CORE-JetFuel

Coordinating research and innovation in the field of sustainable alternative fuels for aviation

WP6: Synthesis of Results and Recommendations

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CORE-JetFuel

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Deliverable 6.3:
Report on Recommendations

SUBMITTED VERSION 1.0

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Work Package 6: Synthesis of Results and Recommendations
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EXECUTIVE SUMMARY

One of the main objectives of the CORE-JetFuel project was to provide the European Commission with recommendations concerning the re-orientation and re-definition of its funding strategy with respect to R&I activities in the field of alternative aviation fuels. CORE-JetFuel provided essential decision and strategy elements to achieve the best returns from future research and innovation actions in the field of sustainable aviation fuels within the constraints of the inherent uncertainty in the nature of science and innovation.

In order to achieve this objective, the CORE-JetFuel project conducted a twofold assessment along the entire value chain of alternative aviation fuels. On the one hand, the performance of selected renewable jet fuel production pathways was evaluated in terms of their environmental and social sustainability, the maturity of feedstock production and conversion, the overall production potential as well as their economic viability. On the other hand, the R&I project 'landscape' of renewable jet fuels was evaluated in order to highlight needs in research.

In addition, deployment and certification initiatives as well as policies and regulations addressing alternative aviation fuels at Member State, European and international level have been analysed with the objective of identifying the main barriers to renewable jet fuel production and deployment. The project's assessment activities and derived recommendations were presented to and discussed with experts in the field on occasions of the numerous CORE-JetFuel workshops that took place over the entire project duration, thereby safeguarding transparent results and minimizing potentially biased recommendation as much as possible.

This Report on Recommendations first summarizes the main assessment results of the project in order to provide the factual basis for the subsequent recommendations as well as to establish a reference to the project work.

For the purpose of seamless accessibility, all recommendations are briefly summarized with corresponding potential courses of action in the conclusions at the end of the report. The most important recommendations of the CORE-JetFuel project include:

- As the regional availability of biomass has a direct impact on the renewable jet fuel production costs, the sustainable feedstock production potential and its geographical distribution in Europe have to be assessed in more depth.
- Decrease the costs of feedstock production in the near-term by developing small-scale production sites and a network of supply chains
- Complement the set of key performance indicators with indicators for future potentials for climate impact and European energy supply security. Develop fuel technologies with simultaneous advantages in cost efficiency, scalability, sustainability and feedstock supply security
- Balance technology development risks with an adequate level of rewarding GHG reduction potentials. Maintain a balanced R&D portfolio to enable short-term innovation and to create long-term innovation opportunity. A healthy balance between use-inspired

basic science on potentially impactful “high-risk” fuel production technologies (“Pasteur’s quadrant”) and development of more mature technologies (“Edison’s quadrant”), and support the linkage between the two by turning new knowledge of innovation opportunity into real technological innovation

- Decrease the industrial risk of producing renewable jet fuel within a highly moving world of fossil crude and fuel prices, by securing the production through long term contracts and/or partnerships with airlines, oil companies, national defense/civil administration, Government departments.
- Count renewable jet fuels towards the obligation of fuel suppliers in several EU Member States (opt-in)
- Push for Market-based Measures (MBM) with revenue generation geared towards innovation in the aviation sector
- Stimulate innovation and projects in the supply chain to reduce the costs for renewable jet fuel stimulate innovation throughout the supply chain. Policy making can be directed to the removal of existing barriers through direct funding support

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LIST OF ABBREVIATIONS

ACARE	Advisory Council for Aviation Research and Innovation in Europe
AFTF	Alternative Fuels Task Force
aireg	Aviation Initiative for Renewable Energy in Germany e.V.
AJF	Alternative Jet Fuel
ANL	Argonne National Laboratory
APR	Aqueous Phase Reforming
ARA	Applied Research Associates
ASCENT	Aviation Sustainability Center
ASTM	American Society for Testing and Materials
AtJ	Alcohol-to-Jet
BIC	Biofuels IsoConversion
BPD	Barrel per Day
BtL	Biomass-to-Liquid
CAAFI	Commercial Aviation Alternative Fuel Initiative
CapEx	Capital Expenditure
CCE	Camelina Company España
CH	Catalytic Hydrothermolysis
CHJ	Catalytic Hydrothermolysis Jet
CLG	Chevron Lummus Global
CO_2	Carbon Dioxide
CtL	Coal to Liquid
DG	Directorate General
DOE	Department of Energy
DPA	Department of Agriculture
DPA	Defence Production Act
DSHC	Direct Sugar to Hydrocarbon (now called SIP)
EC	European Commission
EIBI	European Industrial Bioenergy Initiative
EPA	Environmental Protection Agency

EPC	Engineering, Procurement and Construction
ETS	European Trading Scheme
EU	European Union
FAA	Federal Aviation Administration
FQD	Fuel Quality Directive
FT	Fischer-Tropsch
FT-SK	FT Synthetic/Synthesized Paraffinic Kerosene
FT-SPK/A	FT SPK base with the addition of alkylated mono-aromatics
GHG	Greenhouse Gas
GMBM	Global Market-Based Measure
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
HDCJ	Hydrotreated/Hydroprocessed Depolymerized Cellulosic Jet
HDO SK	Hydro-DeOxygenated Synthetic/Synthetized Kerosene
HEFA	Hydroprocessed Esters and Fatty Acids
HFP HEFA	High Freezing Point Hydroprocessed Esters and Fatty Acids (Green Diesel)
HFS	Hydrotreated Fermented Sugar(s)
HPO	Hydrogenated/Hydrotreated/Hydroprocessed Pyrolysis Oil
HVO	Hydrogenated/Hydrotreated/Hydroprocessed Vegetable Oil
ICAO	International Civil Aviation Organization
ILUC	Indirect Land Use Change
ISAFF	Italian Sustainable Aviation Fuel Forum
ITAKA	Initiative Towards sustAinable Kerosene for Aviation
LCA	Lifecycle Analysis
LUC	Land Use Change
MCA	Multi-Criteria Assessment
Mgpy	Million gallons per year
MSW	Municipal Solid Waste
NISA	Nordic Initiative for Sustainable Aviation
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturers
OpEx	Operational Expenditure
PM	Particulate Matter

PNNL	Pacific Northwest National Laboratory
PtL	Power-to-Liquid
R&D	Research and Development
R&I	Research and Innovation
RED	Renewable Energy Directive
RFS	Renewable Fuel Standard
RSB	Roundtable on Sustainable Biomaterials
SAFUG	Sustainable Fuel Users Group
SAJF	Sustainable Alternative Jet Fuel
SAK	Synthetic/ Synthesized Aromatic Kerosene
SIP	Synthetic/Synthesized Iso-Paraffins (Iso-C15 farnesane) from hydroprocessed fermented sugar (formerly called DSHC)
SK	Synthetic/Synthesized Kerosene
SKA	Synthetic/Synthesized Kerosene with Aromatics
SPK	Synthetic/Synthesized Paraffinic Kerosene
StL	Sun-to-Liquid
TRIC	Tahoe Reno Industrial Center
TRL	Technology Readiness Level
UCO	Used Cooking Oil
USDA	US Department of Agriculture
VO	Vegetable Oil
WP	Work Package
WtW	Well-to-Wake

Introduction

One of the main objectives of the CORE-JetFuel project is to provide the European Commission with recommendations concerning the re-orientation and re-definition of its funding strategy with respect to R&I activities in the field of alternative aviation fuels. CORE-JetFuel provides essential decision and strategy elements to achieve best returns from future research and innovation actions in the field of sustainable aviation fuels within the constraints of the inherent uncertainty in the nature of science and innovation.

