SET Plan Implementation Plan

Action 8: Bioenergy and Renewable Fuels for Sustainable Transport

05-June-2018

Contents

Executive summary

This Implementation Plan (IP) of Action 8, *Bioenergy and Renewable Fuels for Sustainable Transport*, describes the Research and Innovation (R&I) activities that need to be implemented in order to achieve the strategic targets adopted in the SET Plan Declaration of Intent (DoI), agreed in December 2017 by the representatives of the European Commission services, SET Plan countries and stakeholders most directly involved in the respective sectors.

In line with the SET Plan DoI, the Implementation Plan has three common goals for the field of Bioenergy at large: Improve performance (yield and efficiency) of production, reduce GHG emissions along the value chain and reduce cost.

In order to capture the major segments of Bioenergy, this IP describes targeted implementation approaches for Renewable Fuels for Sustainable Transport (automotive and aviation fuels, as well as hydrogen produced from renewable sources), Bioenergy (biosolids, bioliquids, and biogases) and intermediate bioenergy carriers.

Owing to the complexity, but also to the versatility of the value chain Feedstocks >>> Conversion >>> Intermediate Carriers >>> Final Product, the IP describes 13 activities. They are structured along Technology Readiness level (TRL)[1] and consequently divided into **Development**, for **Demonstration** and **Scale-up** according to the table 1: Total investment for R&I activities below**.**

The estimated volume of **investment for development is 2,29 Billion €**, whereas 104,31 billion € is foreseen for demonstration and scale-up activities.

Table 1: Total investment for R&I activities

	Billions €	Industry		MS Funding		EU	
Total Bioenergy and Renewable Fuels for Sustainable Transport	**106,61**	**77,74**	***73%***	**22,23**	***21%***	**6,64**	**6%**
Renewable Fuels for Sustainable Transport	**84,81**	**62,34**	***74%***	**17,48**	***21%***	**4,99**	**6%**
Advanced Biofuels	**73,00**	**53,75**	***74%***	**15,00**	***21%***	**4,25**	**6%**
#1 Development	1,00	0,25	*25%*	0,50	*50%*	0,25	25%
#2 Demonstration	2,00	1,00	*50%*	0,50	*25%*	0,50	25%
#3 Scale-Up	70,00	52,50	*75%*	14,00	*20%*	3,50	5%
Other renewable liquid and gaseous fuels	**11,40**	**8,35**	***73%***	**2,36**	***21%***	**0,69**	**6%**
#4 Development	0,20	0,05	*25%*	0,10	*50%*	0,05	25%
#5 Demonstration	0,40	0,20	*50%*	0,10	*25%*	0,10	25%
#6 Scale-Up	10,80	8,10	*75%*	2,16	*20%*	0,54	5%
#7 Renewable Hydrogen	**0,41**	**0,24**	***59%***	**0,12**	***28%***	**0,05**	**13%**
TRL 2-6 (Development)	0,10	0,03	*25%*	0,05	*50%*	0,03	25%
TRL 7-8 (Demonstration)	0,06	0,03	*50%*	0,02	*25%*	0,02	25%
TRL 9 (Scale-Up)	0,25	0,19	*75%*	0,05	*20%*	0,01	5%
Bioenergy	**11,30**	**8,03**	***71%***	**2,45**	***22%***	**0,83**	**7%**
#8 Development	0,50	0,13	*25%*	0,25	*50%*	0,13	25%
#9 Demonstration	0,80	0,40	*50%*	0,20	*25%*	0,20	25%
#10 Scale-Up	10,00	7,50	*75%*	2,00	*20%*	0,50	5%
Intermediate Bioenergy Carriers	**10,50**	**7,38**	***70%***	**2,30**	***22%***	**0,83**	**8%**
#11 Development	0,50	0,13	*25%*	0,25	*50%*	0,13	25%
#12 Demonstration	1,00	0,50	*50%*	0,25	*25%*	0,25	25%
#13 Scale-Up	9,00	6,75	*75%*	1,80	*20%*	0,45	5%

[1] See Annex II for details of TRLs for many value-chains

Regarding the strategic fields of implementation, the following activities and estimated investments are foreseen to be implemented:

For **Renewable Fuels for Sustainable Transport** there are each

- three [#1, #2, #3] for advanced liquid and gaseous biofuels through biochemical / thermochemical/ chemical conversion from sustainable biomass and/or from autotrophic microorganisms and primary renewable energy (needed investment 73,0 Billion €)
- three [#4, #5, #6] other renewable liquid and gaseous fuels (excluding hydrogen) through thermochemical/ chemical/ biochemical /electrochemical transformation of energy neutral carriers with renewable energy (needed investment 11,4 Billion €).

One [#7] on production of **renewable hydrogen** from water electrolysis and renewable electricity (needed investment 0,4 Billion €).

Three [#8, #9, #10] on **Bioenergy** for high efficiency large scale biomass co-generation of heat and power (needed investment 10,5 Billion €).

And three [#11, #12, #13] on **other intermediate carriers** (needed investment 10,5 Billion€).

The total needed investment for R&I activities for this Implementation Plan is an estimated 107 Bill. €. The magnitude of investment is understood cumulative until 2030, and a split of 73% corporate R&D (78 Bill.€), 21% national (22 Bill.€) and 6% EU (7 Bill.€) funding is assumed. This split varies for stages Development, Demonstration and Scale-up, along the different levels of TRL from low to high.

The detailed programme of the R&I activities is provided in Annex I.

A successful outcome of this IP will depend on enablers and barriers alike. The TWG has identified quite a number, the more Bio-energy specific **enablers** being:

- Well-established, transparent and agreed framework on sustainability criteria for all feedstocks from agriculture, forestry as well as for biological and municipal waste.
- Support of sustainable feedstock mobilisation. The development and use of currently unexploited sustainable waste, biomass and land resources to supply the advanced technologies, with particular emphasis on the application of principles of circular economy, as well as on logistics.
- Increased integration of renewable fuels/bioenergy in different energy systems, exemplified by power-to-gas and power-to-liquid pathways, the use of biomass-based energy generation and renewable Hydrogen in heating, cooling and electricity networks.

Likewise, as bio-energy specific **barriers:**

- Restrictions in current policy framework that introduce or maintain unnecessary obstacles to the development of biofuels/bioenergy/renewable hydrogen such as tailpipe emission or grid fees for power-to-fuel applications.
- A heavily restricted feedstock portfolio today will limit the development of technologies while >60% GHG threshold limits will significantly reduce the availability of sustainable feedstock.
- A stricter view on sustainability criteria applied to renewable fuel/bioenergy than other uses of biomass could slow down development. The application of the sustainability criteria only for the energy uses of biomass only creates a disadvantage in competition with other uses of biogenic sources for food, feed and fibre.

1. Introduction

Bioenergy is considered a key source to meet EU 2020 and beyond renewable energy targets, and at the same time helping ensuring GHG emission reduction, security of energy supply and supporting economic growth in particular in rural areas. Furthermore, the development and deployment of low-carbon renewable fuels is key to the decarbonisation of the European transport sector and to attain greenhouse gas emissions reduction targets. Electric vehicles (EV), both battery and plug-ins still have relative small share in market and at present have yet limitations in heavy duty and long range solutions.

In 2016, about 67% of total primary energy production of renewable energy in the EU-28 is generated by biomass (solid, liquid and gaseous fuels) [Eurostat, last update January 2018], being the heat and power production, including in cogeneration plants, the main applications; specifically in the transport sector, the share of renewable energy in fuels consumption was 7,1%, mainly from biofuels with a large variation across different Member States [Figure 1 - Eurostat, last update January 2018].

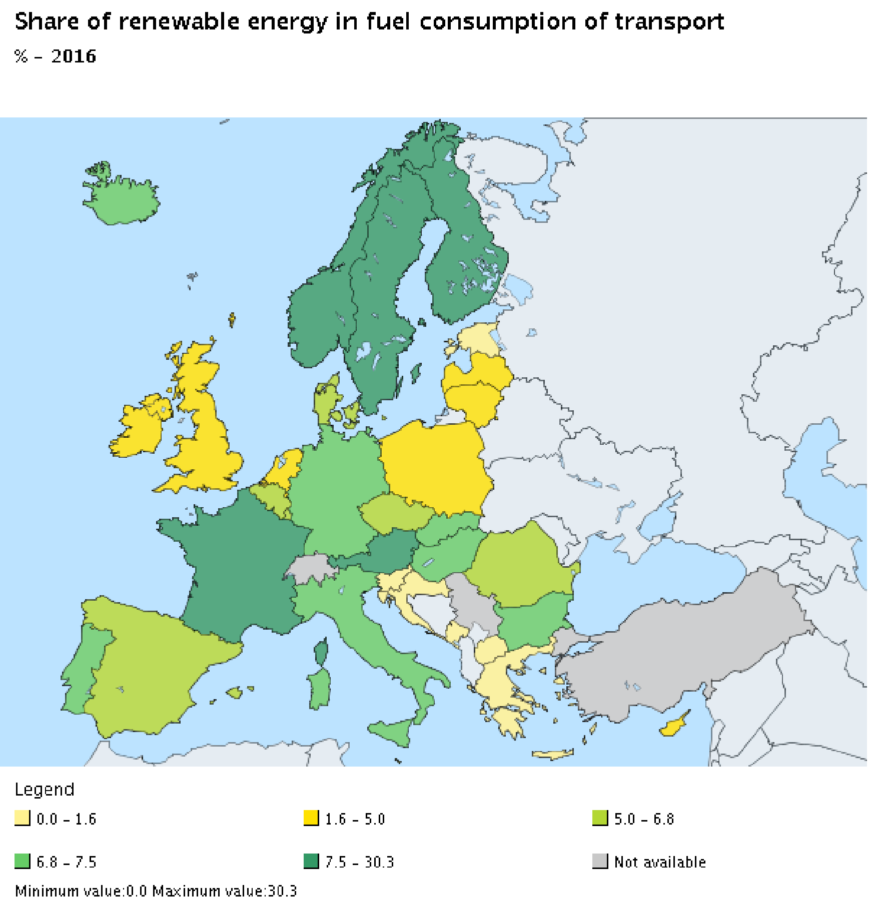

Figure 1: Share of renewable fuels in transport in 2016 [Eurostat, 2018]

Bioenergy is a renewable energy source that is continuously available and versatile: on the product side; it can contribute to replace fossil fuels in all energy markets, heat, electricity with base load and flexible capabilities, as well as fuels for transport, including for shipping and aviation. Different products can be stored in big amounts and with relative low cost. On the supply side it may benefit from large availability and wide variety of potential feedstock such as energy crops and wooden biomass, but also residues from both agriculture and forestry, the organic fraction of municipal and industrial solid waste, as well as algae and aquatic biomasses. Feedstock flexibility is an important requirement for future plants as it is important for the security of the plant supply and for cost reduction.

On the path from resources to the final energy product there are many technologies used for feedstock preparation on one hand and for the conversion into the final product, being electricity, heat or transport fuel. It is due to this versatility that an integrated approach is followed here to enhance the synergies and economies of scale, to achieve economic benefits in the value chain to ultimately reduce the production costs and to optimise the greenhouse-gas performance of all bioenergy-products. Although cost structure is heavily influenced by feedstock costs, these are market variable and thus this document focuses on R&I needs and targets solely for the conversion steps. Biofuels currently represent the main alternative to fossil fuels in transport in terms of volume. Drop-in biofuels in particular allow a smooth transition to low fossil carbon fuels in the existing transport fleet and fuel infrastructure. Resource efficiency and sustainability optimisation pose high expectations in advanced biofuels based on biomass residues and lignocellulosic energy crops and wastes, which will play an increasing role in the EU post-2020 policy framework for energy and climate. This is also the focus of this Implementation Plan for what concerns transport biofuels.

Renewable electro-fuels (such as renewable hydrogen, methane, methanol etc.) are increasingly seen as suitable storage media for excess electricity generated by wind and solar power, facilitating the renewable uptake and integration of the power, transport, industry and heating sectors. They are thus likely to become more widely available, also as renewable fuels for transport in the medium and long term. The use of renewable hydrogen and other renewable liquid and gaseous fuels (Biomass-to-liquid, renewable Power-to-Gas including hydrogen and renewable Power-to-Liquid) could play an important role not only in decarbonizing transport, but also in enabling the cross-sectorial integration of surplus renewable electricity and realizing a fully renewable energy supply linking the electricity, heating, transport and industrial sectors. These technologies could prove indispensable in the scenario where low-carbon renewable electricity needs to be stored either in large quantities or over very long-time (inter-seasonal storage). In addition, renewable hydrogen can also be used for increase the output of biomass, allowing for additional synergies.

2. Policy Context

The 2030 Climate and Energy Policy Framework for the period from 2020 to 2030 has set the objectives to reach a 40% reduction in GHG emissions by 2030 compared to 1990, a binding target of at least 27% for the share of renewable energy in 2030 and an indicative target of at least 27% improvement in energy efficiency. The Energy Roadmap 2050 investigated possible pathways for a transition towards a GHG emission reduction of 80% economy-wide. Bioenergy production for heating & cooling, electricity and transport is expected to play a major role in the decarbonisation in all scenarios of the Energy Roadmap 2050. The final share however will depend equally on conversion technology development and the cost and availability of sustainable biomass as a whole for all biomass origins and for uses including food, feed, and industrial uses of biomass.

The Energy and Climate policy of the EU places a great emphasis on the deployment of sustainable advanced biofuels. Since 2015, when the so-called ILUC Directive[2] entered into force, the use of 1st generation biofuels, i.e. biofuels produced from starch, oil or sugar crops, has been capped in

[2] Directive (EU) 2015/1513

the EU. This means that advanced biofuels, i.e. produced from lignocellulosic and residual biomass feedstocks, are an essential component of decarbonisation strategies for the transport sector. The same directive called on the EU Commission to present a comprehensive proposal for a cost-effective and technology-neutral post-2020 policy in order to create a long-term perspective for investment in sustainable advanced biofuels.

On November 30, 2016, the European Commission (EC) published a proposal for a recast of the Renewable Energy Directive[3] (RED-Recast). The RED-Recast strengthens the sustainability criteria for agricultural biomass and introduces new sustainability criteria for forest biomass. In addition to those criteria, Art. 26(7) specifies the minimum GHG saving threshold that bioenergy used in different sectors (transport, heat and power) has to comply with in order to count towards the renewables targets and to be eligible for public support. For electricity, heating and cooling produced from biomass fuels the threshold of the minimum GHG savings compared to fossil fuels is fixed at 80% for installations starting operations after 1 January 2021 and at 85% for installations starting operations after 1 January 2026. On transport, the EU Commission proposes to gradually reduce the cap on food and feed-based biofuels up to 3,8% by 2030 and to establish a mandate on fuel suppliers, requiring them to blend 6,8% of advanced fuels and other alternative fuels, including renewable electricity, by 2030. The aim of the incorporation obligation is to encourage the continuous development of alternative renewable transport fuels, including advanced biofuels, and the energy diversification in the transport sector. In transport, attention must be given to avoid unnecessary high value for the threshold of GHG savings compared to petrol and diesel, which may significantly limit the sustainable biomass resources base.

However, the deployment of some alternative fuels is hampered mainly by high prices of vehicles and lack of recharging /refuelling infrastructure.[4] The Alternative Fuels Infrastructure Directive[5] aims at facilitating the installation of infrastructure to support the deployment of alternative fuels. While the definition of alternative fuels goes beyond renewable fuels, in this context renewable alternatives to petrol and diesel (like renewable electricity, renewable gas and renewable hydrogen) are supported in their deployment.

2.1 The Integrated SET Plan

The Energy Union Strategy[6] launched in early 2015 and being one of the ten big priorities of the EC, includes research, innovation and competitiveness at the same level of importance with its four other dimensions, for accelerating the decarbonisation of the European energy system cost-effectively. The Strategic Energy Technology (SET) Plan has been recognised as one of the major tools to deliver this goal by contributing to the cost reduction and improve of performance of low carbon energy technologies through impactful synergetic innovation actions.

As part of the deliverables of the Energy Union strategy, the European Commission adopted a Communication for an Integrated Strategic Energy Technology Plan[7]. The Communication identifies ten priority actions to accelerate the energy system transformation through coordinated

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[3] COM(2016)767

[4] Other reasons for low deployment of alternative fuels vechicles are also due to the high price of vehicles and poor consumer acceptance, as recognised in the Impact Assessment Accompanying the Proposal for a Directive on the deployment of alternative fuels infrastructure, COM(2013)5.

[5] Directive (EU) 2014/94

[6] COM(2015) 80

[7] C(2015) 6317 final

or joint investments between European countries, private stakeholders (including research and industry) and the European Commission. These actions have been defined building on the proposals of the Integrated Roadmap (that was developed with stakeholders and Member States) and in line with the new political priorities defined in the Energy Union strategy. Out of the ten priorities, Actions 1, 2 and 8 (these actions are not to be confused with this Action 8) addressed in this implementation plan aim at the same time continuing of our efforts to make EU industry less energy intensive and more competitive as well as strengthening market take-up of renewable fuels needed for sustainable transport solutions and bioenergy.

