access and access to feedstock are a requirement for a rapid ramp-up of production, currently there is only a limited amount of new capacity for advanced biofuels in planning or construction, a new financial tool for establishment of industrial capacity.

The growing interest in electro-fuel (PtL) competes on financing with the production of biofuels (BtL). From the work done in AMBITION, an integration of advanced biofuel production with hydrogen production will improve overall carbon efficiency (PBtL)

5.3 General Recommendations

Research towards advanced liquid biofuels is highly diverse, scattered and numerous parallel projects and research initiatives and programs are performed. Besides specific research needs, generic issues need to be addressed to facilitate and efficient and large-scale introduction of advanced liquid biofuels into the market. The most important asset of advanced biofuels for their rapid deployment is their inherent compatibility with the existing fuel distribution infrastructure and engines types. However, the following issues need to be addressed through an adapted policy framework:

- Secure market access for advanced biofuels to stimulate technology development and scale-up.
- Give priority to advanced biofuels for specific end-uses with few alternatives.
- Develop incentives which promote production of the "most" sustainable and “greener” fuels.
- Develop a transparent standardized system to monitor the overall sustainability.