In order to meet this objective, the project covers the entire renewable jet value chain, which is divided into four thematic domains, namely: feedstock and sustainability, conversion technologies and radical concepts, technical compatibility, certification and deployment as well as policies, incentives and regulation.

In each of these domains a twofold assessment has been conducted. On the one hand, R&D activities in the field have first been collected and then mapped by applying D.E. Stokes' Quadrant Model, which organizes a research portfolio in pure basic research, use-inspired basic research and pure applied research. In correlation with the funding volumes of the collected R&D activities, the model provided the project consortium with a good impression of the current status of the European renewable jet research portfolio and allowed for indications in which areas of the field more research is required in the short- medium- and long-term.

On the other hand, an assessment of selected production chains has been conducted. In order to ensure transparent evaluation of the pathways selected, an assessment framework has been established in the beginning of the project that defined important assessment criteria and the corresponding metrics such as Feedstock and Conversion Technology Readiness Levels (FRL, TRL), GHG emission reduction potential over the life-cycle of the product, greenhouse gas (GHG) emissions emerging from feedstock production and conversion as well as metrics pertaining to production scaling and economic competitiveness. In addition, an analysis of deployment initiatives, currently certified and soon to be certified production pathways was undertaken in the course of the project.

Apart from the technological assessments described above, policies and the current existing gaps addressing alternative aviation fuels at national, European and international level have been analysed and compared to each other with the objective of identifying the main barriers to renewable jet production and deployment.

Based on the assessment results as well as input retrieved in context of the series of workshops organized by the project, the report at hand features the main recommendations of the CORE-JetFuel project. The chapters hereby correspond to the thematic project structure. First, the main results will be briefly introduced, subsequently to which recommendations are given.

1 Feedstock and Sustainability

Fuels based on biogenic types feedstock will apart from technical improvements in aircraft design be the only viable option for the aviation sector to decrease its GHG footprint in the near- to medium-term. While oily crops such as rapeseed are generally well established and utilized for the production of biodiesel by the road transport sector in Europe, aviation is reluctant to utilize these types of feedstock due to a number of sustainability concerns linked to their cultivation. Negative environmental impacts such as eutrophication as well as significant GHG emissions as a consequence of fertilization, the risk of inducing indirect land use changes and competition with food production are just a selection of the most prominent negative impacts that are often brought forward.

On the other hand, advanced types of feedstocks such as lignocellulosic biomass or residue material from agriculture and forestry do have several advantages in terms of their sustainability (and availability), but they are either at a low Feedstock Readiness Level (FSRL), meaning that their production is accompanied by logistical challenges and generally at a technically immature level, or there are already well-established markets in place. In case of agricultural residue material, i.e. straw, particularly the heating and cooling sector can be regarded as a major competitor that is already utilizing straw as well as wood pellets based on forestry residues at industrial scale. In addition, the relatively difficult and expensive conversion of woody / advanced types of feedstock decreases their economic viability, particularly in light of the current low oil price but also compared to oily crops that can be converted into biojet via the well-established HEFA pathway (cf. Chapter 3).

In general, recommending one single feedstock that can be sustainably produced, is sufficiently available at an acceptable price for the various application sectors in Europe, and does additionally not compete with food production is neither possible nor advisable. In order for the aviation sector to reach its GHG reduction targets until 2050, a broad range of different types of feedstock (and corresponding flexible conversion technologies) will be needed.

Deliverable 4.2 of the CORE-JetFuel project therefore analyzed a variety of different biogenic feedstocks by applying a set of sustainability indicators, the GHG balances of feedstock production, i.e. cultivation and further processing being the most important indicator.

In addition to the assessment of different feedstock types, the R&D landscape in the area of feedstock and sustainability was analyzed by applying Stokes' Quadrant Model, which helps organizing a research portfolio into pure basic research, use-inspired basic research as well as pure applied research. By mapping R&D activities across the different quadrants, the model gives an indication on the current focus and correlated funding of research activities and thereby allows drawing conclusions in which areas of feedstock R&D more engagement and higher levels of funding are required, respectively.

The following sections therefore feature recommendations that refer both to the technology level in terms of feedstock production and its sustainability as well as to recommendations that are based on mapping the R&D landscape of alternative aviation fuels, in the case at hand, projects that are allocated in feedstock production and / or research.

Furthermore, input from experts in the field of feedstock R&D has been retrieved on occasion of the various stakeholder workshops organized by the CORE-JetFuel project. Some of the expert statements are also included in the following chapters in order to safeguard a holistic view based on the assessments conducted in course of the project as well as on experts in the field.

1.1 Main Results

1.1.1 Assessment of feedstock sources and supply chains

The assessment of various feedstock sources suitable for the production of alternative jet fuels is conducted in CORE-JetFuel Deliverable 4.2. The following paragraphs can be understood as very brief summaries that highlight the most important assessment results.

Due to the vast theoretical production potential of **microalgae**, they have received a lot of attention in recent years by science, policy and industry alike as a promising bio- (jet) fuel feedstock. However, in order to reach the desired lipid content and overall biomass productivity, microalgae cultivation requires considerable amounts of fertilizers. In addition, keeping the aquatic biomass in motion, either in closed photobioreactors or open pond systems requires a lot of energy. From both of these requirements considerable GHG emissions emerge. Algae production particularly in closed photobioreactors is additionally technically immature and very expensive. If microalgae are to become an economically and environmentally viable feedstock for the production of alternative aviation fuels, sufficiently scalable CO_2 sources for example from industry, a reduction of fertilizer as well as energy requirements will be crucial in order to reduce the price of cultivation and increase its sustainability.

Camelina is a promising feedstock for sustainable biojet fuel production with a high GHG emission reduction potential of the end product bio-kerosene. Sustainability advantages of this terrestrial oil crop are its relatively low fertilizer and irrigation requirements, its adaptability to arid and semi-arid climatic conditions as well as the fact that the crop can be cultivated on marginal / degraded land in intercropping systems. However, the large range of oil yields in different regions of Europe and the currently uncertain production potential of camelina hamper its large-scale utilization as a renewable jet fuel feedstock (cf. Table 1).