3. Scope of the Implementation plan

The goal of the Implementation Plan (IP) is to translate SET Plan key actions into specific recommendations for R&I engagements and/or policy measures related to innovation, identifying strategy and R&I activities that need to be implemented to reach targets set in the Declaration of Intent (DoI), coordinating R&I activities and stimulate joint actions by funding actors, also considering international cooperation. Specifically, the IP shall contribute to

- determine joint and/or coordinated actions; to identify the ways in which the EU and national research and innovation programs could most usefully contribute;
- identify the contributions of the private sector, research organizations, and universities;
- identify all issues of a technological, socio-economic, regulatory or other nature that may be of relevance in achieving the targets;
- report regularly on the progress with the purpose to monitor the realization of the targets and take rectifying actions where and whenever necessary.

In this context, the role of the SET Plan countries and stakeholders involved in the preparation of the IP is to:

- Identify ongoing R&I activities (at national / EU / industry levels) clearly contributing to the targets. Among these, it is crucial to identify flagships (i.e. the most relevant ongoing activities with high public visibility, such as large-scale demonstration projects).
- Identify non-technological barriers/enablers
- Share experience, if any, in monitoring the targets
- Identify potential new Joint R&I activities with other countries in the WGs or complementing existing ones (e.g. ongoing ERA-Nets).

The scope of this IP is on bioenergy and renewable fuel solutions for sustainable transport and biomass CHP, mainly large scale. The following targeted technologies are addressed: renewable fuels for transport, other renewable fuels of non-biological origin, bioenergy intermediate carriers, renewable hydrogen and large-scale biomass CHP.

Effective decarbonisation of transport will depend also on other actions like energy efficiency in transport and evolution of electrification and introduction of 100% biofuels (not used in blends) such as renewable methanol, ethanol, methane and DME. While final assessment requires a cautious well to wheel approach and overall sustainability analysis, this is not covered in this context. The same frame applies to biomass CHP.

3.1 Renewable Fuels for Transport

The Renewable Energy Directive[8] established a 10% share of renewable sources for transport in 2020. For 2030, the Council adopted on 18 December 2017 a 14% share for each member state and a sub-target of 3% for advanced biofuels. However, the debate on sustainability of crop-based biofuel production has led to more stringent sustainability criteria, which influences all biofuels. At the same time, advanced biofuels still face multiple technical and economic barriers. Significant improvements are thus required to achieve technical maturity and commercial availability of various conversion technologies for lignocellulosic biofuels production. In general, for advanced biofuel production, the necessary technical maturity and efficiency can only be achieved through experiences with industrial scale-up and "first-of-a-kind" plants.

The share of renewable fuels in transport was 7,1% in 2016 (Eurostat, 2018) and constitutes about 13% of all bioenergy. There is a need to increase this share by using replacement fuels from lignocellulosic energy crops, residues, and power to gas/liquid that do not result in competition with food or used agricultural land. In the absence of long-term supporting policies, innovative financing instruments and in times of relatively low oil-prices, largescale production of cost-competitive biofuels will be very challenging. There are various options for the substitution of fossil-derived diesel for road transport. Some can be classified as drop-in fuel made from sustainable biomass, which do not require any engine modification. Others require engine and infrastructure modifications but these applications will on the other hand be of 100% renewable origin and therefore permits immediate introduction. Some advanced biofuels and renewable fuels could be used in non-combustion devices like fuel cells.

Waste & residue-based biomethane could add substantial advanced biofuel volumes to the market to replace fossil Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG).

For aviation and maritime, liquid renewable drop-in fuels are seen as the only viable option for the mid-term to long-term (30-40 years). Currently, there is hardly any production of aviation and maritime biofuels in the EU.

3.2 Other renewable Fuels of non-biological origin

There are other promising technologies under development to produce both liquid and gaseous renewable fuels. Renewable electricity can be used to produce renewable hydrogen (H2) which can be used both for transport and non-transport purposes.

Several pathways to use renewable hydrogen as a fuel in transport are also feasible, for example via the use of pure hydrogen in zero emissions fuel cell electric vehicles (FCEVs). It could be converted to synthetic methane or methanol for use in compressed natural gas (CNG) vehicles or as a blending component. Renewable and cost-efficient hydrogen could also be used as substitute of fossil hydrogen used in refineries in the production process of diesel and gasoline, hence reducing the GHG emissions of the transport sector in the short term. Furthermore renewable hydrogen can be used to substantially increase carbon utilisation in biomass gasification, with high energy efficiency.

[8] Directive 2009/28/EC

3.3 Bioenergy for power and heating/cooling generation

With the increase of electricity production by solar and wind, the flexibility of power generation by biomass power plants has developed into a strategic asset for increasing further renewable electricity production for maintaining grid stability, and allowing higher shares of variable renewables (wind, solar). Bioenergy is more efficiently used in Combined Heat and Power (CHP), compared to condensing power. It will make production more economical and save the needed bioenergy sources. Bioelectricity generated from biogas has exhibited the largest growth rate, reaching more than 36% of bioelectricity production. Bioelectricity production across EU has increased significantly, and the current share (18,9%) of bioelectricity is already close to the 2020 expected, EU-wide share (19,3%)[8]. As an economically viable means to increase further grid penetration of solar and wind, power generation from biomass is expected to continue to increase significantly, both on a small and large scale.

Further improvement for efficiency and emissions reductions in bioenergy cogeneration for heat and power may be possible if novel technologies are explored, like high-temperature stationary fuel cells.

The bioenergy contribution for heating and cooling has currently the largest share (88%) of all renewable energy sources used for heat and cooling with 76 Mtoe, quite close to the 2020 Member States plan of 90 Mtoe. Towards 2030 a moderate increase can be anticipated due to increased CHP deployment, together with the integration requirements of renewable electricity satisfied by bioenergy produced electricity and further energy efficiency improvements of Europe's building stock. In countries with high share of district heating bioenergy is already replacing fossil fuels in CHP and heat-only-boilers.

3.4 Intermediate Bioenergy Carriers

Intermediate bioenergy carriers are formed when biomass is processed to energetically denser, storable and transportable intermediary products analogous to coal, oil and gaseous fossil energy carriers that could be further refined to final bioenergy products or directly used for heat and power generation. The former European Industrial Bioenergy Initiative[9], nowadays part of the ETIP on Bioenergy, provides examples of intermediate bioenergy carriers such as torrefied biomass, and pyrolysis oils, microbial oils, algae oils, etc.

A main issue regarding the viability of bioenergy plants lies in the development of reliable, integrated biomass supply chains from cultivation, harvesting, transport, storage to conversion and by-product use across Europe. Secure, long-term supply of sustainable feedstock – often by local supply chains -is essential to the economics of bioenergy plants. Consequently it is necessary to foster development of regional biomass supply and value chains, as well as to assist in overcoming the barriers of feedstock and economics of bioenergy production vis-à-vis higher capacity plants. This can be done by increasing efficiency in the biomass conversion to intermediate bioenergy carriers analogous to coal, oil and gaseous fossil energy carriers and thus creating the sustainable bio-crude energy feedstock basis that could be further refined to final bioenergy products or directly used. The conversion solutions can be based either on local feedstocks or in large scale and long transportation distances on low-cost bioenergy carriers.

The further processing of intermediate bioenergy carriers to advanced biofuels for transport purposes and the development of heat and power from biomass have additional particular

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[9] https://setis.ec.europa.eu/system/files/Bioenergy%20EII%202013-2017%20IP.pdf

challenges, related to performance concerning necessary technological development for improving the conversion efficiency and reduce the production cost of the end product, which are addressed in the other parts of this document. Increasing the efficiency of intermediate bioenergy carriers' production paves the way for reducing costs of the final bioenergy products and allows for new industrial and market opportunities. Creating such a commodity market of intermediate bioenergy carriers will increase local availability while confining feedstock costs and reducing the GHG emissions. Cheaper and standardized intermediate bioenergy tradable commodities will allow for energy decentralized production with positive results to both rural development and cost reduction of final bioenergy products (biofuels, bio heat and bio power).

4. The Temporary Working Group

In line with the common principles guiding the preparation of the Implementation Plans within the Integrated SET Plan, a Temporary Working Group (TWG) on Renewable Fuels and Bioenergy was set up. It is composed of members forming a balanced group of SET Plan countries, Stakeholders and EC, see Annex V.

SET Plan countries are committed to use their energy R&I national programmes and policies to implement some of the R&I activities that will be selected; and are preferably interested in developing and pursuing joint research with other countries. Country representatives in the TWG of Action 8 are government representatives, or nominated by their governments.

Stakeholders are experts from activities of ETIP, EERA, JU and industries not organized in the ETIP.

The EC facilitates and supports the TWG as needed in agreement with the Chair and Co-Chairs.

Chair and Co-chairs were nominated and confirmed by the SET Plan Steering Group:

Chair: Timo Ritonummi [Deputy Director General, Ministry of Economic Affairs and Employment, Finland]

Co-Chair: Franco Cotana [University of Perugia, CRB-CIRIAF, Engineering Department, Italy]

Co-Chair: René Venendaal, [CEO BTG Biomass Technology Group b.v.] and Björn Fredriksson Möller [Senior Specialist, EON Sweden] on behalf of ETIP Bioenergy

Supported by EC:

L. Marelli (**Coordinating officer**), Directorate-General Joint Research Centre, Directorate D, Resource Efficiency, I - Ispra; H. Ossenbrink (Support and scientific consultancy), Active Senior, Directorate General Joint Research Centre, IT-Ispra

M. Georgiadou and T. Schleker, Directorate-General for Research & Innovation, Directorate G – Energy, BE-Brussels

K. Maniatis, Directorate-General for Energy, Directorate C – Renewables, Research and Innovation, Energy Efficiency, BE-Brussels

The TWG had 5 plenary meetings in Brussels in the period November 2017 – May 2018 to arrive at the final consensus on the Implementation Plan.

5. Strategic Targets

The Implementation Plan should address the following targets included in the Declaration of Intent. Successful execution will depend on boundary conditions being in particular the policy framework in relation to the recast of the RED, its enactment by the Member States; the design of dedicated and innovative financial instruments and industry's commitment to the specific activities proposed and the market. The targets are later addressed more in section 8 and Annex I.

Renewable Fuels for Sustainable Transport

1. Improve production performance

1.1. *Advanced Biofuels*

By 2030, improve net process efficiency of conversion to end biofuels products of up to 30% compared to present levels, with simultaneously reducing the conversion process costs

By 2020, obtain total production of 25 TWh (2,15 Mtoe) advanced biofuels[10]

1.2. *Other renewable liquid and gaseous fuels*

By 2030, improve net process efficiency of various production pathways of advanced renewable liquid and gaseous fuels[11] of at least 30% compared to present levels

By 2030, for renewable hydrogen production by electrolysis improve net process efficiency to reach 70%. [12]

2. Improve GHG savings

Total GHG savings through use of advanced biofuels and renewable fuels will be at least that required in Directive (EU) 2015/1513 where Article 7b (amended) states that greenhouse gas emissions saving from the use of advanced renewable fuels shall be at least 60%. The greenhouse gas emission saving from the use of biofuels shall be calculated in accordance with Article 7d(1) of the same Directive and should be at least 60% of the 40% target in 2030.

3. Reduce Costs *(excluding taxes and feedstock cost)*

In conclusion, the target price in 2020 and 2030 for advanced biofuels and renewable fuels should be within a reasonable margin from parity with the fossil based fuels. Nevertheless, when policy incentives for CO2 reduction are taken into account, they should aim to be in parity with fossil fuel prices in 2030. Besides the need to address other boundary conditions outside this Implementation Plan, this will require in particular improvements in process efficiency and energy balance through the application of innovative practices[13].

3.1. Reduce cost for end biofuel products

Liquid or gaseous advanced biofuels by thermochemical or biochemical processing: <50 €/MWh in 2020 and <35 €/MWh in 2030 e.g. at least by 30% from 2020 levels

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10 this corresponds to the non-binding target of 0,6% of the approximately 4100 TWh (350 Mtoe in 2014) total transport fuel consumption and to 3 GW installed production capacity.

11 for example using renewable electricity to produce gaseous or liquid fuels, including the capture and reuse of CO2, as well as synthetic fuels made by other innovative processes

12 50-47kWh/kg H2 LHV

13 To determine the price margin, input from stakeholders and Member States will be needed for developing the Implementation Plan.

Algae based advanced biofuels <70 €/MWh in 2020 and <35 €/MWh in 2030 e.g. at least by 50% from 2020 levels

3.2. Reduce cost for renewable liquid and gaseous fuels

Other renewable liquid and gaseous fuels excluding renewable hydrogen: at least by 50% from 2020 levels (<50 €/MWh)

Renewable hydrogen: <7 €/kg by 2020 <4 €/ kg by 2030 (electrolysis, reforming, ...).

Bioenergy

1. Reduce conversion system costs for high efficiency (>70% based on net calorific value of which >30% electrical) large scale biomass cogeneration of heat and power by 20% in 2020 and 50% in 2030

2. Improve performance and reduce GHG emissions by increasing efficiency: Obtain net efficiency[14] of biomass conversion to intermediate bioenergy carriers of at least 75% by 2030 with GHG emissions reduction of 60% from use of all types of intermediate bioenergy carrier products[15] resulting to a contribution to at least 4% reduction of the EU GHG emissions from the 1990 levels.

Intermediate Bioenergy Carriers[16]

Improve performance and reduce cost (excluding taxes and feedstock cost)[17] for intermediate bioenergy carriers (before further processing to final bioenergy products)

A. Liquid and gaseous intermediate bioenergy carriers by thermochemical or biochemical processing: <20 €/MWh in 2020 and <10 €/MWh in 2030 for e.g. pyrolysis oil; <40 €/MWh in 2020 and <30 €/MWh in 2030 for higher quality, e.g. microbial oils

B. Solid intermediate bioenergy carriers by thermochemical or biochemical processing (e.g., bio-char, torrefied biomass, lignin pellets): <10 €/MWh in 2020 and <5 €/MWh in 2030 compared to present levels.

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14 Net efficiency is the percentage of useful energy output compared with the net sum of energy inputs where the energy content is based on LHV (Lower Heating Value)

15 For bioenergy products, other than biofuels and bioliquids for which GHG savings are not yet defined in directive 2009/28/EC, the Commission has indicated the targets set for biofuels and bioliquids should be used. Otherwise the reference will be the displaced fossil fuel use

16 In the context of this document intermediate bioenergy carriers are formed when biomass is processed to energetically denser intermediary products analogous to coal, oil and gaseous fossil energy carriers that could be further refined to final bioenergy products or directly used for heat and power generation. The former European Industrial Bioenergy Initiative (https://setis.ec.europa.eu/system/files/Bioenergy%20EII%202013-2017%20IP.pdf), nowadays part of the ETIP on Bioenergy, provides examples of intermediate bioenergy carriers such as torrefied biomass and pyrolysis oils, microbial oils, algae oils, etc,

17 The purpose of this target is to give a rating for different technologies concerning their cost competitiveness. Hence this includes production plus profit margin and relevant costs to point of sale to a customer where applicable, and excludes product related taxes applied (e.g. VAT) and feedstock cost

6. Innovation Agenda

Bioenergy and renewable fuels address two of the ten EU priorities together. The first one is the Resilient Energy Union with a Forward-Looking Climate Change Policy, which is aiming to diversify Europe's sources of energy and to support breakthroughs in low-carbon technologies with coordinated research. Replacing fossil feedstock with biological and non-biological renewable resources is an indispensable component of a forward-looking climate change policy.

The second one is the New Boost for Jobs, Growth and Investment, where innovation in bioeconomy is an important source of new jobs – especially at local and regional level, and in rural and coastal areas – with big opportunities for the growth of new markets, for example in bio-fuels, food and bio-based products as well as renewable energy technologies and derived fuels.

Hence, the R&I chain encompasses the full development chain, from research into new processes and resources to first commercial plants until technology is fully mature. This is reflected in the Technology Readiness level definitions of Horizon 2020 and the EU funding instruments.

The challenge is the integration of the energy sector, transport sector, (petro) chemical industry, agro-and forestry sectors. Further information to the innovation potential of this SET Plan Action can be found in Annex I, which describes the wide variety of the technology pathways, their cost potential (the cost and availability of feedstock is not addressed in this document) and the current technology readiness level (TRL).

The relation between EU-policies, energy prices and innovation are given in Figure 2. The figure is based on scenario thinking and modelling. The **ideal scenario** for advanced biofuels is a combination of high energy prices and stimulating policies (mandates, high CO2-prices, high taxes for fossil fuels, etc.). The **worst-case scenario** is a combination of low energy prices and reluctant policies on advanced biofuels (as experienced by the advanced biofuels industry during last years). In such a scenario even stronger innovation policies are needed.

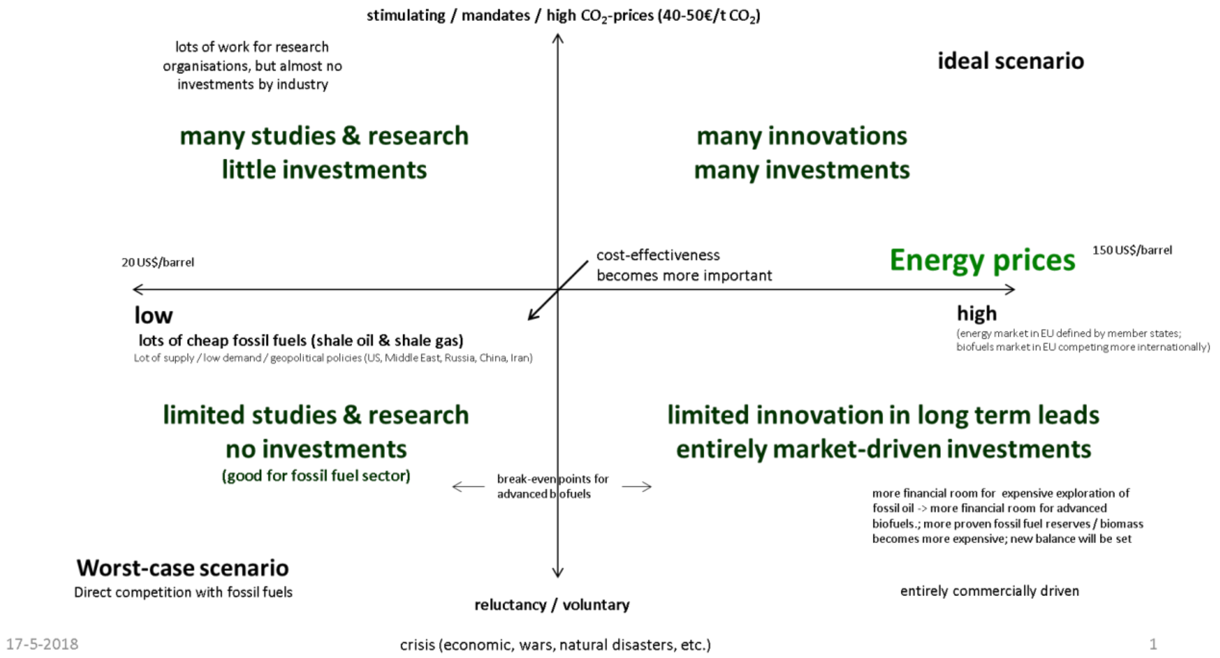

Figure 2: Scenarios based on framework conditions for renewable fuels and bioenergy.

7. Identified enablers / barriers

Priority actions are needed to boost the development and deployment of bioenergy, advanced biofuels and renewable fuels and to help reaching the targets set in the Declaration of Intent. These have been extensively discussed within the TWG and stakeholders have been invited to submit their suggestions for enablers and barriers to successful implementation of the targets. The detailed outcomes of the discussions are summarised in bullet points below. Many of identified enablers or barriers are dealt in different forum, many for instance in the revision of the Renewable Energy Directive RED II. They are not to be solved here or in the afterwork of the IP, but are just listed as issues to be tackled.

1. Identified **enablers**:
   - The creation of a long term stable policy framework. A stable policy framework is recognized as a system where future targets are known and changes in the view of current technologies are rare.
   - A well-established and agreed sustainability criteria for feedstock from agriculture, forestry as well as biological and municipal waste.
   - Support emerging technologies at low TRL to increase efficiency as well as supporting continued R&I efforts in high TRL technologies to comply with reduced cost projections, GHG emissions goals and deployment.
   - Support of sustainable feedstock mobilisation. The development and use of currently unexploited sustainable waste, biomass and land resources to supply the advanced technologies, with particular emphasis on the application of principles of circular economy.
   - Recognition of the renewable fuel /bioenergy role in transport through holistic approach to feedstocks. It means that the GHG properties of a fuel is recognized throughout the value chain and properly accounted for, i.e. in fuel production, distribution and use in vehicles.
   - Support increased integration of renewable fuels/bioenergy in different energy systems, exemplified by power-to-gas and power-to-liquid pathways or use of intermediate bioenergy carriers or renewable hydrogen in existing infrastructure.

2. Identified **barriers:**

   - Restrictions in current policy framework that introduce or maintain unnecessary obstacles to the development of biofuels/bioenergy/renewable hydrogen such as tailpipe emission or grid fees for power-to-fuel applications.
   - A heavily restricted feedstock portfolio today will limit the development of technologies while >60% GHG threshold limits will significantly reduce the availability of sustainable feedstock.
   - Lack of dedicated actions and policies to meet the demand for appropriate infrastructure and dedicated vehicles.
   - A stricter view on sustainability criteria applied to renewable fuel/bioenergy than other uses of biomass could slow down development. The application of the sustainability criteria only for energy uses of biomass instead of all uses of biomass can be considered a barrier.

International cooperation (e.g. Mission Innovation, IEA as well as several European schemes within ERA-NET) is also considered crucial from a cooperation and development point of view but the working group agreed that it cannot alone facilitate to reach the targets.

8. Summary and Next Steps

The Temporary Working Group on Action 8: Bioenergy and Renewable Fuels for Sustainable Transport, composed by representatives of interested SET Plan countries and relevant stakeholders, representing industry and academia, has identified the priority research and innovation activities (of both technological and non-technological nature) included in the present Implementation Plan. The work has progressed in the course of 2017/18.

The strategic targets presented in section 5 are originally set in Declaration on Intent (DoI) from 2016. Some targets have been found by the TWG to be challenging at least in the timeframe under consideration. Taking into consideration technology development over time, targets should be reviewed during the course of the implementation phase.

The priority R&I activities are considered to be essential for achieving the corresponding SET Plan targets contained in the Declaration of Intent on Bioenergy and Renewable Fuels (of 16 November 2016) within the context of the EU Climate and Energy Package, the Energy Union and the Paris climate agreement. Across the proposed activities, the overall volume of investment to be mobilised is summarized in section 9 in Table1.

The activities proposed have reached different levels of maturity in terms of reliability, partnership and financing. There is therefore a significant need for further development of the actions. Also, further investments, funding sources and financial instruments will be needed to fully achieve the DoI targets, especially in connection to demonstration, first-of-a-kind plants and market deployment of technologies including socio-economic aspects.

With the preparation and submission of this IP and after its endorsement by the SET Plan Steering Group, the mission of the TWG is completed. A new structure based largely on stakeholders of TWG is needed for the follow up of the effective execution of the IP and it is expected to be put in place.

The EC intends to facilitate through a Coordination and Support Action (CSA) the coordination activities needed for the execution of the IPs[18]. The proposed consortium should count with the participation of research organisations and/or companies (industry) committed in principle to execute all or some of the R&I activities specified in the corresponding IP as endorsed by the SET Plan Steering Group.

Taking note and learning from the variety of flagship definition in different sector Implementation Plans, already endorsed, in this plan the value chains are regarded as flagships to address the complexity of this sector. Therefore each value chain may include activities for different Technology Readiness levels.

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18 See topic "LC-SC3-JA-2-2019: Support to the realization of the Implementation Plans of the SET Plan" of the Horizon 2020 Work Programme 2018-2020 - Secure, clean and efficient energy.

9. R&I Priorities

9.1 Criteria for Priorities

The R&I activities should assist achieving the targets for renewable fuels, bioenergy and intermediate bioenergy carriers as set out in the DoI. Criteria for their selection include:

1. Should support the development, demonstration and scale-up encompassing the entire TRL range
2. Should support efficiencies improvements and cost reductions versus the DoI targets
3. Should boost installing commercial capacity of renewable fuels for transport
4. Should comply with the timeline from now towards 2020 and 2030

9.2 SET Plan Priorities and Targets

R&I Activities

The R&I activities presented below and in more detailed in annex I are based on the R&I activities of the DoI. There are altogether 13 activities.

Renewable Fuels for Sustainable Transport

Advanced biofuels

#1 Develop advanced liquid and gaseous biofuels through biochemical / thermochemical/ chemical conversion from sustainable biomass and/or from autotrophic microorganisms and primary renewable energy

#2 Demonstrate advanced liquid and gaseous biofuels through biochemical / thermochemical/ chemical conversion from sustainable biomass and/or from autotrophic microorganisms and primary renewable energy

#3: Scale-up advanced liquid and gaseous biofuels through biochemical / thermochemical/ chemical conversion from sustainable biomass and/or from autotrophic microorganisms and primary renewable energy

Other renewable liquid and gaseous fuels

#4 Develop other renewable liquid and gaseous fuels (excluding hydrogen) through thermochemical/ chemical/ biochemical /electrochemical transformation of energy neutral carriers with renewable energy

#5 Demonstrate other renewable liquid and gaseous fuels (excluding hydrogen) through thermochemical/ chemical/ biochemical/electrochemical transformation of energy neutral carriers with renewable energy

#6 Scale-up other renewable liquid and gaseous fuels (excluding hydrogen) through thermochemical/ chemical/ biochemical/electrochemical transformation of energy neutral carriers with renewable energy

Renewable Hydrogen

#7 Develop and Demonstrate the production of renewable hydrogen from water electrolysis and renewable electricity

Bioenergy

#8. Develop high efficiency large scale biomass cogeneration of heat and power

#9 Demonstrate high efficiency large scale biomass cogeneration of heat and power

#10 Scale-up high efficiency large scale biomass cogeneration of heat and power

Intermediate Bioenergy Carriers

#11 Develop solid, liquid and gaseous intermediate bioenergy carriers through biochemical / thermochemical/ chemical conversion from sustainable biomass

#12 Demonstrate solid, liquid and gaseous intermediate bioenergy carriers through biochemical / thermochemical/ chemical conversion from sustainable biomass

#13 Scale-up solid, liquid and gaseous intermediate bioenergy carriers through biochemical / thermochemical/ chemical conversion from sustainable biomass

The detailed programme of the R&I activities is provided in Annex I.

9.3 Total Investment for R&I activities

Table 1 summarizes the indicative budget needs for investments by 2030. The numbers represent cumulative public –both EU and national- and private investments needed for achieving the SET Plan priorities and targets for the R&I activities laid out in section 9.2 and detailed in Annex I. These 13 activities are numbered and shown also here in the table.

This estimation of the needed investments over the years until 2030 and trough different levels of TRL from low to high can be roughly split to 73% private, 21% national and 6% EU funding: 78 billion euros private, 22 billion national and about 7 billion EU funding. As in annex I can be seen, in different activities there are different assumption for this division along development, demonstration and scale-up activities.

Table 1: Total investment for R&I activities

	Billions €	Industry		MS Funding		EU	
Total Bioenergy and Renewable Fuels for Sustainable Transport	**106,61**	**77,74**	***73%***	**22,23**	***21%***	**6,64**	**6%**
Renewable Fuels for Sustainable Transport	**84,81**	**62,34**	***74%***	**17,48**	***21%***	**4,99**	**6%**
Advanced Biofuels	**73,00**	**53,75**	***74%***	**15,00**	***21%***	**4,25**	**6%**
#1 Development	1,00	0,25	*25%*	0,50	*50%*	0,25	25%
#2 Demonstration	2,00	1,00	*50%*	0,50	*25%*	0,50	25%
#3 Scale-Up	70,00	52,50	*75%*	14,00	*20%*	3,50	5%
Other renewable liquid and gaseous fuels	**11,40**	**8,35**	***73%***	**2,36**	***21%***	**0,69**	**6%**
#4 Development	0,20	0,05	*25%*	0,10	*50%*	0,05	25%
#5 Demonstration	0,40	0,20	*50%*	0,10	*25%*	0,10	25%
#6 Scale-Up	10,80	8,10	*75%*	2,16	*20%*	0,54	5%
#7 Renewable Hydrogen	**0,41**	**0,24**	***59%***	**0,12**	***28%***	**0,05**	**13%**
TRL 2-6 (Development)	0,10	0,03	*25%*	0,05	*50%*	0,03	25%
TRL 7-8 (Demonstration)	0,06	0,03	*50%*	0,02	*25%*	0,02	25%
TRL 9 (Scale-Up)	0,25	0,19	*75%*	0,05	*20%*	0,01	5%
Bioenergy	**11,30**	**8,03**	***71%***	**2,45**	***22%***	**0,83**	**7%**
#8 Development	0,50	0,13	*25%*	0,25	*50%*	0,13	25%
#9 Demonstration	0,80	0,40	*50%*	0,20	*25%*	0,20	25%
#10 Scale-Up	10,00	7,50	*75%*	2,00	*20%*	0,50	5%
Intermediate Bioenergy Carriers	**10,50**	**7,38**	***70%***	**2,30**	***22%***	**0,83**	**8%**
#11 Development	0,50	0,13	*25%*	0,25	*50%*	0,13	25%
#12 Demonstration	1,00	0,50	*50%*	0,25	*25%*	0,25	25%
#13 Scale-Up	9,00	6,75	*75%*	1,80	*20%*	0,45	5%

EU investments in grants for projects under the Horizon 2020 WP "Secure Clean and Efficient Energy" in the area bioenergy/renewable fuels until the end of 2017 reached 245 million € with 205 million € contributed by the EU. 45 projects are running with 10 participants and 5,5 million € budget on average, 21 of which support research development, 5 demonstration and 19 market up-take actions. Figure 3 shows the participant EU contribution by Country and the signed Grants by type of action.

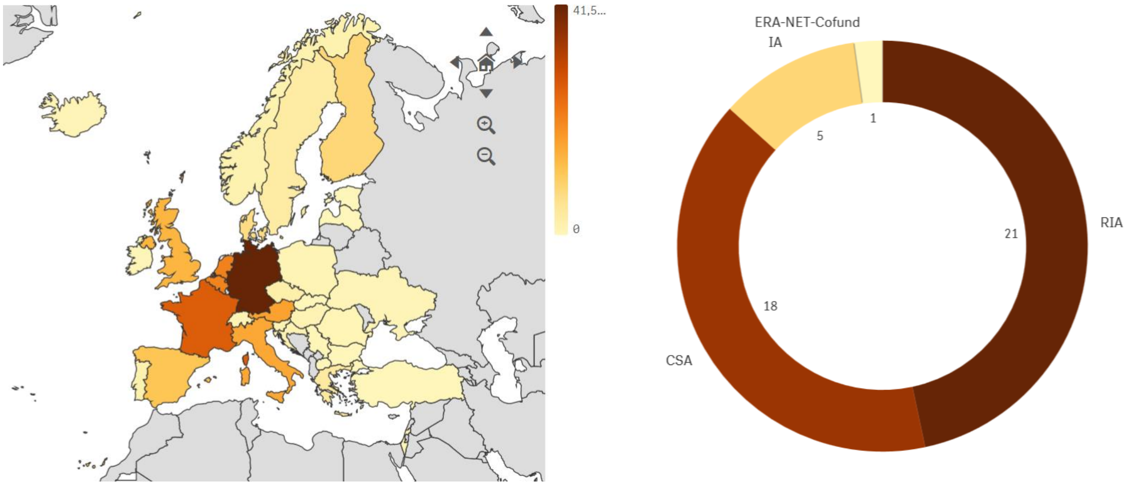

Figure 3: *Selection of H2020 EU funded relevant projects in Cordis/Dashboard, excluding projects signed in 2018 (RIA is Research and Innovation Action typically TRL<=5, IA is Innovation Action typically 5<TRL<=8, CSA is Coordination and Support Action).*

Under Work Programme 2016-2017 Other Actions / 28. InnovFin Energy Demonstration Projects (EDP) Pilot Facility, the flagship project CHO Tiper on large scale biomass cogeneration received a 30 million euro loan from the European Investment Bank with the support of Horizon 2020 for renewable energy.

Four still ongoing industrial scale demonstration projects from the 7th Framework Programme support the first steps in commercialization of cellulosic ethanol and biojet production with an EU contribution of 80 million €. Also five demonstration projects on hydrogen for fuel cell buses are funded under the Fuel Cell Hydrogen Joint Undertaken with 72 million € EU contribution.