Although **rapeseed** is not the preferred feedstock option of the aviation sector due to a number of sustainability concerns such as high fertilizer requirements with the corresponding GHG emissions, it is nevertheless the most widely cultivated energy crop in Europe. It is for this reason that the energy crop is included in the CORE-JetFuel assessment, i.e. it serves as a reference case in terms of oil yield, production potential and sustainability performance for the other feedstocks that are subject to the CORE-JetFuel assessment. Particularly its high oil content as well as its high yields per hectare make rapeseed the most widely utilized feedstock for biofuel production in Europe. However, the unfavorable GHG balance of rapeseed production and other negative environmental impacts linked to its cultivation and the general discussion about food crop-based biofuels are all reasons why the aviation industry does currently not give priority to this feedstock. If the costs of renewable jet production via the HEFA pathway further decrease, this might change.

Used Cooking Oil (UCO), i.e. waste oils from gastronomy are a well-established renewable jet fuel feedstock that is like other waste and residue materials favored by the RED, which considers their collection carbon neutral. In addition, fuels based on UCO are eligible to double-counting and therefore show a considerable GHG emission reduction potential of up to 80% compared to fossil fuels. However, seeing as the collection network is well organized and the market for UCO flourishing, the maximum availability of approximately 1Mt per year is already reached. Collecting UCO from private households could potentially increase the availability to 3Mt per year, but due to the immense challenges in collection and quality control it is not very likely that this potential will be unlocked in the near future.

Short rotation coppices (SRC) such as willow or poplar are an interesting feedstock for renewable jet fuel production due to their fast-growing nature, low fertilizer requirements as well as a non-existent competition with food production. Negative traits of SRC include their high water requirements. In addition, particularly logistical challenges in collecting and transporting this type of feedstock may hamper its economic viability– at least with respect to large-scale plantations.

Waste and residues as a side product of wheat production, for example, have a series of sustainability advantages compared to those types of feedstocks that are cultivated and directly utilized for bioenergy applications. In particular the very high GHG emission reduction potential of fuels based on straw, its high availability and the low risk of inducing indirect land use changes make it a preferred feedstock for the aviation industry. However, a strong competition exists with other bioenergy and biomaterial sectors where agricultural residues such as straw are well-established and utilized at industrial scale. Apart from industrial uses, straw also fulfills a series of on-site functions at farm level such as supplying soils with nutrients or functioning as animal bedding. Depending on indicators for calculating the sustainable removal rate of residues and their importance for soil (nutrient supply, erosion protection), the availability of waste and residues can vary considerably, particularly in case of forestry residue material. Comparable to SRC, the collecting of waste and residues is also linked to certain logistical challenges.

Table 1 shows some of the most important feedstock traits that were considered in D4.2, in which a more detailed overview is given.

Table 1: Overview of assessed feedstocks

Feedstock Group	Source	Lipid / Energy Content	GHG balance	Yield / Productivity	Production in Europe	Production Potential / Availability
Oils and Fats	Microalgae	15 – 60% (dry weight)[1]	45 – 550 g CO_2 eq./MJ[2]	Open Pond: 5 – 25g/m^2/day PBR: 60 – 650 g/m^2/day[1]	9.200t (2015)[3]	Europe: 41Mt/y (technical potential)[4]
	Camelina	35 – 45% dry weight)[5]	Cultivation: 40.2 g CO_2 eq./MJ Oil extraction: 12.3 g CO_2 eq./MJ[6]	0.34 2.24 t/ha – 2240kg/ha[5]	500 – 2000t/ha[5]	N/A

[1] Petrick et al., 2013
[2] Bauen et al., 2009
[3] Rocca et al., 2015
[4] Skarka, 2015
[5] Moser, 2010
[6] Miller/Kumar, 2013

	UCO	N/A	RED: 0 g CO_2 eq./MJ up to collection	N/A	Europe: ~1 Mt/y[7]	Europe: ~3 Mt/y (households)
	Rapeseed	40 – 44% (dry weight)[5]	Cultivation: 50.4 g CO_2 eq./MJ Oil extraction: 10.7 g CO_2 eq./MJ	2.68 – 3.39 t/ha[5]	22Mt (2015)[8]	Europe: 22.4 Mt (2017)[7]
Lignocellulosic Biomass	SRC	Heating value at 15-25% moisture content: 16.7 – 19.7 MJ/kg	Bio-SPK: 49.1 g CO_2 eq./MJ	4 – 16 t/ha[9]	France: 2.4 Mt/yr Italy: 1.2 Mt/y[10]	Germany: 9.5 Mt/y (on 'very suitable' land)[9]
	Switchgrass	Heating value at 15-25% moisture content: 16.8 – 19.1 MJ/kg[11]	Cultivation: 17.6 – 39.7 g CO_2 eq./MJ	18 – 25 t/ha[12]	N/A	N/A
Waste and Residues	Agricultural	Heating value at 15-25% moisture content: 13MJ/kg	RED: 0 g CO_2 eq./MJ up to collection Straw removal: 10 g CO_2 eq./MJ Machinery and N fertilization: 23 g CO_2 eq./MJ[10]	3.75 t/ha (wheat straw)[13]	315.9 Mt/y[12]	Europe: 84.6 Mt/y (sustainable availability)[12]
	Forestry	Heating value at 15-25% moisture content: 17.5 – 20.8	RED: 0 g CO_2 eq./MJ up to collection Transportati on:		67.59 Mt/y[12]	Europe: 9.23 Mt/y (sustainable availability)[12]

[7] Alberici et al., 2013
[8] USDA FSA, 2016
[9] Tubby, 2002
[10] Aust et al., 2013
[11] Zeller et al., 2013
[12] Elbersen et al., 2010
[13] Searle/Malins, 2016

		MJ/kg[10]	8.25 kg CO_2 eq./MJ[10]			

1.1.2 R&D portfolio of feedstock and sustainability projects

The mapping of the R&D landscape was conducted according to the Quadrant Model of Research (Stokes, 1997), as depicted in Figure 1. This model allows for the distinction of pure basic research (Bohr's quadrant; devoted to knowledge creation), pure applied research (Edison's quadrant; product-oriented) and use-inspired basic research (Pasteur's quadrant). Activities located in Pasteur's quadrant link basic science with technological innovation and are neither purely "basic" nor purely "applied" in nature.