ANNEX I R&I Priorities

R&I Activity #1	
Title: Develop advanced liquid and gaseous biofuels through biochemical / thermochemical/ chemical conversion from sustainable biomass and/or from autotrophic microorganisms and primary renewable energy	
Targets: • By 2030, improve net process efficiency of conversion to end biofuels products of at least 30% compared to present levels, with simultaneously reducing the conversion process costs • Reduce costs of liquid or gaseous advanced biofuels by thermochemical or biochemical processing: <50 €/MWh in 2020 and <35 €/MWh in 2030 e.g. at least by 30% from 2020 levels (excluding taxes and feedstock cost) • Reduce costs of algae based advanced biofuels <70 €/MWh in 2020 and <35 €/MWh in 2030 e.g. at least by 50% from 2020 levels (excluding taxes and feedstock cost) • GHG saving from the use of advanced renewable fuels shall be at least 60%. (including biomass feedstock contribution)	**Monitoring mechanism**: *an explanation of how each target will be monitored and reported to SETIS* *R&D spending in the area - number and cost of EU & national projects* *Patents in the area* *Spin-off companies* *Technology progress in the area, TRL evolution* *New R&I concepts implemented in demonstrations* *Evolution of conversion cost of advanced liquid and gaseous biofuels* *List of GHG savings level per each new technology with GHG > 60%*
Description • Development of novel concepts for the thermochemical/chemical conversion of sustainable biomass, biomass by-products or biogenic wastes to advanced biofuels. The innovation may lie in one or more of the sub-processes, e.g. feedstock pre-treatment, primary conversion, upgrading to or formation of ready-for-use product and where both stand-alone and co-processing is considered • Development of novel concepts for the biological / biochemical conversion of sustainable biomass, biomass by-products or biogenic wastes pathways to biofuels. The innovation may lie in one or more of the sub-processes, e.g. feedstock pre-treatment, primary conversion, upgrading to or formation of ready-for-use product and where both stand-alone and co-processing is considered. • Development of next generation technologies for biofuels, i.e., from non-lignocellulosic biomass such as aquatic biomass or from autotrophic processes. • Improve established advanced biofuel concepts by addressing specific sub-processes with high impact on overall process cost, and performance as well as GHG reduction (e.g. biomass fractionation, gasification gas cleaning or synthesis, intermediate bio-liquid upgrading etc.). • Broaden the biofuel typology by developing concepts for the conversion of primary products or intermediates (e.g. alcohols, sugars) to hydrocarbons and derivatives, e.g., optimal fuel oxygenates using chemical (Including electrochemical) or biotechnological methods. • Development of concepts for retrofitting 1 G biofuel plants to advanced biofuel plants or for integrating advanced biofuel production with other industries • Identification and evaluation of value-added renewable blend components in fossil fuels for maximizing the share of renewable in the blends. • Development of processes and strategies for integration of advanced biofuels production into conventional refinery production flows • Development of reliable tools for scaling-up advanced biofuels technologies simulation and performing scaling-up simulation studies (including logistics of raw materials supply) and techno-economic and sustainability assessment of commercial plants of advanced biofuels in order to determine the viability of technologies for further demonstration and market deployment	
TRL: Advanced research TRL2-3 to TRL5	
Total budget required 1 billion	
Expected deliverables	**Timeline**
Fill in one line per deliverable ... • One or more targets for cost reduction, efficiency gain for different pathways • At least 8 new R&I concepts going to demonstration	**Up to 2030**

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties MS/Industry/EU	FP RIA, European Partnership Initiatives, MS R&I programs, non-public co-funding	**MS:50%** **EU: 25%** **Industry: 25%**

R&I Activity #2	
Title: Demonstrate advanced liquid and gaseous biofuels through biochemical / thermochemical/ chemical conversion from sustainable biomass and/or from autotrophic microorganisms and primary renewable energy	
Targets: • By 2030, improve net process efficiency of conversion to end biofuels products of at least 30% compared to present levels, with simultaneously reducing the conversion process costs • Reduce costs of liquid or gaseous advanced biofuels by thermochemical or biochemical processing: <50 €/MWh in 2020 and <35 €/MWh in 2030 e.g. at least by 30% from 2020 levels (excluding taxes and feedstock cost) • Reduce costs of algae based advanced biofuels <70 €/MWh in 2020 and <35 €/MWh in 2030 e.g. at least by 50% from 2020 levels(excluding taxes and feedstock cost) • GHG saving from the use of advanced renewable fuels shall be at least 60% (including biomass feedstock contribution)	**Monitoring mechanism**: *an explanation of how each target will be monitored and reported to SETIS* Systematic follow-up of technology development, cost and performance for efficiency & GHG savings for benchmarking purposes Plant-capacity-product-status inventories Monitoring of RED II / GHG, and reporting
Description: • Demonstration of biochemical/thermochemical/chemical conversion of sustainable biomass, biomass by-products or biogenic wastes, to advanced biofuels, either directly to ready-for-use or by conversion of an intermediate to the advanced biofuel product. • Demonstration of biochemical/thermochemical/chemical conversion of aquatic biomass or autotrophic microorganisms and primary renewable energy to advanced biofuels, either directly to ready-for-use or by conversion of an intermediate to the advanced biofuel product. • Demonstration of conversion of primary products or intermediates (e.g. alcohols, sugars) to hydrocarbons and derivatives, e.g. optimal fuel oxygenates using chemical (including electrochemical) or biotechnological methods • Demonstration of enhancements in established advanced biofuel concepts due to significant sub-process improvements (cost, efficiency, GHG reduction).. • Demonstration of the renewable part of hybrid advanced biofuel concepts enhanced by primary RE energy as co-feed. • Demonstration of retrofitting of 1G biofuel plants to advanced biofuels or advanced biofuels integrated with other industries. • Elaboration of processes and strategies for integration of advanced biofuels production into conventional refinery production flows.	
TRL: Industrial research & demonstration TRL6-7 to TRL8	
Total budget required 2 billion	
Expected deliverables	**Timeline**
Fill in one line per deliverable ... • Technology handbook with cost and performance for efficiency & GHG savings data and learning curve parameters • Techno-economic assessment of scaling-up the technology to First –of-a kind demonstration • Integration concepts and retrofitting strategies with existing industries • 3 value chains demonstrated in 2022 • 6 value chains demonstrated in 2030	**3 value chains for 2022 and 6 value chains for 2030**

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties MS/Industry/EU	MS grants and other funding, equity, commercial loans, Risk Finance, IF, EFSI, ESIF, FP IA & Innovfin, European Partenship Initiatives, other	**MS:25%** **EU:25%** **Industry:50%**

R&I Activity #3

Title: Scale-up advanced liquid and gaseous biofuels through biochemical / thermochemical/ chemical conversion from sustainable biomass and/or from autotrophic microorganisms and primary renewable energy

<table>
<tr><td colspan="2">Targets:
By 2030, improve net process efficiency of conversion to end biofuels products of at least 30% compared to present levels, with simultaneously reducing the conversion process costs
By 2020, obtain total production of 25 TWh (2,15 Mtoe) advanced biofuels
Reduce costs of liquid or gaseous advanced biofuels by thermochemical or biochemical processing: <50 €/MWh in 2020 and <35 €/MWh in 2030 e.g. at least by 30% from 2020 levels (excluding taxes and feedstock cost)
Reduce costs of algae based advanced biofuels <70 €/MWh in 2020 and <35 €/MWh in 2030 e.g. at least by 50% from 2020 levels (excluding taxes and feedstock cost)
GHG saving from the use of advanced renewable fuels shall be at least 60%.(including biomass feedstock contribution)</td><td colspan="2">Monitoring mechanism: an explanation of how each target will be monitored and reported to SETIS
Systematic follow-up of technology development, cost and performance for efficiency & GHG savings for benchmarking purposes
Plant-capacity-product-status inventories
Monitoring of RED II / GHG and reporting</td></tr>
<tr><td colspan="4">Description:
Deployment of established and novel advanced biofuel value chains as applicable.
Lessons learned reporting including progress achieved towards objectives and remaining breakthroughs for market full deployment</td></tr>
<tr><td colspan="4">TRL: Scale-up, deployment & market uptake. TRL7-8 to TRL9</td></tr>
<tr><td colspan="4">Total budget required 50 plants of on an average 0,5 TWh each for 2022 (14 plants in operation, 16 in construction and 20 committed) and 200-250 respective plants in 2030 leading to an estimate of 10 bn € investment for 2022 and up to 60 bn € in 2030 (economies of scale, technology improvements are expected to significantly lower the investment for 2030 if sufficient investment is done in R&D&D meanwhile)</td></tr>
<tr><td colspan="2">Expected deliverables</td><td colspan="2">Timeline</td></tr>
<tr><td colspan="2">Fill in one line per deliverable ...
Technology handbook with cost and performance for efficiency & GHG savings data and learning curve parameters.
Feasibility analysis of each first-of-a-kind plant
50 plants producing and committed to produce 25 TWh in 2022
200-250 plants producing 200 TWh net (without accounting efficiency improvement and renewable electricity contributions in transport or energy or energy by-products) of advanced biofuels in 2030
7 billion €/year economic activity in 2030 at 35 €/MWh produced)</td><td colspan="2">50 plants 2022 and 200-250 plants for 2030</td></tr>
<tr><td>Party / Parties (countries / stakeholders / EU)</td><td colspan="2">Implementation instruments</td><td>Indicative financing contribution</td></tr>
<tr><td>Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties

Industry/MS/EU</td><td colspan="2">2022 :, Equity, commercial loans, MS funding (loans and risk guarantees), IF EFSI, ESIF, Innovfin, EIB,
2030: Equity, commercial loans. Public support including MS funding (loans and risk guarantees), IF, EFSI, ESIF, Innovfin, EIB, only for selected novel technologies or strategic reasons</td><td>MS:20%
EU: 5%
Industry:75% (including loans from public financing institutions)</td></tr>
</table>

R&I Activity #4
Title: Develop other renewable liquid and gaseous fuels (excluding hydrogen) through thermochemical/ chemical/ biochemical /electrochemical transformation of energy neutral carriers with renewable energy

Targets:	**Monitoring mechanism**: *an explanation of how each target will be monitored and reported to SETIS*
• By 2030, improve net process efficiency of various production pathways of advanced renewable liquid and gaseous fuels by at least 30% compared to present levels • Reduce costs of other renewable liquid and gaseous fuels excluding renewable hydrogen: at least by 50% from 2020 levels (<50 €/MWh) (excluding taxes and feedstock cost) • GHG saving from the use of advanced renewable fuels shall be at least 60%	*R&D spending in the area- number and cost of EU & national projects* *Patents in the area* *Spin-off companies* *Technology progress in the area, TRL evolution* *New R&I concepts implemented in demonstrations* *Evolution of conversion cost of other renewable liquid and gaseous biofuels* *List of GHG savings level per each new technology with GHG > 60%*

Description:

- Develop appropriate sub-processes covering the renewable part of the overall process, e.g., synthesis technologies for coupling renewable energy (renewable heat and electricity directly or via electrolysis/co-electrolysis using AEC, PEM-EC, MCEC, SOFC technologies) to the carrier, with particular focus on process intensification for increased efficiency,
- Develop affordable high-temperature, corrosion-resistant materials or new alloys resistant to extreme conditions (high temperature, oxidizing-reducing environments, fouling, etc.) for more resistant core components (catalysts, membranes, reactors) in the system process
- Develop synergies to renewable hydrogen and CO_2 streams
- Develop process optimization and concepts with dynamic response capability

TRL: Advanced research TRL2-3 to TRL5

Total budget required 0,2 billion

Expected deliverables	**Timeline**
Fill in one line per deliverable ... • One or more targets for cost reduction, efficiency gain for different pathways • 10 new R&I concepts going to demonstration	**Up to 2030**

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties MS/Industry/EU	FP RIA, European Partnership Initiatives, MS R&I programs, non-public co-funding	**MS:50%** **EU: 25%** **Industry: 25%**

R&I Activity #5

Title: Demonstrate other renewable liquid and gaseous fuels (excluding hydrogen) through thermochemical/ chemical/ biochemical/electrochemical transformation of energy neutral carriers with renewable energy

Targets:	**Monitoring mechanism**: *an explanation of how each target will be monitored and reported to SETIS*
• By 2030, improve net process efficiency of various production pathways of advanced renewable liquid and gaseous fuels10 by at least 30% compared to present levels • Reduce costs of other renewable liquid and gaseous fuels excluding renewable hydrogen: at least by 50% from 2020 levels (<50 €/MWh (excluding taxes and feedstock cost) • GHG saving from the use of advanced renewable fuels shall be at least 60%	Systematic follow-up of technology development, cost and performance for efficiency & GHG savings for benchmarking purposes Certificate or origins for RE power RED II monitoring and reporting

Description:

- Demonstration of the renewable part of the value chain, e.g., synthesis technologies for coupling renewable energy (renewable heat and electricity directly or via electrolysis/co-electrolysis using AEC, PEM-EC, MCEC, SOFC technologies to the carrier with particular focus on process intensification and improvement for increased overall efficiency
- Demonstrate the possibility for dynamic response and contribution towards renewable energy storage as renewable liquid and gaseous fuel (excluding hydrogen) within the core production process
- Lessons learned reporting including progress achieved towards objectives and remaining breakthroughs

TRL: Industrial research & demonstration TRL6-7 to TRL8

Total budget required 0,4 billion

Expected deliverables	**Timeline**
Fill in one line per deliverable ... • Technology handbook with cost and performance for efficiency & GHG savings data and learning curve parameters. • Techno-economic assessment of scaling-up the technology to First –of-a kind demonstration • 4 demonstrated concepts in 2022 • 10 demonstrated concepts in 2030	**4 concepts in 2022** and **10 concepts in 2030**

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties MS/Industry/EU	MS grants and other funding, equity, commercial loans, Risk Finance, IF, EFSI, ESIF, FP IA & Innovfin, European Partnership Initiatives, other	**MS:25%** **EU:25%** **Industry:50%**

R&I Activity #6	
Title: Scale-up other renewable liquid and gaseous fuels (excluding hydrogen) through thermochemical/ chemical/ biochemical/electrochemical transformation of energy neutral carriers with renewable energy	
Targets: • By 2030, improve net process efficiency of various production pathways of advanced renewable liquid and gaseous fuels10 of at least 30% compared to present levels • Reduce costs of other renewable liquid and gaseous fuels excluding renewable hydrogen: at least by 50% from 2020 levels (<50 €/MWh (excluding taxes and feedstock cost) • GHG saving from the use of advanced renewable fuels shall be at least 60%	**Monitoring mechanism**: an explanation of how each target will be monitored and reported to SETIS Systematic follow-up of technology development, cost and performance for efficiency & GHG savings for benchmarking purposes Plant-capacity-product-status inventories Certificate or origins for RE power RED II monitoring and reporting
Description: • Deployment of the demonstrated technologies including synergies to renewable hydrogen including from advanced electrolysers such as AEC, PEM-EC, MCEC, SOEC technologies) and CO2 streams as applicable • Lessons learned reporting including progress achieved towards objectives and remaining breakthroughts for market full deployment	
TRL: Scale-up, deployment & market uptake. TRL7-8 to TRL9	
Total budget required: Up to 1TWh for 20 plants of 0,8 billion in 2022 and 25 TWh for 450-500 plants of 10 billion in 2030 Investment expected to go down for 2030 if sufficient R&D&D investment is made triggering the required technology improvements and economies of scale	
Expected deliverables	**Timeline**
Fill in one line per deliverable ... • Technology handbook with cost and performance for efficiency & GHG savings data and learning curve parameters. • Feasibility analysis of each first-of-a-kind plant • Quantity of RE fuel produced/RE power consumed	**1 TWh for 2022 and 25 TWh for 2030**

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties Industry/MS/EU	2022: Equity, commercial loans, MS funding (loans and risk guarantees), IF, EFSI, ESIF, Innovfin, EIB, 2030: Equity, commercial loans. Public support including MS funding (loans and risk guarantees), IF, EFSI, ESIF, Innovfin, EIB, only for selected novel technologies or strategic reasons	**MS:20%** **EU: 5%** **Industry: 75%** (including loans from public financing institutions)

R&I Activity #7	
Title: Production of renewable hydrogen from water electrolysis and renewable electricity	
Targets: the targets that the R&I Activity will help to achieve • By 2020, reduce capex of alkaline electrolysers from 1,600 to 1,250 Euro/(kg/d), reduce renewable electricity consumption from 57 to 50 kWh/kg and improve dynamic performance for better integration with renewables. Respective figures for PEM electrolysers are 2,000 Euro/(kg/d), 55kWh/kg. The aim is for 7 Euro/kg cost of renewable hydrogen.(excluding taxes and including feedstock cost; electricity costs is estimated being 60% of the cost) • By 2030, reduce capex of alkaline electrolysers to 800 Euro/(kg/d), reduce renewable electricity consumption to 48 kWh/kg and reduce O&M costs to 16 Euro/(kg/d)/yr for renewable hydrogen production. Respective figures for PEM electrolysers are 1,000 Euro/(kg/d), 50 kWh/kg and 21 Euro/(kg/d)/yr. The aim is for 4Euro/kg cost of renewable hydrogen(excluding taxes and including feedstock cost; electricity costs is estimated being 60% of the cost)	**Monitoring mechanism**: an explanation of how each target will be monitored and reported to SETIS Annual reporting of projects and to funding authority, e.g FCH JU Use of FCH JU TRUST data base Patents in the area Demonstration projects of increasing scale and complexity Competent authority for tracking generation and cancelling of Garanties of Origin for renewable hydrogen Annual reporting of industry to monitoring authority, e.g FCH JU or Hydrogen Europe Reporting to funding instruments like CEF Transport or the EIB

Description: a summary of the R&I Activity including the goals and a justification of why the Activity is key

Activities should address the key challenges which are electrolyser systems able to respond to dynamic intermittent renewable power and lower capital cost to compensate for lower utilisation. The share of the development costs for electrolysers which correspond to this activity is limited to the renewable fraction of the EU electricity mix.