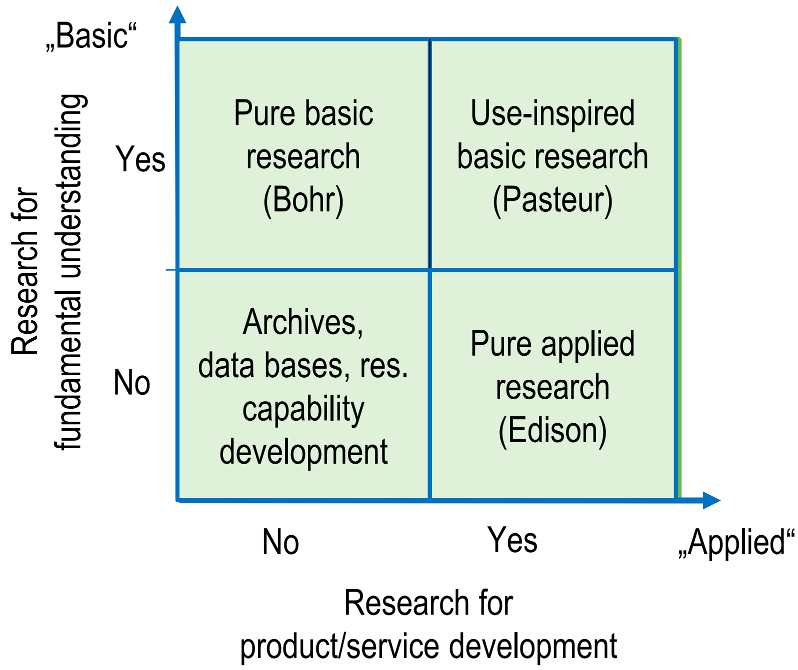
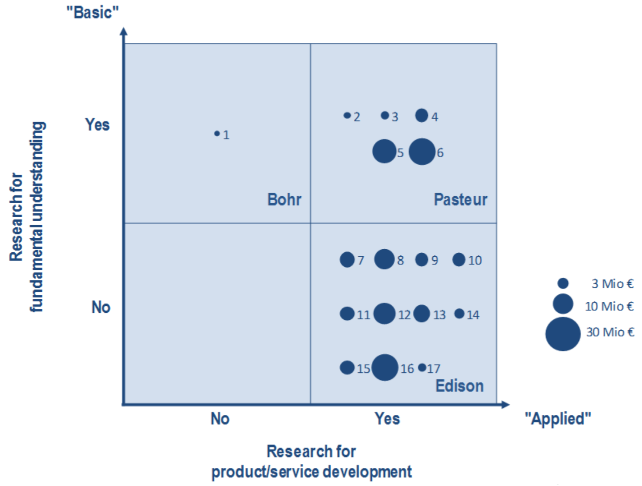


Figure 1: Quadrant model of research (Donald E. Stokes: „Pasteur's Quadrant – Basic Science and Technological Innovation"; The Brookings Institution, 1997)

The summarized results of the mapping of R&D activities in the area of feedstock and sustainability are presented in Figure 2 and Figure 3. It can be seen that the R&D portfolio and the corresponding funding is focused on pure applied research (Edison's quadrant). This means that the majority of the projects considered in the mapping are concerned with **increasing the FSRL of a certain feedstock type**, i.e. increasing the economic competitiveness or advancing current production systems in terms of their sustainability performance, achievable yields and so on.



Nr.	Project	Basic	Applied	Category	Volume
1	Aquafuels	Yes	No	Feedstock logistics	0.7 Mio€
2	4FCROPS	Yes	Yes	Algae oils	1.3 Mio€
3	Aufwind	Yes	Yes	Algae oils	1.7 Mio€
4	BABETHANOL	Yes	Yes	Lignocellulose	4.4 Mio€
5	EnAlgae	Yes	Yes	Algae oils	14.6 Mio€
6	ITAKA	Yes	Yes	Non-food bio oils	17.5 Mio€
7	BIOBOOST	No	Yes	Lignocellulose	5.7 Mio€
8	BIOFAT	No	Yes	Algae oils	10.0 Mio€
9	EUROPRUNING	No	Yes	Feedstock logistics	4.6 Mio€
10	INFRES	No	Yes	Lignocellulose	4.6 Mio€
11	LOGISTEC	No	Yes	Feedstock logistics	5.1 Mio€
12	MIRACLES	No	Yes	Algae oils	11.9 Mio€
13	OPTFUEL	No	Yes	Lignocellulose	7.2 Mio€
14	PROETHANOL2G	No	Yes	Lignocellulose	2.5 Mio€
15	S2Biom	No	Yes	Lignocellulose	5.2 Mio€
16	SUPRA-BIO	No	Yes	Lignocellulose	17.5 Mio€
17	Recoil	No	Yes	Non-food bio oils	1.5 Mio€
	Total volume				116.2 Mio€

Figure 2: Feedstock-related R&D portfolio showing the share of total project budgets in pure basic research, use-inspired basic research and pure applied research.

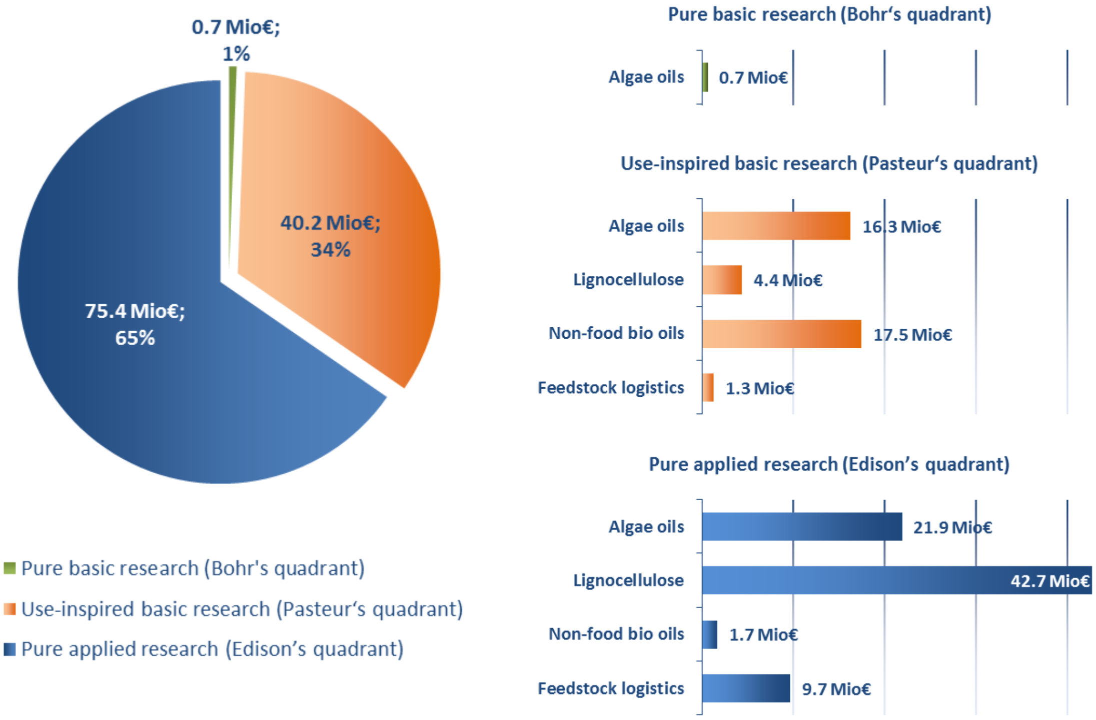


Figure 3: R&D portfolio identified by CORE-JetFuel in the area of feedstock & sustainability / quadrant-specific funding volumes

Considering the highly product-oriented field of research that is aviation as well as other sectors utilizing the same feedstocks as aviation, the distribution shown in Figure 3 was expected. It is, however, interesting that only four projects that are allocated in Pasteur's Quadrant (use-inspired basic research) make up approximately one-third of the total funding volume, i.e. 40.2 Million Euro or 34%. The projects allocated in Pasteur's Quadrant are so-called flagship projects with considerable amounts of funding.

In general, it has to be mentioned that it is difficult to identify projects that are solely concerned with a single type of feedstock and its production, respectively. The European R&D activities rather consider an entire production chain or parts of it, for example from cultivation to conversion or improving the logistics of a certain type of feedstock.

1.2 Recommendations

1.2.1 Assess the sustainable biomass availability in Europe and its geographical distribution

As the **regional availability of biomass** has a direct impact on the renewable jet fuel production costs, the sustainable feedstock production potential and its geographical distribution in Europe have to be assessed in more depth. Although some stakeholders of the CORE-JetFuel project are of the opinion that this topic is sufficiently covered in the literature and by European R&D activities, the CORE-JetFuel findings have nevertheless shown the need for such an assessment.

Although a certain type of feedstock might theoretically be available in large quantities, if its collection is technically too challenging, for example because the feedstock is widely dispersed, making it available might not be economically worthwhile due to long transport distances. Assessments with the objective of establishing the regionally available biomass potential coupled with an assessment of feedstock production costs (logistics, distance to processing sites etc.) could potentially help in defining areas that are economically favorable for sustainable feedstock production[14].

In addition, the sustainable availability of a certain type of feedstock, e.g. residue material, may vary significantly in the literature due to different assumptions concerning sustainable removal rates and other sustainability indicators. Here, a uniform approach is recommended.

If the competition for biomass across different application sectors is additionally taken into account, demand will most likely surpass the sustainably achievable supply. It is therefore essential to introduce strict sustainability criteria that ensure sound agricultural practices and minimize indirect land uses changes as a consequence of feedstock production.

1.2.2 Decrease the costs of feedstock production by developing small-scale production sites and a network of supply chains

As was mentioned in the introduction of this chapter, the aviation industry is very concerned with utilizing only those types of feedstocks that show a very good sustainability performance, which applies according to current assessments in the field mainly to lignocellulosic biomass or waste and residues, so-called advanced types of feedstock.

However, apart from competing uses with other application sectors that particularly in case of residues need to be taken into account, collecting these types of feedstocks is still somewhat challenging and therefore capital-intensive. In light of the very little progress that has been made in utilizing advanced types of feedstock for the production of actual quantities of bio-kerosene, new ways of kick-starting production have to be found.

As opposed to the petrochemical industry, where economies of scale ("bigger is better") is the guiding concept, for alternative aviation fuels this concept and its appropriateness has to be re-evaluated, at least in the near-term. Particularly in case of lignocellulosic biomass such as short rotation coppices

[14] An example of such an approach is the S2Biom project (www.s2biom.eu)

(SRC), shifting to **small-scale applications**, i.e. small-scale conversion plants with the corresponding small collection radius will take away large parts of the logistical challenges as well as challenges in building a network of supply chains - and therefore ultimately contribute to decreasing the price of renewable jet fuel.

Particularly in case of lignocellulosic biomass, the advantages of **decentralized production** incentives are comparably small capital investments with the corresponding smaller risk, which is particularly from an investor's point of view a crucial factor for making a business case with the production of sustainable alternative aviation fuels. Although building large-scale facilities for the conversion of lignocellulose is not recommendable at the moment, linking and coordinating these decentralized initiatives at larger scale is nevertheless important. **A combination of densifying the energy carrier in a first, decentralized step and then converting it into renewable jet fuel in a second, centralized step would also be a viable and practical option.**

Small-scale (and decentralized) production sites have the additional advantage of generating socio-economic benefits for the local population, which will increase the acceptance of renewable jet fuel production and therefore contribute to the social sustainability of alternative aviation fuels – an issue that is often neglected in the discussion about renewable jet fuel production. The conversion itself, however, should as mentioned above take place in a centralized refinery, inter alia due to safety concerns.

Although the focus of the aviation sector is placed on utilizing advanced types of feedstock, it is not in the position to exclude any types of feedstock. If the GHG emission reduction targets are to be met, **all sustainably available biomass has to be utilized**. It is not a matter of picking the "winning" feedstock and corresponding conversion technology, but instead a basket of various, fully established value chains will be needed. In order to set up these production chains considerable investments will be required.

Another way of decreasing the costs of alternative aviation fuels is to **take advantage of synergies** in terms producing jet fuel as a side product of more valuable products, i.e. co-processing. The costs of feedstock cultivation and further processing are generally very much dependent on the regional feedstock availability as well as the logistics of biomass procurement, which was addressed above.

Another issue that is rarely addressed in current projects is the **unforeseeable impact of climate change on feedstock production**, particularly in the timeframe until 2050. If areas of high biomass productivity were to become unsuitable for feedstock production due to extreme weather conditions, fuel costs will most likely increase and reverse the desired cost competiveness of renewable jet fuel with conventional fuels. This is, in case renewable jet fuel reaches cost parity with fossil fuels at all someday. However, the already noticeable impact of climate change on food and feedstock production should be addressed more carefully in future R&D and deployment activities dealing with the production of any kind of biofuel.

1.2.3 Establish an integrated biomass policy for a smart use of the resources with a special attention to aviation needs

Competition for biomass between different application sectors is an issue that is vividly discussed between the different actors from policy, industry and academia, and has therefore been mentioned numerous times in the previous paragraphs. Apart from the competition for energy crops between the aviation sector and the road transport sector, particularly the competition between the well-established electricity, heating and cooling as well as biomaterial sector and aviation for advanced types of feedstock such as straw has to be addressed and coordinated if aviation is predominantly aiming at focusing its efforts on utilizing advanced feedstock types.

Due to the competition outlined above, **an integrated biomass policy that takes into account all biomass application sectors is recommended.** This is according to CORE-JetFuel stakeholders very much needed as the RED is in their view more a plan than a policy with numerous issues regarding biomass utilization not sufficiently addressed. Before the need for a prioritization is brought forward, an assessment of biomass demand sectors should be conducted in order to determine if a prioritization of biomass between the sectors is necessary.

Aviation representatives are often stating that the available biomass should be prioritized for the use by the sector, as fuels based on biogenic feedstocks will supposedly be the only option to decrease GHG emissions in the medium-term, while the road transport sector is in the position to shift to other propulsion systems such as electricity or fuel cells. If incentives in terms of GHG emission reduction are shifted to aviation, the proposed integrated biomass policy must include a strategy that states how GHG emissions of the road transport sector should be dealt with. In addition, as biomass availability in Europe will most likely not be sufficient for all application sectors, the strategic approach should therefore include wind and solar energy so that biomass sectors / potentials are freed.

In general, **synergies with the road transport sector** as well as other sectors requiring a lot of energy should be established and made use of, respectively.

1.2.4 Sustainability certification

In the European Union, all biofuels that are brought into the market, receiving governmental support and / or are counting towards renewable energy targets, have to comply with the sustainability requirements of the RED. To demonstrate the sustainability of a biofuel including the processing chain, all biofuels have to be checked by Member States or must comply with legally accepted 'voluntary' certification schemes that are recognized by the European Commission. The most prominent of the various voluntary schemes are RSB EU RED and ISCC EU. Although the two schemes are recognizing each other and the other certification schemes to a large degree already, **a higher level of mutual recognition / harmonization is considered as a desirable development.**

The advantage of harmonizing voluntary certification schemes recognized by the EC is that it provides a larger degree of flexibility in the supply of biomass from producers that are already certified by one or the other schemes. In addition and as outlined above, a mutual recognition of the different schemes avoids the need for certification under multiple schemes and therefore makes the process itself more cost efficient for feedstock and fuel producers, and ultimately for the end-user, for example airlines.