- Development of high pressure electrolysis with renewable hydrogen output pressure of at least 100 bar; rapid response of below 1 second for a hot start and below 10 seconds for a cold start; increased base load current density to at least 4 A/cm2 for PEM or 1 A/cm2 for Alkaline; increased peak-load current density for short periods of up to 1 hour to above 6 A/cm2 for PEM or above 1.5 A/cm2 for alkaline; electrolysis at water temperature of above 80°C.
- Demonstrate Megawatt-scale electrolysers of minimal footprint installation and operation in renewable hydrogen refuelling stations producing at least 50tons of H2 per annum using renewable electricity, increasing penetration of renewables with variable production and capturing at the same time revenues for the provision of grid services.
- Demonstrate business cases for the on-site renewable hydrogen production for refuelling fuel cell vehicles..
- Develop, establish and operate, a mechanism to guarantee the origin of renewable hydrogen.
- By 2020 showcase with projects the ability of renewable hydrogen to interact with the grid to further enable RES penetration
- By 2030, full commercialization of renewable electrolysis (i.e., with renewable electricity).

TRL: Advanced research /Industrial research & demonstration / Innovation & market uptake. Also mention TRL at start and envisaged at the end

Research & Innovation TRL2 to TRL9

Total budget required 102 M (TRL 2-6), 60 M (TRL7-8), 250 M (TRL 9) – Amounts correspond to renewable hydrogen production and for electrolysers to the cost of the renewable part in the electricity mix only

Expected deliverables	**Timeline**
Fill in one line per deliverable ... • Electrolysers of Improved efficiency, dynamic performance and reduced cost • Electrolysers installed in renewable hydrogen refuelling stations	2020-2030

• Megawatt-scale electrolysers for the on-site production of renewable hydrogen for fuel cell vehicles. • 1GW of electrolysers installed in 1000 renewable hydrogen refuelling stations	

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties Consortia in RIA/IA projects, local authorities / DG RTD, DG ENER, DG MOVE	FP RIA, IA, MS programs, European Partnership Initiatives,, CEF Transport, CEF Energy	**MS + EU: 78,8 M(TRL 2-6)** **MS + EU: 30 M (TRL 7-8)** **MS + EU: 61,5 M (TRL 9)**

R&I Activity #8	
Title: Develop high efficiency large scale biomass cogeneration of heat and power	
Targets: • Reduce conversion system costs for high efficiency (>70% based on net calorific value of which >30% electrical) large scale biomass cogeneration of heat and power by 20% in 2020 and 50% in 2030	**Monitoring mechanism**: *R&D spending in the area- number and cost of EU & national projects* *Patents in the area* *Spin-off companies* *Technology progress in the area, TRL evolution* *New R&I concepts implemented in demonstrations* *Evolution of conversion cost of high efficiency large scale biomass cogeneration* *List of GHG savings level per each new technology with GHG > 60%*
Description: • Develop and validate high-efficiency (> 40 % to power) biomass gasification-based co-generation cycles (fuel cells in combination, gas turbines cycles and combined cycles etc., alone or in combination with bottoming cycles) and components and sub-processes within such cycles. • Develop biomass co-generation steam cycles and components with flatter efficiency-load curves and/or higher power/heat ratio • Survey of co-generation opportunities for heating and for industrial use.	
TRL: Advanced research TRL2-3 to TRL5	
Total budget required 0,5 billion	
Expected deliverables	**Timeline**
Fill in one line per deliverable … • One or more targets for cost reduction, efficiency gain • 5 new R&I Concepts ready for demonstration in 2030	**2030**

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties MS/Industry/EU	FP RIA, European Partnership Initiatives, MS R&I programs, non-public co-funding	**MS:50%** **EU: 25%** **Industry: 25%**

R&I Activity #9	
Title: Demonstrate high efficiency large scale biomass cogeneration of heat and power	
Targets: • Reduce conversion system costs for high efficiency (>70% based on net calorific value of which >30% electrical) large scale biomass cogeneration of heat and power by 20% in 2020 and 50% in 2030	**Monitoring mechanism**: an explanation of how each target will be monitored and reported to SETIS Use on-going systematic follow-up of technology development, cost and performance for efficiency & GHG savings for benchmarking purposes. (SE, DE, DK and UK have such technology catalogues) Use existing certificate of origins, RED II and ETS monitoring and follow-up
Description: • Demonstrate steam cycles with improved efficiency using scaled-down improved utility boiler cycles (pressure, superheat, re-heat, regenerative pre-heat cycles) and components (e.g. superheater materials, HP turbines) for use in large-scale bioenergy plants. • Demonstrate large-scale biomass cogeneration of heat and power technologies with improved performance, in particular flatter efficiency-load curves and ramp rates, higher power/heat-ratio). • Demonstrate high efficiency (> 40 % to power) bioenergy gasification-based co-generation cycles. • Demonstrate integrated CHP systems enhancing annual total efficiency and power capacity factor (e.g. by using heat accumulators, heat pumps, flue gas condensers, absorption heat or cooling cycles). • Lessons learned reporting including progress achieved towards objectives and remaining breakthroughs	
Total budget required 0,8 billion	
Expected deliverables	**Timeline**
Fill in one line per deliverable ... • Demonstrated concepts, 3 of enhanced steam cycles and 2 of gasification-based cycles	**2030**

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties MS/Industry/EU	MS grant and other funding, equity, commercial loans, Risk Finance, IF, EFSI, ESIF, FP IA & Innovfin, European Partenship Initiatives, other	**MS:25%** **EU: 25%** **Industry: 50%**

R&I Activity #10

Title: Scale-up high efficiency large scale biomass cogeneration of heat and power

Targets:	**Monitoring mechanism**: an explanation of how each target will be monitored and reported to SETIS
• Reduce conversion system costs for high efficiency (>70% based on net calorific value of which >30% electrical) large scale biomass cogeneration of heat and power by 20% in 2020 and 50% in 2030	Use on-going systematic follow-up of technology development, cost and performance for efficiency & GHG savings for benchmarking purposes. Use existing certificate of origins, RED II and ETS monitoring and follow-up

Description:

- Deployment of gasification of sustainable biomass and biogenic fraction of residues and wastes for high efficiency co-generation enhancing the WFD R1 efficiency factor > 1
- Deployment of high-efficiency biomass gasification (> 40 % to power) co-generation cycles.
- Deployment of steam-based high-efficiency co-generation cycles in integrated heating systems and for industrial heat generation.
- Retrofitting of existing coal fired and biomass based plants to enhance efficiency
- Lessons learned reporting including progress achieved towards objectives and remaining breakthroughs for market full deployment

TRL: Scale-up, deployment & market uptake. TRL7-8 to TRL9

Total budget required On average 200 M€ per large scale biomass CHP plant for 30-50 plants 10 billion

Expected deliverables	**Timeline**
Fill in one line per deliverable ... • 30 TWh of installations of new concepts in 2030	**2030**

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties Industry/MS/RU	2022: Equity, commercial loans, MS funding (loans and risk guarantees), IF, EFSI, ESIF, Innovfin, EIB, 2030: Equity, commercial loans. Public support including MS funding (loans and risk guarantees), IF, EFSI, ESIF, Innovfin, EIB, only for selected novel technologies or strategic reasons	**MS:20%** **EU: 5%** **Industry: 75% (including loans from public financing institutions)**

R&I Activity #11

Title: Develop solid, liquid and gaseous intermediate bioenergy carriers through biochemical / thermochemical/ chemical conversion from sustainable biomass

Targets:

- Reduce costs of liquid and gaseous intermediate bioenergy carriers by thermochemical or biochemical processing: <20 €/MWh in 2020 and <10 €/MWh in 2030 for e.g. pyrolysis oil; <40 €/MWh in 2020 and <30 €/MWh in 2030 for higher quality, e.g. microbial oils (excluding taxes and feedstock cost)
- Reduce costs of solid intermediate bioenergy carriers by thermochemical or biochemical processing (e.g., biochar, torrefied biomass, lignin pellets): <10 €/MWh in 2020 and <5 €/MWh in 2030 compared to present levels (excluding taxes and feedstock cost).
- Improve performance and reduce GHG emissions by increasing efficiency: Obtain net efficiency of biomass conversion to intermediate bioenergy carriers of at least 75% by 2030 with GHG emissions reduction of 60% from use of all types of intermediate bioenergy carrier products resulting to a contribution to at least 4% reduction of the EU GHG emissions from the 1990 levels (including biomass feedstock contribution)

Monitoring mechanism: an explanation of how each target will be monitored and reported to SETIS

R&D spending in the area- number and cost of EU & national projects

Patents in the area

Spin-off companies

Technology progress in the area, TRL evolution

New R&I concepts implemented in demonstrations

Evolution of conversion cost of other renewable liquid and gaseous biofuels

List of GHG savings level per each new technology with GHG > 60%

Description:

- Development of novel concepts for the thermochemical/chemical conversion of sustainable raw biomass, biomass by-products or biogenic wastes to intermediate energy carriers, including multiple output concepts (e.g. gas and bio-char, liquid and bio-char etc.).
- Development of novel concepts for biological / biochemical conversion of sustainable raw biomass, biomass by-products or biogenic wastes pathways to intermediate bioenergy carriers, including multiple output concepts (e.g. bio-gas and liquid, liquid and bio-char etc.).
- Development of methods to facilitate market acceptance of liquid and solid intermediates by improved handling, storage or performance properties or by improved user-friendliness (e.g. by pelletization, torrefaction, contaminant extraction, stabilization, water removal).
- Development of methods to make solid, liquid or gaseous intermediate bioenergy carriers obtain properties like fossil fuels (e.g. flame temperature, specific flue gas generated per energy unit, clean combustion etc.) to allow substitution of fossil fuels in more demanding industrial installations.

TRL: Advanced research TRL2-3 to TRL5

Total budget required 0,5 billion

Expected deliverables	**Timeline**
• One or more targets for cost reduction, efficiency gain for different pathways • 4 new R&I concepts going to demonstration for 2022 and 8 new concepts for 2030	**4 new R&I concepts going to demonstration for 2022 and 8 new concepts for 2030**
Fill in one line per deliverable ...	

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties MS/Industry/EU	FP RIA, European Partnership Initiatives, MS R&I programs, non-public co-funding	**MS:50%** **EU: 25%** **Industry: 25%**

R&I Activity #12	
Title: Demonstrate solid, liquid and gaseous intermediate bioenergy carriers through biochemical / thermochemical/ chemical conversion from sustainable biomass	
Targets: • Reduce costs of liquid and gaseous intermediate bioenergy carriers by thermochemical or biochemical processing: <20 €/MWh in 2020 and <10 €/MWh in 2030 for e.g. pyrolysis oil; <40 €/MWh in 2020 and <30 €/MWh in 2030 for higher quality, e.g. microbial oils (excluding taxes and feedstock cost). • Reduce costs of solid intermediate bioenergy carriers by thermochemical or biochemical processing (e.g., biochar, torrefied biomass, lignin pellets): <10 €/MWh in 2020 and <5 €/MWh in 2030 compared to present levels (excluding taxes and feedstock cost). • Improve performance and reduce GHG emissions by increasing efficiency: Obtain net efficiency of biomass conversion to intermediate bioenergy carriers of at least 75% by 2030 with GHG emissions reduction of 60% from use of all types of intermediate bioenergy carrier products resulting to a contribution to at least 4% reduction of the EU GHG emissions from the 1990 levels (including biomass feedstock contribution)	**Monitoring mechanism**: an explanation of how each target will be monitored and reported to SETIS Systematic follow-up of technology development, cost and performance for efficiency & GHG savings for benchmarking purposes Use RED II monitoring and reporting.
Description: • Demonstrate concepts for the thermochemical/chemical conversion of sustainable raw biomass, biomass by-products or biogenic wastes to intermediate bioenergy carriers' processes such as e.g. pyrolysis, hydrothermal liquefaction with or w/o use of catalysts, thermocatalytic cracking, etc including multiple output concepts (e.g. gas and bio-char, liquid and bio-char etc.), addressing specified end-users (refineries, industry, utilities etc.). • Demonstrate concepts for biological /biochemical conversion of sustainable raw biomass, biomass by-products or biogenic wastes pathways to intermediate bio-energy carriers, including multiple output concepts (e.g. bio-gas and liquid, liquid and bio-char etc.), addressing specified end-users (refineries, industry, utilities etc.). • Demonstrate the value chain for property-improved liquid and solid intermediates for specific end-use markets. • Demonstrate the use of property -improved solid, liquid or gaseous intermediate energy carriers for substitution of fossil fuels in more demanding industrial installations. • Lessons learned reporting	
TRL: Industrial research & demonstration TRL6-7 to TRL8	
Total budget required: 1 billion	
Expected deliverables • Value chains • Technology handbook with cost and performance for efficiency & GHG savings data and learning curve parameters. • Techno-economic assessment of scaling-up the technology to First –of-a kind demonstration • 4 demonstrated concepts in 2022 • 8 demonstrated concepts in 2030	**Timeline** **4 demonstrated concepts in 2022 and 8 demonstrated concepts in 2030**
Fill in one line per deliverable ...	

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties	MS grant and other funding, equity, commercial loans, Risk Finance, IF, EFSI, ESIF, FP IA & Innovfin, European	**MS:25%** **EU: 25%**

working together. One line should be filled in per group of parties MS/Industry/EU	Partenship Innitiatives, other	**Industry: 50%**

R&I Activity #13

Title: Scale-up solid, liquid and gaseous intermediate bioenergy carriers through biochemical / thermochemical/ chemical conversion from sustainable biomass

Targets:	**Monitoring mechanism**: an explanation of how each target will be monitored and reported to SETIS
• Reduce costs of liquid and gaseous intermediate bioenergy carriers by thermochemical or biochemical processing: <20 €/MWh in 2020 and <10 €/MWh in 2030 for e.g. pyrolysis oil; <40 €/MWh in 2020 and <30 €/MWh in 2030 for higher quality, e.g. microbial oils (excluding taxes and feedstock cost). • Reduce costs of solid intermediate bioenergy carriers by thermochemical or biochemical processing (e.g., biochar, torrefied biomass, lignin pellets <10 €/MWh in 2020 and <5 €/MWh in 2030 compared to present levels (excluding taxes and feedstock cost).	Use RED II monitoring and reporting Systematic follow-up of technology development, cost and performance for efficiency & GHG savings for benchmarking purposes

Description:

- Deployment of demonstrated new or property- improved value chains for intermediate bio-energy carriers,, in different market segments.
- Introduction of property-improved intermediate bio-energy carriers into more demanding industries.
- Establishment of large-scale logistic chains/markets to ensure a secure market availability of specified qualities of intermediate bioenergy carriers.
- Facilitation of development of standards/specifications for intermediate bioenergy carriers, both product (e.g. pyrolysis oil, lignin, additivated and torrefied pellets) and end-use oriented (biofuels, bio-heating oil or fuel gas.) as required.
- Exploration of markets where intermediate bioenergy carriers can substitute fossil fuels, their specific requirements and potential volumes
- Lessons learned reporting

TRL: Scale-up, deployment & market uptake. TRL7-8 to TRL9

Total budget required Up to 8 plants of 1 billion in 2022 and 50 plants of 8 billion in 2030. Different budget requirements ranging from mobile (100 K€) or small decentralized units (50 M€) to large scale plants (200 M€) per unit/plant.

Expected deliverables	**Timeline**
Fill in one line per deliverable … • Technology handbook with cost and performance for efficiency & GHG savings data and learning curve parameters. • Feasibility analysis of each first-of-a-kind plant • Production capacity of intermediates and type • 8 plants in 2022 • 50 plants in 2030	**8 plants in 2022 and 50 plants in 2030**

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Each R&I Activity might be implemented by one or more groups of parties working together. One line should be filled in per group of parties Industry/MS/RU	2022: Equity, commercial loans, MS funding (loans and risk guarantees), IF, EFSI, ESIF, Innovfin, EIB, 2030: Equity, commercial loans. Public support including MS funding (loans and risk guarantees), IF, EFSI, ESIF, Innovfin, EIB, only for selected novel technologies	**MS:20%** **EU: 5%** **Industry: 75% (including loans from public financing institutions)**

ANNEX II: Technology Pathways Table

The following table includes costs figures for the value chains addressed within this IP, and it gathers the contributions from all stakeholders involved in this working group. It shall serve as an overview about the value chains of this Implementation plan, and allow a relative comparison of costs and technological maturity.

It must be noted that prices reported in the table must be dealt with caution. The figures are often based on estimates, and should be better represented by a range rather than an exact value. Moreover, it is impossible to directly compare different values from different sources with altering boundary conditions, without carefully examining boundary limits, scale, scale factors and other specific or assumed input. This applies more for the lower TRL solution, but also for higher TRL values there might be big variation, as the sector is still developing.

Another consideration concerns specifically the reported conversion costs excluding feedstock and CAPEX: these normally accounts for 5-20% of the cost of producing biofuel/renewable hydrogen (in the lower range if the feedstock are refined already anyway, i.e. using vegetable oils, electricity, pellets as feedstock in a process). These costs depend strongly on the volume and type (virgin or waste) in current and future feedstock markets. They have a very large variety and if taken into account would make this overview of limited value especially for the low OPEX pathways. This is also the case for the production of Renewable Hydrogen where electricity costs are excluded for the sake of comparison.