In addition, databases featuring input data that are being used for lifecycle assessments and other tools for certification should be improved in order to reach a comparative level on criteria regarding environmental impacts.

1.2.5 Include feedstock-focused research activities in R&D portfolio

Although it is **important not to detach feedstock cultivation, further processing and the accompanying costs from the desired end product**, particularly in aviation, in some cases though, focus should be placed solely on a single type of feedstock and its cultivation in order to make this production step more efficient, or in order to create more / deeper knowledge of plant genetics, photosynthetic efficiencies as well as other vital characteristics without necessarily aiming at technology applications.

This is especially true for the cultivation of microalgae, as renewable (jet) fuels based on this aquatic biomass are far from commercialization and focus should therefore be placed on the feedstock production itself. In order to make microalgae-based fuels a reality in the future, the environmental and economic viability of the cultivation process (particularly in PBRs) has to be increased.

Also in case of lignocellulosic biomass as well as agricultural residues, whose collection is often considered challenging, focusing R&D efforts on making this part of the production chain more efficient is recommended. Although feedstock collection does technically not belong to cultivation,

1.2.6 Increase share of pure applied research

In the special case of aviation, however, focusing R&D activities on pure-applied research on feedstock production and sustainability enables to reach a higher level of deployment and market penetration. At the same time and following the suggestion above, basic research should not be neglected as aviation (and other application sectors) will need a very broad and diverse set of (feedstock) options in order to reach its GHG emission reduction targets in the long-term.

In the near-term on the other hand, all efforts should be placed on fully utilizing the feedstocks that are currently available in order to reach higher production volumes and deployment of alternative aviation fuels. This would also assist in collecting experience along the entire renewable jet production chain, for example with respect to the currently only marginally cost-competitive HEFA conversion. Once other conversion technologies become available, advanced types of feedstock can be utilized. Before such feedstock types can be utilized at large-scale, a number of issues such as an efficient feedstock collection have to be resolved first.

2 Conversion Technologies, Radical Concepts and Holistic Assessment

The CORE-JetFuel Task 4.2 was dedicated to provide a comprehensive overview, mapping and evaluation of R&D activities related to conversion technologies, including mature as well as more radical and less developed approaches. The objective was to identify knowledge gaps and to draw a clear picture of further needs for specific R&D efforts in Europe. In order to analyze the potentials of different technology options in terms of environmental and techno-economic performance and impact, a holistic and comparative assessment of integrated production pathways was conducted.

2.1.1 Main Results

2.1.2 Selected conversion technologies and radical concepts

The following conversion technologies have been analyzed:

- Pyrolysis (Hydroprocessed Depolymerized Cellulosic Jet, HDCJ)
- Hydrothermal Liquefaction (HTL jet fuel)
- Fermentation of sugars to hydrocarbons (Synthetic Isoparaffinic Jet, SIP)
- Hydroprocessed Esters and Fatty Acids (HEFA-SPK)
- Gasification / Fischer-Tropsch synthesis (FT-SPK)
- Solar-thermochemical conversion of water and CO_2 (Sun-to-Liquid, StL)
- Electrochemical conversion of water and CO_2 (Power-to-Liquid, PtL)
- Alcohol-to-Jet (AtJ)

The only conversion technology currently available at industrial scale is *hydroprocessing of oils and fats*, yielding HEFA-SPK. Two additional technologies, namely *fermentation of sugars to hydrocarbons* (SIP) and *Alcohol-to-Jet conversion* (AtJ), have reached a level of maturity that enables provision of limited quantities of fuel to airlines for demonstration flights. Importantly, AtJ and SIP jet fuels have been approved for use in commercial aviation. However, both technologies have not yet been industrially implemented for large-scale production.

2.1.3 Results of the holistic assessment of production pathways

In the holistic technology assessment carried out in CORE-JetFuel, production pathways based on the conversion technologies listed above in combination with certain types of feedstock were considered. The assessment was focused on a set of questions of key importance when discussing renewable fuels for aviation:

- How much can we make?
- What is the potential environmental impact, particularly in terms of greenhouse gas emissions?
- How much would it cost?
- Drop-in capable or not?

- What is the current state of development (maturity)?

These questions were translated into key performance indicators (metrics), i.e. quantitative and measurable properties, and used for the assesment of different production pathways. In this context it is important to emphasize that there is no single most important performance indicator, as the desired solution has to fulfill several highly weighted criteria reasonably well. However, the assessemnt shows that a favorable performance in one criterion might be compromised by disadvantageous performance with respect to other criteria of equal importance.

Useful trade-off relations between criteria were identified. In CORE-JetFuel there are the **specific greenhouse gas reduction potential vs. cost of production** (Figure 4) and the **potential reward vs. risk** (Figure 5).

In Figure 4, the *specific GHG emission reduction potential of the unblended fuel relative to conventional jet fuel*, i.e. the percent reduction potential by substitution of the same amount conventional jet fuel (denoted as ε)[15], is plotted versus the *production cost relative to the market value of conventional jet fuel* (denoted as γ)[16].