Finally, it must be mentioned that low TRL Technologies often underestimate cost for site preparation, consents, feedstock and final product storage, auxiliaries, etc.

TRL: Technology Readiness Level[19]

CAPEX: Capital Expenditure (cost of developing or providing non-consumable parts for the system)

OPEX: Operational Expenditure (maintenance&repairs, fees, insurance, capital interest rate etc)

19 See for instance: https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
Liquid advanced biofuels													
	Thermochemical processes												
3	Woody feedstock or agri residues	BIOMASS to LIQUIDS via Gasification		Thermochemical processes with sub-stoichiometric oxygen rate Syngas (chemical) conversion					2.1-6.5 for waste and farmed wood respectively [1]			DME	EERA Bioenergy
4	Woody feedstock or agri residues	BIOMASS to LIQUIDS via Gasification	FT synthesis (FT-SPK FT-SPK/A)	Gasification (Pox) +FT	6-7 [2]			110 - 140 [2]	9.8 - 24.7 *			Synthetic Jet Fuel	B. Kerckov - D and ETIP * JRC calculations from E3 database (in publication)
5	Woody feedstock or agri residues	BIOMASS to LIQUIDS via Gasification	FT synthesis (FT-SPK FT-SPK/A)	Gasification (Pox) + FT + Hydro-isomerisation	6-8]	1.2 – 1.5 M€/MWth		50-80	5-15		825' 000	Synthetic Diesel and Jet Fuel	Communicated by. IFP, Energies Nouvelles, FR
6	Lipid feedstock	BIOMASS to LIQUIDS via Gasification	Catalytic Hydrotreatment						tbd *			Jet Fuel	Under ASTM cerfitication *JRC: GHG values similar to HEFA, but not calculated
7	Woody feedstock or agri residues	Thermochemical other than gasification	Electrolysis and Fischer Tropsch to liquid hydrocarbons	H2 produced from solid-oxide electrolysis and CO2 from various sources, processed by FT to liquids.	6-7					Total exergetic efficiency > 80% Carbon Conversion to fuels > 53%		Synthetic petrol or diesel type fuels	K. Pollak - AT
8		Thermochemical other than gasification	Gasification + fermentation					67 - 87 [2]				Methanol and Ethanol	B. Kerckov - D and ETIP
9	Woody feedstock or agri residues	Thermochemical other than gasification	Hydrothermal liquefaction (HTL)	Hydrothermal liquefaction of lignocellulose, fractionation, cracking and hydrotreatment of biocrude to maximize gasoline component	5	1600-2000	60-80	50-60	20 - 21 [3] depending on biomass and processs energy source 1.5 - 3 (depending on HTL conditions)	35-40	planned 10-30 MW (up to 2000 kg/day dry feed)	Liquid - SynFuel	EERA Bioenergy, SYNTEF
10	Residual biomass*	Thermochemical other than gasification	Thermo-catalytic reforming (TCR) + Corefining	Decentralized biomass conversion to intermediates (biocrude oil, biochar and syngas) Biocrude co-refined with fossil or UCO	6-7	46 - 281 €/MWh/year for intermediate production	22 - 66 €/MWh incl. refining spread	17 - 36 €/MWh incl. refining spread	tbd	tbd	3,500 - 550,000 MWh/year of biocrude per unit	Diesel, Gasoline, Jet Fuel	A. Hornung - UMSICHT , Susteen Technologies [V 10]
11	Residual biomass*	Thermochemical other than gasification	Thermo-catalytic reforming (TCR) + HDO onsite	Centralized biomass conversion with dedicated refining of biocrude oil. Hydrogen supply via synygas separation. Conversion of remaining intermediates (char and tail gas) to power & heat	6-7	300-500 €/MWh/year	55 - 100 MWh	25 - 50 €/MWh based on fuel and power output	ca. 4**	> 55% energy efficiency	50,000 - 600,000 MWh/of fuels per year	Diesel, Gasoline, Jet Fuel	A. Hornung - UMSICHT , Susteen Technologies [V 11]
12	Sugar for lignocell or first gen.	Thermochemical other than gasification	Catalytic conversion of sugars by aqueous phase reforming*									CCS-APR	*Under ASTM cerfitication
13	Ligno-cellulosic, woody feedstock	Thermochemical other than gasification	Heat-to-Fuel	Upgrading alternative, residual biomass feedstocks and conversion of excess heat to liquid fuels in a combined gasification, Fischer Tropsch and Aqueous Phase Reforming plant	3-6 *							Advanced liquid biofuels	K. Pollak - AT *wide range for TRL

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
14	Lipid feedstock	Hydrotreatment	Hydrotreatment		9			Corrected from 80-90 as pointed out by Saari Kuuisto 8 [2]	11.6 - 28 [1]			Synthetic Jet Fuel (HEFA)	B. Kerckov - D and ETIP * 8.1 for HVO from UCO; 24.5 for HVO from tallow oil. Then 3.5 g CO2 added for isomerisation for aviation fuels.
15	Lipid feedstock (vegetable oil, PFAD, UCO and Tallow)	Hydrotreatment	Hydrotreatment	Modification of traditional refinery (de-sulphurization) units into a deoxygenation unit and an isomerization unit. New plant for treating UCO and Tallow feedstock (Biomass Treatment Unit)	7-9*				5-14**		720 kt/y***	Green Diesel, Green Naphta, Green GPL	Eni - Italy * Under construction, 45% completed ** to be further evaluated *** EcofiningTM process
	Biochemical processes												
17	Sewage gas/ natural gas	Cellulosic sugars to alcohols via fermentation	Microbial Fermentation	Sewage gas (diverted from heat and/or elec production, replaced by natural gas (NG)) and NG processed in a plasma reactor; requires electricity (may be additional). Resulting gas mixture processed by bacteria into ethanol.								Ethanol	
18	Lignocellulosic	Cellulosic sugars to alcohols via fermentation	Fermentation (enzymatic)		8-9	1.2-1.9 M€/MWh		85-120	9.2 [1]		440'000	Ethanol	B. Kerckov - D and ETIP, resp. SGAB report", and IFP Energies Nouvelles, France
19	Lignocellulosic agricultural and forest waste	Cellulosic sugars to alcohols + Sugars to hydrocarbons	Microbial fermentation / Hydrotreatment	Stage 1: biomass saccharification Stage 2: cellulosic sugar fermentation to microbial oil Stage 3: microbial oil hydrotreating to green diesel	4				to be evaluated*		Target: 50 kt/y	Green Diesel	Eni - Italy *Similar to that reported (RED Directive) for cellulosic ethanol (wheat straw ethanol GHG reduction = 85%)
20	Alcohols from other processes	Sugars to hydrocarbons	Fermentation		5-6 [2]				From 23 for forestry residues, to 71 for maize feedstock. *			Syntethic Jet Fuel (ATJ, ATJ - SPK)	* JRC calculations from E3database
21	Sugar for lignocell or first gen.	Sugars to hydrocarbons	Fermentation (enzymatic)	Amyris has developed a technology to produce diesel fuel or chemicals from a 15-carbon isoprenoid called farnesene.	8-9 [2]			110 - 140 [2]	29 to 48 but for automotive [1]			Synthetic Paraffinic kerosene (SPK)	B. Kerckov - D and ETIP
22	Waste or agri residues	Biochemical via Anaerobic Digestion	Anaerobic Digestion	Biomethane is obtained by separation of CO2 and other compounds and subcessive liquefaction or by simultaneousc CO2 removal and methane liquefaction	8-9							Liquid Methane	LEAP - Italy

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
23	organic waste, sewadge sludge	Hydrothermal Liquefaction	Hydrothermal Liquefaction	The homogenized feedstock is sent to a batch reactor where it is subject to hydrothermal liquefaction. The obtained bio-oil is separated from solid residue, gas and water phase	5 [10]				84% of emission reduction		Target: 30 kg/h	Bio-oil	Eni - Italy *In construction phase. Start-up planned by 2nd half 2018
Gaseous advanced biofuels													
	Thermochemical processes												
25	industrial wastewater, municipal sewage or digestate	vacuum membrane distillation	Ammonia – to - Power	a vacuum membrane distillation method (MD) for ammonia gas extraction and an ammonia fuel cell (SOFC ammonia)	2							Ammonia	K. Pollak - AT
26		Biomass to gas via gasification	Biomethane by gasification	Thermochemical processes with sub-stoichiometric oxygen rate				112	21.5-26.2 for compressed or liquefied biomethane respectively [4]			Compressed BioMethane	F. Cotana - IT
27	Residual biomass*	Biomass to gas via gasification + fermentation	Thermochemical + fermentation	Thermo-catalytic reforming (TCR) + Archae bacteria reactor	4-6	under examination						BioMethane	A. Hornung - UMSICHT
28	Waste or agri residues	Biomass to gas via gasification	Hydrothermal gasification	Gasification at suppercritical temperature	4-5								EBA
29	Biogas and H2 (renewable)	Biomass to gas via gasification	Methanation	Catalytic process									EBA
30	CO2 and H2 (renewable)	Thermochemical other than gasification	Methanation with Sabatier process	Chemical process	4-5							Biomethane	
	Biochemical processes												
32	Waste or agri residues	Anaerobic Digestion	Anaerobic Digestion (Microbial process)	Addition of H2 from renewable electricity to use	6-7								EBA
33	CO2 and H2 (renewable)	Anaerobic digestion	Microbial power to gas process										EBA
34	Waste/ residues	Anaerobic Digestion	Anaerobic Digestion upgraded to biomethane		9			40 - 120 [2]	- 69,9 liquid manure with closed storage 14,8 MSW [1]			Compressed BioMethane	B. Kerckov - D and ETIP

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
Algae based advanced biofuels													
35		Conversion of aquatic biomass (autotrophic)	Lipid feedstock from microalgae	autotrophic conversion	8-9							Lipid	
36		Conversion of aquatic biomass (autotrophic)	Sugar feedstock from microalgae	autotrophic conversion	8-9							Lipid	
37	Sugars/glycerol	Other Biological pathways	Lipid feedstock from microalgae or yiests	heterotrophic	5-6							Lipid	
38	CO2 + Glycerol	Conversion of aquatic biomass (heterotrophic)	Lipid feedstock from microalgae	heterotrophic conversion	5-6				84% of emission reduction			Lipid	Eni - Italy

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
Other renewable liquid and gaseous fuels excluding renewable hydrogen													
41		Power to liquid	Methanol from hydropower	Methanol synthesis based on hydrogen from electrolysis and CO2 from a point source extracted by Post-Combustion Capture in Norway (25 €/MWh(el)) power grid	8-9	47	48.5	90	1.25 - 7	65%	54900 per year	Methanol	EPPSA
42		Power to liquid	Gasoline from hydropower	Methanol synthesis based on hydrogen from electrolysis and CO2 from a point source extracted by Post-Combustion Capture in Norway (25 €/MWh(el)) power grid afterwards treated in a methanol to gasoline plant (MTG)	8-9	63	71	116	1.5 - 8	62%	54900 per year	Gasoline	EPPSA
43			Methanol from electricity and high concentration waste CO2	Ther electricity is possible additional renewable electricity, or MS avg GHG intensity of electricity consumed. Waste Co2 has a typical concentration >90%								Methanol	
44		Depending on the pathway considered (Power to liquid or synthesis)	Fuels from CCU assisted by gasification and/or solar power (also CSP, not only PV)	- Hydrogen is obtained from e.g. gasification or electrolysis, and combined to CO2 to produce methane or methanol in a methanation process assisted by solar or other renewable sources - Indirectly heated carbonate looping									EPPSA
45		Power to gas	Solargas	Methane is produced by the Sabatier process from a CO2 flux and water electrolysis obtained by PV				112	27,5-75 depending on the CO2 source [5]			Gas - Methane	F. Cotana - IT

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
Renewable Hydrogen													
	Thermochemical processes												
48	water, concentrated solar	Thermolysis - Solar to Hydrogen	Hydrogen from concentrated solar	Hydrogen is obtained from thermal dissociation of water using concentrated solar energy	4-5	N.A.	150-270 €/MWh	20 €/MWh (est)	15 gCO2eq/MJ	5-9%	0.04 MWh (1kg H2/h for 750kW thermal plant)	GAS: H2	EERA-FCH and FCH JU [V 48]
49	Solid Biomass/Waste, digestate	Gasification to Hydrogen	Fuels by gasification of renewable raw materials (biomass origin, renewable fraction of wastes)	Thermochemical processes with sub-stoichiometric oxygen rate.	6-7	106 €/MWth	254 €/MWh	147.4	13.8 to 15.7 [1]	54%	2170 MWh(H2 prod)/y	Gas - H2	EEPSA and EERA-Hydrogen [V 49]
50	Residual biomass*	Gasification to Hydrogen	Thermo-catalytic reforming (TCR) + Pressure Swing Adsorption	Conversion of biomass to hydrogen rich syngas. Hydrogen separation via pressure swing adsorption	6-7	240-1000 €/MWh/year	35 - 160 €/MWh H2	10 - 60 €/MWh based on H2, biocrude & power output	tbd	> 70% energy efficiency**	3,500 - 530,000 MWh/of hydrogen per year	Gas - H2	A. Hornung - UMSICHT , Susteen Technologies [V 50]
	Biochemical processes												
52	Carbohydrate rich waste from food, agriculture, industry, OFMSW: example of food waste	Microbial fermentation (dark fermentation)	Hydrogen production from microbial anaerobic dark fermentation (DF)	Hydrogen is obtained from biological conversion of organic waste	6-7	450 €/kW(H2 prod)	96 €/MWh of H2 produced (3.2€/kg H2) for 20y plant service	17.3 €/MWh of H2 produced	depends on microbial metabolic pathways, but plant is simple and process is low-energy-consuming	10% (H2 energy recovery from the substrate)	31600 MWh(H2prod)/y	Gas - H2	only a maximum of 21-33% of the COD can be recovered in H2, the rest is converted in organic acids and other metabolites which can be converted in a follow-up step [V 52]
53	Water as electron donor; sunlight and carbon dioxide	Photobiological water splitting	Hydrogen production by direct biophotolysis	Hydrogen is produced with low sulphur content by microalgae (i.e. Chlamydomonas) photosynthesis system [6]	2-3	850 €/kW(H2 prod)	276 €/MWh of H2 produced (9.2€/kg H2)	<<276 €/MWh of H2 produced (No real data vailable)	solar radiation directly converted in H2. No LCA/GHG data reported in literature	Solar to H2 (STH) Energy Conversion Ratio 5% / Light utilization efficiency 30% (2020 target)	600000 MWh(H2prod)/y	Gas - H2	The process requires high light intensity: green algae and cyanobacteria have low light conversion efficiency. This plant assumes 1000W/m2 solar incidence for 8h/day (requires 4M m2) [V 53]
54	Organic wastewater: urban & industrial	Microbial Elecrolisys Cells (MEC)	Hydrogen from urban and industrial organic wastes via microbial electrolysis	In Microbial electrolysis cells (MECs), microbial substrate oxidation is combined with the addition of a small voltage (≤ 1V) to enable hydrogen (H2) gas evolution at the cathode.	5-6	920€/kW(H2 prod)	114€/MWh of H2 produced(3.8€/kgH2)	317€/MWh of H2 produced	Reduction of CO2 emissions typically associated with COD removal by aerobic treatment	38% electric efficiency	2140 MWh(H2 prod)/y	Gas - H2	Production of H2 depends on substrate type, urban wastewater has low COD content. The treatment of industrial wastewater represents a promising option because of its high energy density. [V 54]
55	Organic waste or agri residues	A.D. + reforming	Hydrogen production by reforming of biogas from waste via A.D	Hydrogen is obtained by reforming of biogas produced from biological conversion of organic wastes via anaerobic digestion	8-9	910€/kw(inlet stream)	140€/MWh of H2 produced (4,7-4,8 €/kgH2)	<1€/MWh of H2 produced		82% (global energy) - 78% (KgH2/KgCH4)	4 MW (inlet stream)	Gas - H2	Size of plant considered is very large [V 55]
	Electrochemical processes												

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
57	water, electricity	Power to Hydrogen	Hydrogen from alkaline water electrolysis	Hydrogen is obtained from alkaline water electrolysis	8-9	1200 €/kW @ 1MW 830 €/kW @ 5MW	70-50 €/MWh	10 - 7 €/MWh (4% of CAPEX)	7.5 if produced from wind energy	57-63%	3400 - 23000 MWh(H2 prod)/y (17 - 96 kg H2/h)	GAS: H2	FCH JU [V 57]
58	water, electricity	Power to Hydrogen	Hydrogen from PEM water electrolysis	Hydrogen is obtained from PEM water electrolysis	7-9	1500 €/kW @ 1MW 1300 €/kW @ 5MW	70-50 €/MWh	12.5 - 10.8 €/MWh (4% of CAPEX)	7.5 if produced from wind energy	52-54%	3900 - 19000 MWh(H2 prod)/y (16 - 82 kg H2/h)	GAS: H2	FCH JU [V 58]
59	water, electricity	Power to Hydrogen	Hydrogen from Solid Oxide water electrolysis	Hydrogen is obtained from water electrolysis using Solid Oxide technology	5-7 (oxygen ion conducting), 3-4 (proton conducting)	3,000 €/kWe	60-80 €/MWh	12 €/MWh (2% of CAPEX)	254.4 EU electricity mix if H2 liquefaction is considered [1]	70-75% - if (waste) steam is available: 80-85%	150 kWe (3.6kgH2/h) (1000 MWh(H2 prod)/y)	GAS: H2	EERA-FCH, Sunfire GmbH and EUA – EPUE Data from Salzgitter steelwork plant, as operated in the GrinHy project
60		Gasification to Hydrogen	Hydrogen from catalytic photosonolysis (ultrasound treatment + sunlight)	Hydrogen is obtained by ultrasound treatment + sunlight	2-3				17,5-27 (solar-assisted biomass gasification system) [7]			Gas - H2	F. Cotana - IT and EERA - Hydrogen
61	Water	PV Power to Hydrogen	Hydrogen from electrolysis	Hydrogen is obtained from water electrolysis using PV electricity	8-9		LCOH: 40 $/MWh at 0 electricity price (vs 50 $/MWh for conventional reforming, independent of electricity price) and 130 $/MWh of H2 at 50 $/MWh electricity price	10-20 €/kgH2	3 - 14 [10]*	60-75% electricity to hydrogen		GAS: H2	F. Cotana - IT, EUA - EPUE and EERA Hydrogen *(JRC proposal)
62	water	Wind power to H2	Hydrogen from electrolysis	Hydrogen is obtained from water electrolysis using wind power electricity	5-7				4.2 for wind energy [1]			GAS: H2	F. Cotana - IT and EUA - EPUE

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
Liquid intermediate bioenergy carriers													
	Thermochemical processes												
64	Residual biomass*	Intermediate Bioenergy carriers via other thermochemical processes	Thermo-catalytic reforming (TCR)	Production of biocrude oil suitable for standard refining from residual biomass	7-8	46 - 281 €/MWh/year	9 - 52 €/MWh	4 - 23 €/MWh	1,2**	> 80% energy efficiency	3,500 - 550,000 MWh/year	TCR® biocrude oil	A. Hornung - UMSICHT , Susteen Technologies [V 64]
65	Woody feedstock or agri residues	Intermediate Bioenergy carriers via other thermochemical processes	Pyrolysis (bio-oil co-processing)	Pyrolysis oil production stand alone, stabilization, hydrotreatment, isomerization at the refinery	5	1500-1700	60-80	58 - 104 [2] (50 - 60)*	1.5-2.8	30-40 %	10-30 MW (up to 2000 kg/day dry feed)	Liquid - bio-oil	B. Kerckov - D and ETIP * SINTEF
66A	Woody feedstock or agri residues	Intermediate Bioenergy carriers via other thermochemical processes	Pyrolysis (bio-oil stand alone)	Standalone pyrolysis oil production and upgrading	5	1800-2000	80-90	83 - 118 [2] (55 - 70)*	1.7-2.9	30-40 %	10-30 MW (up to 2000 kg/day dry feed)	Liquid - bio-oil	B. Kerckov - D and ETIP * SINTEF
66B	Woody feedstock	Intermediate Bioenergy carriers via other thermochemical processesFast pyrolysis - (catalytic)	Fast pyrolysis – (thermal) integrated	Integrated production of pyrolosis oil for upgrading at refinery or dedicated hydrotreater	8	100-170 €/MWh/year input	25-40	35-55		90%	10-100 MWh/h oil		Integrated, highly efficient due to integration to CHP or pulp mill
67A	Woody feedstock or agri residues	Intermediate Bioenergy carriers via other thermochemical processes	Fast pyrolysis - (catalytic)	Thermochemical processes in absence of oxygen, crude oil production for gasification/combustion, no stabilization/hydrotratment	9	1800-2000	35-40	36 [9] (30 - 35)*	0.8-1.3	70-80 %	10-30 MW (up to 2000 kg/day dry feed)		EPPSA * SINTEF
67B	Woody feedstock	Intermediate Bioenergy carriers via other thermochemical processes	Fast pyrolysis – (catalytic) integrated	Integrated production of catalytic pyrolosis oil suitable for use at standard refinery	4	180-250 €/MWh/year input	40-60	50-75		90%	10-100 MWh/h oil		Integrated, highly efficient due to integration to CHP or pulp mill
	Biochemical processes												
Gaseous intermediate bioenergy carriers													
	Thermochemical processes												

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
71	Woody feedstock or agro residues	Power and heat via gasification	Biomass oxidation in low oxygen atmosphere	Power generation in thermal power plant either in gas boiler or replacing coal in PC boiler	8-9	0,15-0,25 M€/Mwhgas		1-3 €/MWh	0	90-98 %	50 - 300 MW gas	Heat and electricity	EPPSA
72	Residual biomass*	Intermediate Bioenergy carriers via other thermochemical processes	Thermo-catalytic reforming (TCR) Char gasification	Production of hydrogen rich syngas. Includes oxygen-driven gasification of biochar	6-7	100 - 200 €/MWh/year	20 - 27 €/MWh	9 - 16 €/MWh	tbd	> 75% energy efficiency	100,000 - 1,300,000 MWh/year	Syngas (ca. 40% H2)	A. Hornung - UMSICHT , Susteen Technologies [V 72]
	Biochemical processes												

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
Solid intermediate bioenergy carriers													
	Thermochemical processes												
77		Intermediate Bioenergy carriers via other thermochemical processes	Pyrolysis + refining	Biomass steam treatment in high pressure				2.5				Bio-coal	EPPSA
78	Residual biomass*	Intermediate Bioenergy carriers via other thermochemical processes	Thermo-catalytic reforming (TCR) Char gasification	Production of biochar through conversion of residual biomass Energy and ash content depends on ash content of feedstock	7-8	46 - 281 €/MWh/year	9 - 52 €/MWh	4 - 23 €/MWh	1,2**	> 85% energy efficiency	7,000 - 1,000,000 MWh/year	Biochar - 90% incarbonization	A. Hornung - UMSICHT , Susteen Technologies [V 78]
79	Waste or other biogenious residues	Intermediate Bioenergy carriers via other thermochemical processes	Hydrothermal Carbonisation (HTC)	Biomass treatment in liquid hot water	6 to8				6 - 25 (depenting on heat source)			Enhanced solid biofuel (bio-coal)	ETIP - RHC
80	lignocellulose biomass / woody feedstock or agri residues	Intermediate Bioenergy carriers via other thermochemical processes	Torrefaction	upgrading processes under pre-determined pressure and atmosphere (different duration time) to increase the LHV/HHV and improving certain fuel properties	6 to 9				15-25 depending on feedstock and energy source; 30-60 (co-firing with hard coal, electric output) 150-210 (replacing natural gas in 15 kW boiler)				ETIP - RHC
81	wet biogenious residues	Intermediate Bioenergy carriers via other thermochemical processes	mechanical treatment and washing	upgrading process to reduce difficult elements (e.g. K, Cl): cutting, washing the material with water and pressing it before conversion (densified product); liquid by-product use e.g. in biogas processes possible	5 to 8								ETIP - RHC
82	wet biogenious residues	Intermediate Bioenergy carriers via other thermochemical processes	mechanical treatment combined with washing and thermally treatment	partly used in combination with thermo-chemical upgrading processes (e,g, torrwash-products)	5 to 8								ETIP - RHC
	Biochemical processe												

Number in Figure 1 [a]	Energy Source	Value chain	Specific Pathway	Production process description	TRL	CAPEX € / MWth (thermal input)	Conversion cost (€/MWh) [b]	OPEX (€/MWh) [c]	GHG (gCO2eq/MJ)	Net Process Efficiency	Production capacity	Final Fuel	Sources/Comments
83	Wood biomass	Use of wood residues for fossil fuel substitution	Densified pellets and briquettes by steam explosion	Biomass steam treatment in high pressure followed by densification to pellets or briquettes	8	30-50 €/MWh/a	12 €/MWh	12 €/MWh	0	> 100	400 – 1400 GWh/a	Densified solid fuel for coal substitution in heat and power plants	Very efficient process at integration to CHP plants and pulp mills - EPPS
84	Agro based biomass residues	Use of agricultural residues for fossil fuel substitution	Densified pellets and briquettes by steam explosion	Leaching of biomass to reduce non process elements followed by steam treatment and densification	6	45-65 €/MWh/a	14 €/MWh	16 €/MWh	0	80%	400 – 800 GWh/a	Densified solid fuel for coal substitution in heat and power plants	Rawmaterials bagasse, rice straw, empty fruit bunches. Challenging to wash rawmaterial.- EPPSA
85	Food industry waste (animal fat, whey)	Anaerobic Digestion	Fuels by anaerobic digestion of renewable raw materials (renewable fraction of wastes from food industry)	Biochemical processes	7-8			110	20-25			Biomethan	EUA - EPUE Cascade Anaerobic Digester
Biomass cogeneration													
	Thermochemical processes												
87	Poultry industry waste	Power and heat via gasification	Gasification/Pyrolysis	Thermochemical processes with sub-stoichiometric oxygen rate	5			60	14-20			Biomethan	EUA - EPUE Gasification using Lurgi gasifier or sequential pyrolyser DEMOSOFC & CH2P Projects, EERA-FCH
88	Woody feedstock or agro residues	Combustion	Biomass oxidation	Power generation in thermal power plant					1.7, credit given for heat produced, waste wood feedstock [1]			Heat and electricity	EPPSA
89	Wood and agro based biomass residues	Combustion	Biomass oxidation	Power generation in thermal power plant	9	2-3 M€/MWe		5-10 €/Mwhe	0	Heat 90-92% and electricity 35-40%	300 MWe or 900 MWth	Heat and electricity	EPPSA
	Biochemical processes												
86	Organic waste or agri residues	Anaerobic Digestion + High-temperature fuel cell (HTFC)	Tri-generation of power, heat and hydrogen from biogas	Biogas produced from biological conversion of organic wastes is converted to electricity+heat with (optional) simultaneous reforming of non-reacted CH4 inside a HTFC, with CO2 separation down-stream	6-7	9200€/kWe	160€/MWhe + 140 €/MWh for H2 produced	19 €/Mwhe	tbd	58% biogas-to-electricity + H2 produced	60 kWe	Hydrogen, heat and electricity	EERA-FCH and FCH JU

Notes

[a] Numbers in bold and with Background colour correspond to data points of Figure 1

[b] Conversion cost (€/MWh) are production cost + profit margin + relevant costs to a point of sale excluding feedstock cost and product taxes (e.g., VAT))

[c] OPEX (Operational Expenditure), includes investments costs but NOT feedstock costs

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[1]: JEC - WTT v4a

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Value Chain Comments

[V 10] Based on 4 - 600 kt/year of feedstock. Equal spread of CAPEX & OPEX across intermediate energy output (oil, gas and char) assumed. 6.2% WACC - 15 years. Refining spread assumed at 160 €/t of fuel product.
* Residual biomass includes all types of forest & agricultural waste, organic muncipal, commercial and industrial waste, agri residue and manure, municipal and commercial organic waste, and sewage sludge. Certain types of residue may require additional pre-processing. Additional feedstock pre-processing to be included in feedstock cost

[V 11] Based on 50 - 600 kt/year of feedstock. Equal spread of cost across fuel and power output assumed. 6.2% WACC - 15 years. Additional heat export not included.
*Residual biomass includes all types of forest & agricultural waste, organic muncipal, commercial and industrial waste, agri residue and manure, municipal and commercial organic waste, and sewage sludge. Certain types of residue may require additional pre-processing. Additional feedstock pre-processing to be included in feedstock cost.
**Values for diesel and petrol for exemplaric calculation for one specific residue. Jet fuel targeted for generic ASTM 6566 annex

[V 48] SOL2HY2 project, http://fch.europa.eu/publications/study-early-business-cases-h2-energy-storage-and-more-broadly-power-h2-applications

[V 49] Deliverable 5.3 Techno-economic analysisof UNIFHY hydrogen production system. UNIfHY Hydrogen Production System, 7FP UNIfHY-UNIQUE Gasifier for Hydrogen Production GA: 299732'.

[V 50] Based on 4 - 600 kt/year of feedstock Equal spread of cost across H2, biocrude and power output assumed 6.2% WACC over 15 years Additional heat export not included
*Residual biomass includes all types of forest & agricultural waste, organic muncipal, commercial and industrial waste, agri residue and manure, municipal and commercial organic waste, and sewage sludge. Certain types of residue may require additional pre-processing. Additional feedstock pre-processing to be included in feedstock cost
**PSA-technology for H2-separation from TCR-gas. Assumption of 90% component efficiency

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[V 57] http://fch.europa.eu/publications/study-early-business-cases-h2-energy-storage-and-more-broadly-power-h2-applications

[V 58] http://fch.europa.eu/publications/study-early-business-cases-h2-energy-storage-and-more-broadly-power-h2-applications

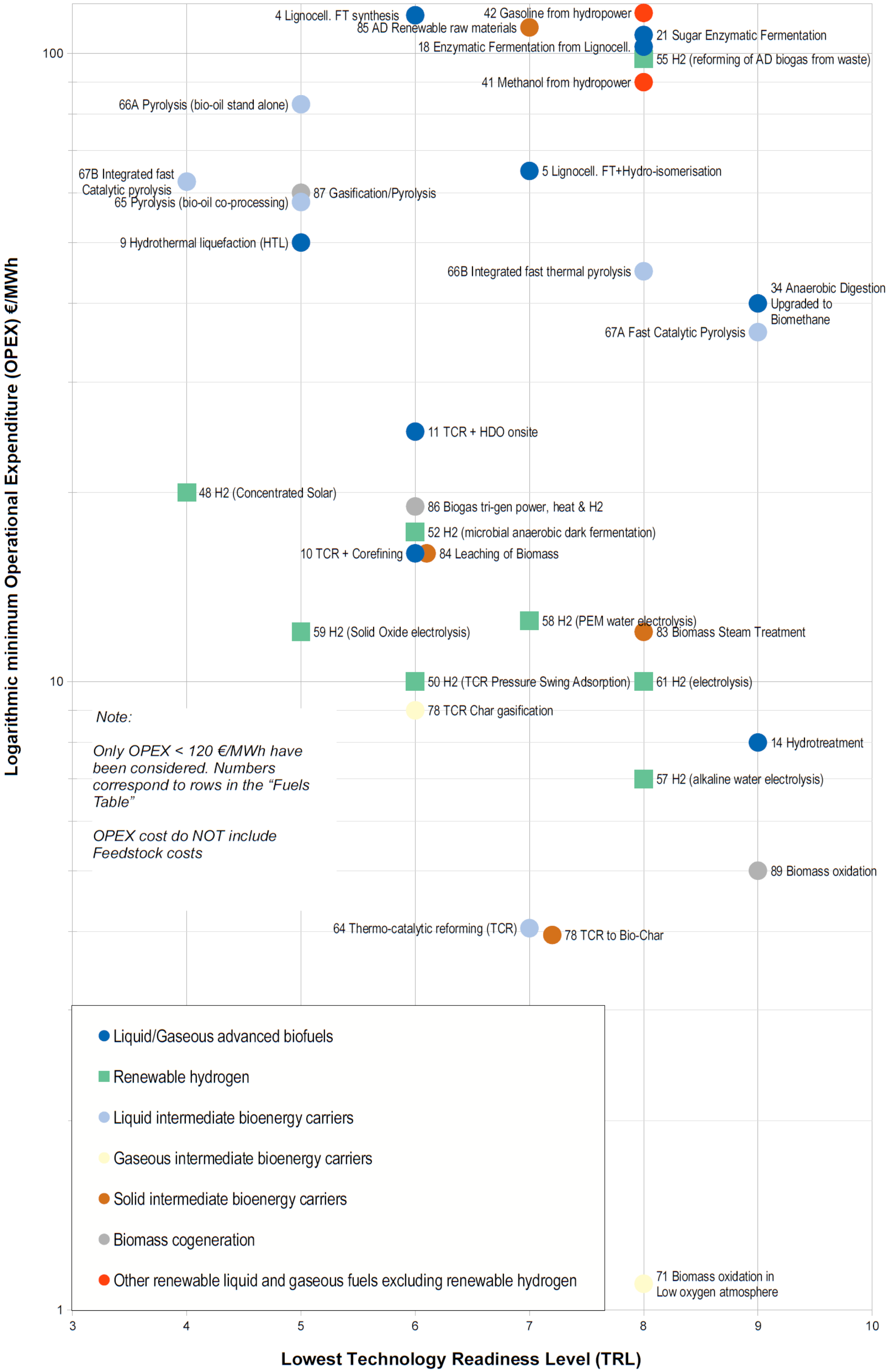
[8] http://lae.mit.edu/uploads/LAE_report_series/2017/LAE-2017-002-T.pdf	[V 64] Based on 4 - 600 kt/year of feedstock. Equal spread of CAPEX & OPEX across intermediate energy output (oil, gas and char) assumed. 6.2% WACC over 15 years *Residual biomass includes all types of forest & agricultural waste, organic muncipal, commercial and industrial waste, agri residue and manure, municipal and commercial organic waste, and sewage sludge. Certain types of residue may.require additional pre-processing. Additional feedstock pre-processing to be included in feedstock cost **Raw products (TCR-oil, TCR-char): only transport GHG-emissions relevant
[9] T.H. Pedersen_, N.H. Hansen, O. Miralles, D. Villamar, L.A. Rosendahl. Renewable hydrocarbon fuels from hydrothermal liquefaction: A techno-economic Analysis. Biofuels, Bioproducts & Biorefining. DOI: 10.1002/bbb.1831	[V 72] Based on 50 - 600 kt/year of feedstock. Equal spread of costs across energy output (biocrude oil, syngas) assumed. 6.2% WACC. *Residual biomass includes all types of forest & agricultural waste, organic muncipal, commercial and industrial waste, agri residue and manure, municipal and commercial organic waste, and sewage sludge. Certain types of residue may require additional pre-processing. Additional feedstock pre-processing to be included in feedstock cost
[10] Study on Hydrogen from renewable resources in the EU, Done for the FCH JU by LBST and Hinicio, ISBN 978-9209246-138-6	[V 78] Based on 4 - 600 kt/year of feedstock. Equal spread of CAPEX & OPEX across intermediate energy output (oil, gas and char) assumed. 6.2% WACC over 15 years. *Residual biomass includes all types of forest & agricultural waste, organic muncipal, commercial and industrial waste, agri residue and manure, municipal and commercial organic waste, and sewage sludge. Certain types of residue may require additional pre-processing. Additional feedstock pre-processing to be included in feedstock cost **Raw products (TCR-oil, TCR-char): only transport GHG-emissions relevant

The following **Figure 1** is intended to show how costs depend on the achieved Technology Readiness Level (TRL). TRL has been applied as recommended by the European Horizon 2020 Research Programme. The data points selected correspond to those rows in the previous table, where both TRL and OPEX values have been available. In the table they are depicted in the first column, on coloured background which corresponds to the colour of the symbols in Figure 1.