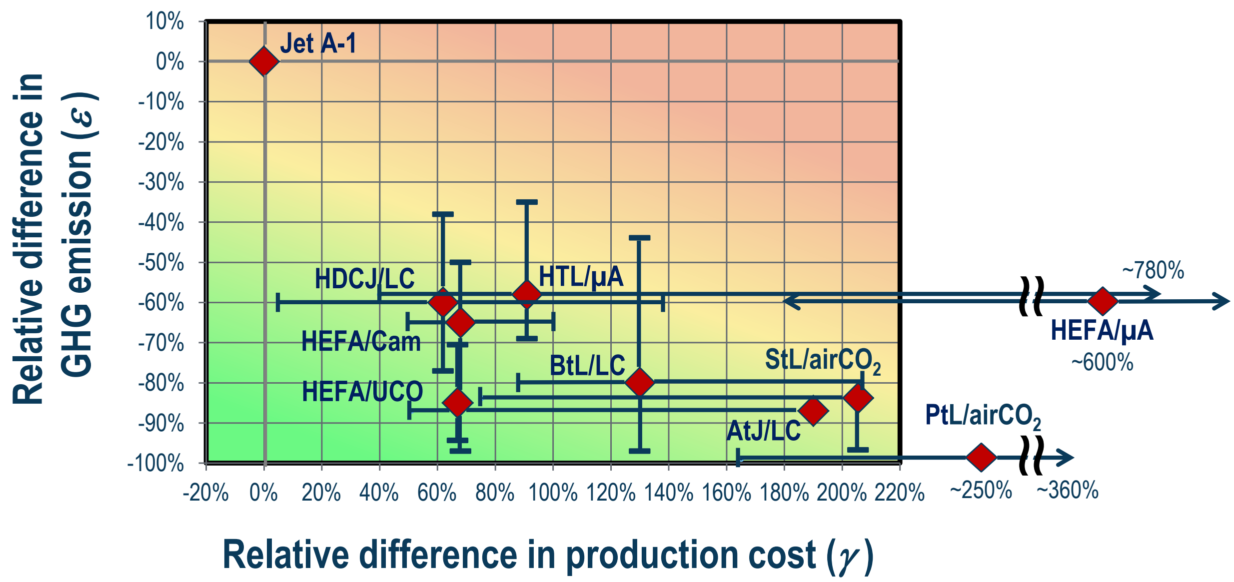


Figure 4: Specific GHG emissions vs. cost of production of analysed production pathways, each relative to conventional jet fuel. HDCJ/LC: Hydroprocessed Depolymerized Cellulosic Jet from lignocellulosic feedstock; HTL/µA: Hydrothermal Liquefaction of microalgae; HEFA/µA, HEFA/UCO, HEFA/Cam: Synthetic paraffinic kerosene using Hydroprocessed Esters and Fatty Acids from microalgae, camelina and used cooking oil, respectively; BtL/LC: FT-SPK from lignocellulosic feedstock; StL/airCO_2: Sun-to-Liquid based on solar-thermochemical conversion of water and CO_2 captured from air; AtJ/LC: Alcohol-to-Jet from lignocellulosic feedstock; PtL/airCO_2: Power-to-Liquid using CO_2 captured from air.

[15] ε are the emissions saved per unit of fuel relative to conventional jet fuel. This is related to CI = (100% + ε), also known as “carbon intensity” of the fuel. With zero carbon intensity (CI = 0), 100% of GHG emssions are saved (ε = -100%).

[16] This applies to the WtT production cost and the reference value us the 2013 market price of the reference fuel, i.e. of conventional Jet A-1, which is approximately 1000 USD/t.

As can be seen from Figure 4 (and also from Figure 5 below), the collected data cover a broad range of values and are associated with considerable variation and uncertainties. There are several reasons for such variation and uncertainties. The data was extracted from numerous different sources, such as scientific articles and reports. The variations originate from the variations in the underlying assumptions, methodologies, system boundaries etc. of different studies and event of systematic variation of assumptions within such studies, e.g. to find typical results and performance envelopes. Uncertainty intervals in the primary assumptions further add uncertainty intervals to the results[17].

The evaluation yielded a wealth of valuable information, with the key findings summarized in the following.

- In the light of the given variations and uncertainties, no obvious correlation of specific GHG emissions and cost of production can be found.
- All considered options provide substantially reduced specific GHG emissions in comparison to conventional jet fuel (Jet A-1), even though the upper values within the ranges of variation and uncertainty of some options would represent only insufficient reductions.
- All considered options are considerably more costly in comparison to conventional Jet A-1. Consequently, a price gap between conventional jet fuel and renewable alternatives is likely to remain at least in the medium-term future. Appropriate regulatory and/or economic measures will be needed to provide a market environment where renewable fuels can be competitive.

In Figure 5, the **potential reward vs. risk analysis**, the potential reward is represented by the *potential impact on GHG emission reduction* (which is the share of fossil fuel displaced by alternative fuels in the market. i.e. the substitution potential, multiplied with the specific GHG emission reduction ε shown in Figure 4) which is plotted versus the *technology readiness level (TRL)* of the fuel production path as a risk-related metric[18].

In the potential impact on GHG emissions reduction the entire fleet (European and global) in 2050 is considered. The interpretation of the upper limit value of 100% for the potential impact on GHG emission reduction is that 100% of the emissions are eliminated which can only be the case if 100% of conventional fossil fuel is substituted with an absolute zero carbon intensity (ε = -100%) fuel. This performance indicator reflects the fact that an advantageous specific GHG balance alone is not sufficient; such fuel would have to be supplied in large quantities to have a real impact. This is an issue often neglected in discussions about renewable fuels.

- All pathways in the “high potential reward” range either depend on lignocellulosic feedstock (including waste streams) or do not require input of biomass at all. This finding reflects the fact that these pathways offer high specific GHG emissions reduction AND are potentially available in large quantities. However, none of these promising options is mature enough to-date for short-term industrial implementation, and consequently certain risks of failure or major challenges are associated with their further development.
- Pathways depending on **microalgal feedstock** show moderate absolute GHG emissions reduction potential at **global level**, while remaining insignificant at **European level**. This is a consequence of the negligible production potential for microalgae in Europe.

[17] Harmonization of assumptions would reduce the spread of data and would to enable a consistent quantitative comparison for a particular set of primary parameters. However such an analysis is out of scope of the CORE-JetFuel work.

[18] It is important to understand that TRL is not identical to a risk metric but is not unrelated to it. TRL is used as indicator for the risk associated with the further development of a technology: The lower the actual degree of development, the higher the risk of failure on the way towards industrial maturity and commercialization.

- For the same reason, the potential reward in terms of GHG emissions reduction of HEFA fuels from **used cooking oil (UCO)** is negligibly small, at European as well as global scale: While the specific GHG balance of this fuel is excellent, the availability of UCO is very limited.