As cost has been considered only operational expenditure (OPEX). The OPEX values include all operation, maintenance, capital interest rate, insurances etc., but not feedstock costs. The graph shall be understood as a relative comparison of the technologies, without taking into account feedstock cost, as these cost depend strongly on the volume and type (virgin or waste) in current and future feedstock markets. They have a very large variety and if taken into account would make this overview in particular for the low OPEX pathways less significant. This is also the case for the production of Renewable Hydrogen from electricity sources like Photovoltaic solar energy and wind energy. In fact, using only excess renewable electricity from these sources, the displayed OPEX would not increase. For an easy evaluation if such processes are relevant for you, based on the costs of feeds, three values are given plus a range for power: Wood (35% Moisture, 1 t 4,8 MWh, 10 €/MWh), Digestate (dry matter 5 €/MWh), waste organics (dry matter 10 €/MWh), power ranging from 0 to 60 €/KWh. A process now at 10 €/MWh taking feed into account of 10 Euro per MWh and converting such feed on 50 % yield would have to add another 20 €/MWh to the cost of the process.

Particular attention should be dedicated to those pathways which in the graph are shown on the upper right. They can be considered as mature in technology readiness, yet at relatively high cost. This could point towards an “Economy-of-scale” issue, where market conditions prevent the initial deployment of technologies, as it would be necessary for reducing cost by increasing production volume. Power based processes to the lower right are strongly dependent on energy prices but are attractive as long as power is available as a low-cost source. Processes to the lower left have to show, if they can operate in higher TRL for the same costs. Processes to the higher left will possibly become attractive either through development in higher TRL or low cost feeds.

Figure 1: Overview of the cost and maturity of selected Value Chains relevant for this implementation plan.



ANNEX III: Flagship Projects Overview

Stakeholders and Member States representatives participating to this Working Group were asked to provide information on relevant flagships activities.

These were defined according to the guidelines in the document *"Common principles guiding temporary Working Groups to prepare Implementation Plans"* as "prominent ongoing R&I activities contributing to achieving the (SET Plan) targets and of interest to the public at large".

The document also explains that " A Flagship activity can be a project or programme considered as the best example of what R&I can achieve in a given sector or with a specific technology towards reaching the SET Plan targets. It is not necessarily the largest and does not necessarily draw the highest financial volume. The innovation potential and the possibility of establishing a positive public image are key, as well as a capacity to "lead by example". The results of such a project or programme are expected to make a real difference."

The list of projects proposed by the participants as flagships is available in the table below, listed in alphabetic order by Member States. The details regarding each project can be consulted in the embedded file, which is ordered by valued chains.

Project	Country	Value Chain	Budget	Timescale
Heat-to-Fuel	Austria	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL: gasification and hydrotreatment	6 M€	2017 - 2021
Güssing Gasifier	Austria	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL: gasificaton and chemicals	n.a.	2018 - 2023
Winddiesel	Austria	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL: Electrolysis, gasification and Fischer-Tropsch to liquid hydrocarbons	150 M€	Not yet defined
bioCRACK / bioBOOST	Austria	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL: pyrolysis + refining	12 M€ (Current expenses)	On-going
Austrocel Hallein GmbH	Austria	LIQUID ADVANCED BIOFUELS – BIOCHEMICAL : Fermentation	40 M€	2019/2020+
OSCYME	Austria	LIQUID ADVANCED BIOFUELS – BIOCHEMICAL : Enzymatic hydrolysis	n.a.	2017+

Ammonia – to - Power	Austria	GASEOUS ADVANCED BIOFUELS – THERMOCHEMICAL	n.a.	2017+
CO2USE and follow-up project CO2USE+EPP)	Austria	Algae-based Fuels	1 M€	On-going
Decentralized hydrogen production from renewable resources	Austria	RENEWABLE HYDROGEN - THERMOCHEMICAL	n.a.	2001 – on-going
CO2-free logistics	Austria	RENEWABLE HYDROGEN - ELECTROCHEMICAL: Power to hydrogen	2.125.000 €	2018 – 2021
H2Future/Steel plant	Austria	RENEWABLE HYDROGEN - ELECTROCHEMICAL: Power to hydrogen	18 M€ (12 M FCH contribution)	2017 - 2021
DEMO4GRID	Austria	RENEWABLE HYDROGEN - ELECTROCHEMICAL: Power to hydrogen	7,7 M€ (2.9 M FCH contribution)	2017 - 2022
TORERO	Austria	INTERMEDIATE BIOENERGY CARRIERS - Torrefaction	11,5 M€	2017 - 2020
Haacke Pilot Plant	Austria (Brazil)	GASEOUS ADVANCED BIOFUELS – BIOCHEMICAL: anaerobic digestion + methane upgrading	81.950 € (pre-feasibility study)	2016
AVEDORE UNIT 2 PLANT	Denmark	BIOENERGY - COGENERATION	n.a.	Already commercial
4Refinery	Denmark and other partners	INTERMEDIATE BIOENERGY CARRIERS - hydrothermal liquefaction	6 M€	2017-2021
MefCO2	EERA Bio	OTHER RENEWABLE LIQUID AND GASEOUS FUELS - Power to liquid (methanol)	11.041 537,46 €	2014-2019
AMBITION	EERA Bio	OTHER RENEWABLE LIQUID AND GASEOUS FUELS - thermochemical and Biological processes	2,5 M€	2016-2019
BTL2030	Finland	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL	2,7 M€ (1st phase)	On-going (1st phase 2016–2018)

Neste oil Porvoo refinery	Finland	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL: Oil refinery co-feed	Confidential	On-going
Integration to refinery co-feed	Finland	INTERMEDIATE BIOENERGY CARRIERS - pyrolysis and direct liquefaction	5 M€	On-going
Äänekoski bioproduct mill	Finland	BIOENERGY - COGENERATION	1,2 Billion €	2015-2017
COMSYN	Finland, Denmark and other partners	INTERMEDIATE BIOENERGY CARRIERS - BTL production and upgrading	5 M€	2017-2020
Balance (EU-ECRIA)	Finland, Denmark and other partners	RENEWABLE HYDROGEN - ELECTROCHEMICAL: Power to hydrogen	2.856 096,25€ (EU Fund 2.500.596,25 €	2016 - 2019
BioTFuel	France	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL	178,1 M€, (including 33,2 M€ state funding)	2019+ (for commercial deployment)
Futurol	France	LIQUID ADVANCED BIOFUELS – BIOCHEMICAL	76,4 M€, (including 29,9 M€ state funding)	
TOSYNFuel	Germany	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL	22 M€	2019 - 2023
BIOLIQ	Germany	LIQUID ADVANCED BIOFUELS – THERMOCHEMICA:Synthetic fuels via bio-slurry gasification	n.a.	Ongoing (since 2005)
VERBIO	Germany	GASEOUS ADVANCED BIOFUELS – BIOCHEMICAL: anaerobic digestion + methane upgrading	Confidential (22 M€ NER300)	2014-2019
REFHYNE/Shell refinery	Germany	RENEWABLE HYDROGEN - ELECTROCHEMICAL: Power to hydrogen	16 M€(10M FCH contribution)	2018 - 2023
FlexiPEM	Germany and France	RENEWABLE HYDROGEN - ELECTROCHEMICAL: Power to hydrogen	Confidential	2015 – on-going
Gela Green Refinery	Italy	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL:	240 M€	2016 - 2018

		hydrotreatment		
Eny Refinery	Italy	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL: hydrotreatment	2 M€	Planned
Eny Refinery	Italy	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL: hydrotreatment	4 M€	2018 - 2019 (R&D project only)
ENI Refinery	Italy	LIQUID ADVANCED BIOFUELS – BIOCHEMICAL : Microbial fermentation / Hydrotreatment	4 M€	2018 – 2019
GoBioM	Italy	GASEOUS ADVANCED BIOFUELS – THERMOCHEMICAL	1,3 M€	2016 - 2018
BioMethER	Italy	GASEOUS ADVANCED BIOFUELS – THERMOCHEMICAL	3.375.465 €	2013-2018 (delayed)
Social Energy	Italy	GASEOUS ADVANCED BIOFUELS – BIOCHEMICAL: anaerobic digestion	1,6 M€	2017-2019
CO2 Biofixation Incubator Plant	Italy	Algae-based Fuels - lipid accumulation	6 M€	2017-2018
WASTE TO FUEL - Gela refinery	Italy	INTERMEDIATE BIOENERGY CARRIERS - hydrothermal liquefaction	1,5 M€	2017 - 2018
Bio4Fuels	Norway + other partners	BIOENERGY - COGENERATION: Gasification, Liquefaction (Pyrolysis & HTL), Fermentation to bio-alcohols, Anaerobic fermentation to Biogas	32,5 M€	2017 - 2024
FCH demo projects on Transport: CHIC, HyFive, JIVE, JIVE-2, H2ME2	Several partners	RENEWABLE HYDROGEN - ELECTROCHEMICAL: Power to hydrogen	n.a.	2016 - 2023
FCH Regions Initiative	Several partners	RENEWABLE HYDROGEN - ELECTROCHEMICAL: Power to hydrogen	372 M€	2017 - 2019
BECOOL and BIOVALU	Spain	LIQUID ADVANCED BIOFUELS – BIOCHEMICAL	n.a.	2017-2021
RenFuel,	Sweden	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL	14 M€	On-going (1st phase 2015 – 2018)

PSI's catalytic fluidized bed technology	Switzerland	OTHER RENEWABLE LIQUID AND GASEOUS FUELS - Power to Gas (methanation)	1,2M CHF	2016-2017
DELFTAB	The Netherlands	LIQUID ADVANCED BIOFUELS – BIOCHEMICAL - Biorefinery	n.a.	2018-2022
HOST	The Netherlands	GASEOUS ADVANCED BIOFUELS – THERMOCHEMICAL	n.a.	n.a.
AMBIGO	The Netherlands	GASEOUS ADVANCED BIOFUELS – THERMOCHEMICAL (Syngas to methane)	25 M€	2018 - 2020
Photanol	The Netherlands	Algae-based Fuels - artificial solar capture	n.a.	n.a.
EMPYRO	The Netherlands	INTERMEDIATE BIOENERGY CARRIERS - pyrolysis	n.a.	n.a.
NEREDA	The Netherlands	BIOENERGY - COGENERATION	n.a.	n.a.
Chain Craft	The Netherlands	BIOENERGY - COGENERATION (waste to energy)	n.a.	2014 - 2020

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It must be noted that flagships presented in this context are dealt differently compared to other Implementation Plans endorsed before this one for Action 8. Some plans have not arised flagships at all, some have picked some projects, some mixture of projects and activities and some really general, higher level broad activities or sub-sectors.

In this plan the value chains can be regarded as flagships. No individual project is raised over others to be excellent flagships over other projects. Since the sector is hopefully developing even faster in coming years, any present individual project could hardly be an excellent flagship for long time. Under each value chain, i.e. flagship activity there are diffent kind of projects on different TRL levels.

Moreover, all Member States representatives were also asked to indicate max two most prominent activities for their Country. The highlighted flagships were recommended by 6 Member States and are listed in the table below.

Project	Country	Value Chain

AMBIGO	The Netherlands	GASEOUS ADVANCED BIOFUELS – THERMOCHEMICAL (Syngas to methane)
EMPYRO	The Netherlands	INTERMEDIATE BIOENERGY CARRIERS - pyrolysis
VERBIO	Germany	GASEOUS ADVANCED BIOFUELS – BIOCHEMICAL: anaerobic digestion + methane upgrading
BIOLIQ	Germany	LIQUID ADVANCED BIOFUELS – THERMOCHEMICA:Synthetic fuels via bio-slurry gasification
RenFuel,	Sweden	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL
ENI Refinery	Italy	LIQUID ADVANCED BIOFUELS – BIOCHEMICAL : Microbial fermentation / Hydrotreatment
CO2 Biofixation Incubator Plant	Italy	Algae-based Fuels - lipid accumulation
BTL2030	Finland	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL
Äänekoski bioproduct mill	Finland	BIOENERGY - COGENERATION
BioTFuel	France	LIQUID ADVANCED BIOFUELS – THERMOCHEMICAL
Futurol	France	LIQUID ADVANCED BIOFUELS – BIOCHEMICAL

ANNEX IV – Working Group Composition

SET Plan Temporary Working Group (TWG)
Action 8: Renewable fuels and Bioenergy

National Representatives (Countries)	
FI **(TWG CHAIR)**	Shared chairmanship with IT: Timo RITONUMMI
IT **(TWG CHAIR)**	Shared chairmanship with FI: Franco COTANA
FR	Xavier MONTAGNE Alternate: Jean Christophe VIGUIE
AT	Theodor Zillner Alternate: Kurt Pollak
BE	Laurence POLAIN Alternate: Lut BOLLEN
CY	Alex LUPION-ROMERO Alternate: Paris FOKAIDES
DE	Birger KERCKOW Alternate: Katja Tschetschorke TSCHETSCHORKE (ALTERNATE)
ES	Carlos Garcia Barquero Alternates: Pilar Gonzalez Gotor M. Luisa Revilla
NL	Kees Kwant
PT	Isabel CABRITA Paulo PARTIDARIO
SE	Greger LEDUNG (MEMBER) Alternate: Jonas LINDMARK
TR	Çağrı YILDIRIM (MEMBER) Alternate: İlknur YILMAZ

Stakeholders	
ETIP Bioenergy (TWG Co-Chair)	Renè Venendaal (CHAIR) Ingvar Landälv (Lulea) Bjorn Fredriksson Moeller (EON – chair alternate)
ETIP RHC	Rainer Janssen
EERA Hydrogen	Peter Holtappels Stephen Mcphail
EERA Bioenergy	Juan Carrasco
FCH-JU	LYMPEROPOULOS Nikolaos
EUBIA	Drilona Shtjefni Giuliano Grassi
EPPSA	Ermenegilda Boccabella Maria Joao Duarte Patrick Clerens
EBA	Martina Conton Patrick Wellinger
Neste	Sari Kuusisto
DONG energy	Niels Henriksen
Technical Research Centre of Finland Ltd (VTT)	Eija Alakangas Niels-Olof Nylund Antti Arasto
IFP Energies Nouvelles (IFPEN)	Gilles FERSCHNEIDER Jean Christophe Viguie
Ente Nazionale Idrocarburi (ENI (Italy)	Alberto Del Bianco
Fraunhofer Institute for Environmental, Safety, and Energy Technology (UMISICHT)	Andreas Hornung
European University Association	Borana Taraj
EC Participants	
DG JRC D.1	Luisa MARELLI

DG RTD G.3	Maria GEORGIADOU
DG RTD G.3	Thomas SCHLEKER
DG ENER C.2	Kyriakos MANIATIS
Support and Consultation	
DG JRC C.4 –Senior active	Heinz OSSENBRINK
ETIP BIOENERGY - Chair of Work Group 2	Lars WALDHEIM