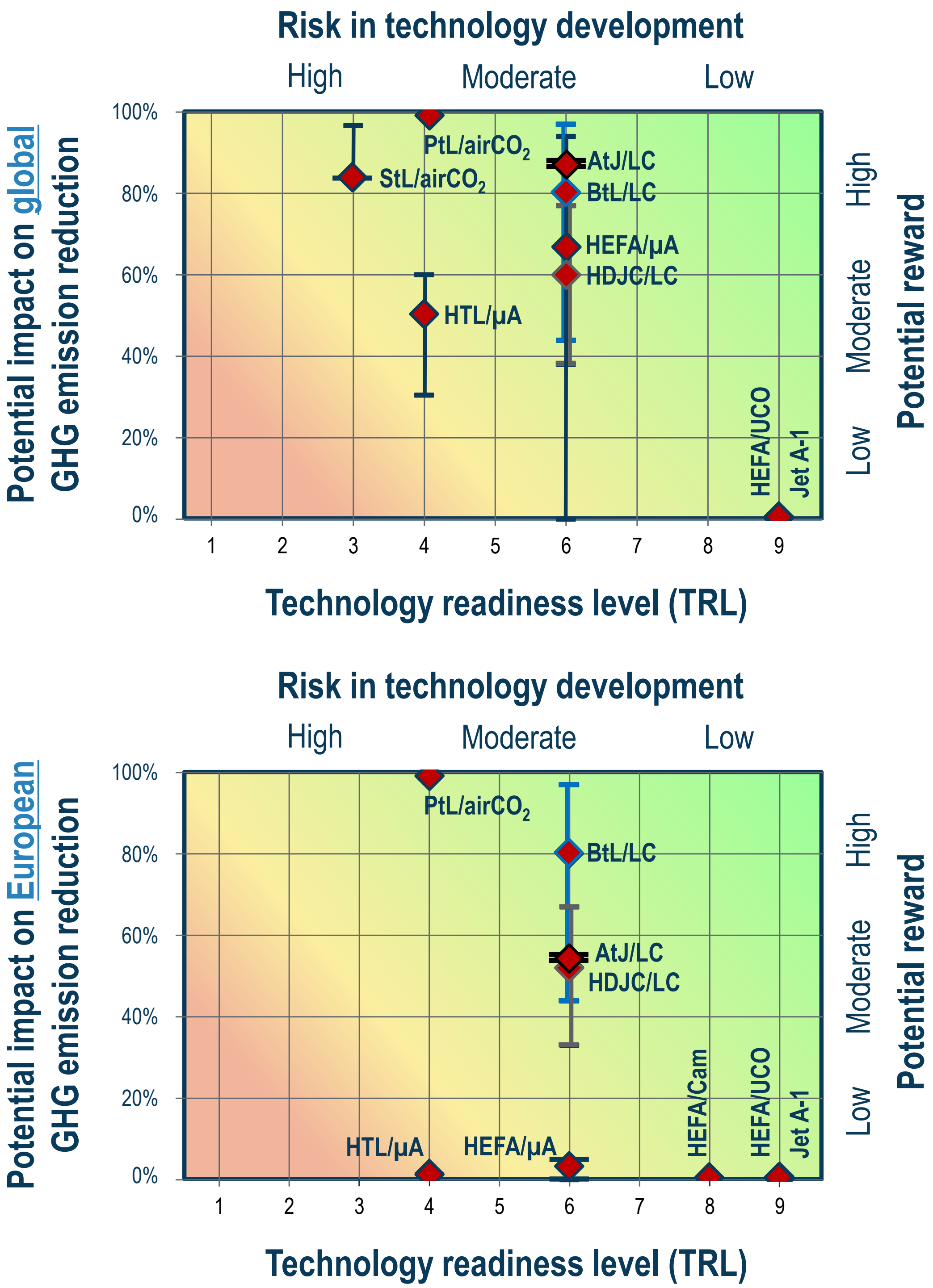


Figure 5: Greenhouse gas emissions reduction potential relative to future fuel emission impacts in the GLOBAL (top) and EUOPEAN (bottom) context, vs. current overall TRL of the analysed production pathways (see caption of Figure 4 for explanation of abbreviations of pathways)

2.1.4 R&I portfolio of projects for conversion technologies and radical concepts

The mapping of R&D activities in the field of conversion technologies and radical concepts has been conducted according to the Quadrant Model of Research (Stokes, 1997), as briefly described in Section 1.1.2. The key findings of the mapping of European R&D activities are summarized in Figure 6 and explained in the following:

- No activities located in Bohr's quadrant (pure basic research) were identified. This can be explained by the fact that fuels-related topics are inherently use-inspired or product-oriented and thus not purely "basic". However, research on fuel production technologies heavily relies on knowledge created in basic research in other thematic domains, e.g. physics, chemistry or materials science
- Most identified R&I projects are located in Pasteur's quadrant (use-inspired basic research).
- However, total budget volume of purely product-oriented activities (Edison's quadrant) is by far exceeding the total volume of other R&I activities. This is a consequence of the large budget volumes required for product-oriented technology development projects that aim for transferring a demonstrated technology from research to operation in industrially relevant environments to enable subsequent commercial implementation. Largest volumes found for projects dedicated to gasification/FT-synthesis (FT-SPK production) based on lignocellulosic feedstock and to AtJ.
- No European project dedicated to HtL technologies and only few activities on the related HDCJ conversion were found. This was unexpected as HtL and HDCJ enable the exploitation of major biomass resources (lignocellulosic materials) in Europe with a significant potential impact in GHG emission reduction. More efforts are required to progress the technologies (including the upgrading) towards industrially relevant scale and maturity.
- Only few activities devoted to HEFA were identified, because HEFA is already industrially applied and there is no need for further development.
- Small overall volume and number of activities are devoted to ***renewable non-biogenic options*** Power-to-Liquid (PtL) and Sun-to-Liquid (StL). With regard to their huge potential reward in terms of GHG emissions reduction, continuous efforts are needed to demonstrate the potential of the integrated pathways in industrially relevant environment.

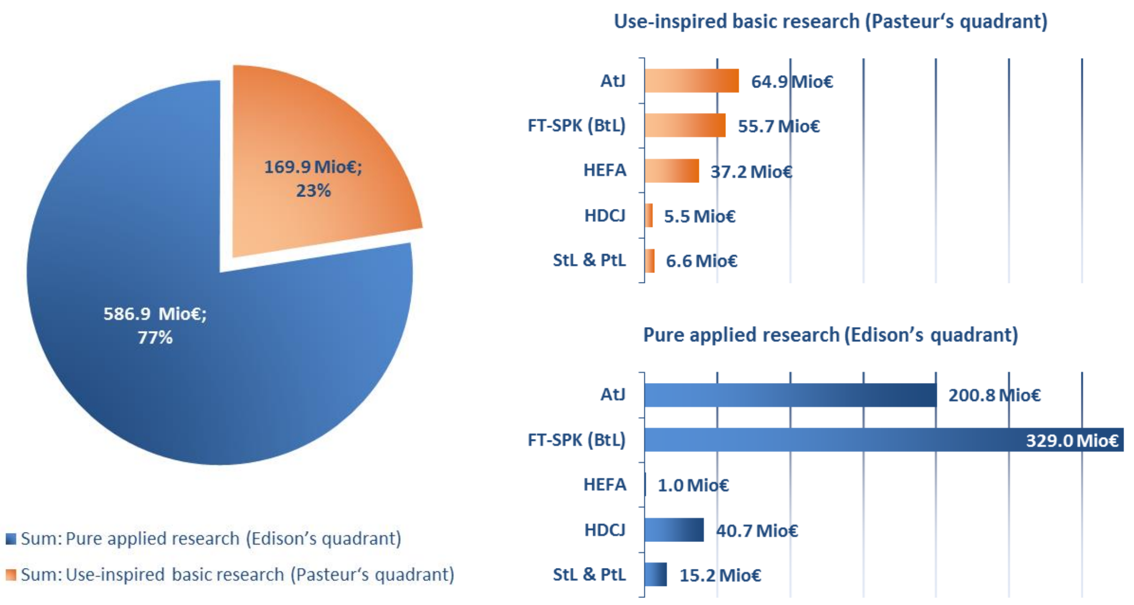


Figure 6: Summary of mapping results of European publicly funded R&I activities on conversion technologies and radical concepts. (Volumes given as total project costs, i.e. EU contribution plus residual costs)

2.2 Recommendations

The first det of recommendations are based on the results obtained from the analysis of technologies conversion technologies, radical concepts and the holistic assessment, recommendations for the following domains have been formulated:

- Technology monitoring and performance indicators
- R&I portfolio: Balance of effort in basic science and technology development
- Correlation of risks and potential rewards of technology development
- Future R&I strategy

2.2.1 Complement the set of key performance indicators with future potentials for climate impact and European energy supply security

It is recommended to revise the set of core metrics (key performance indicators) for the evaluation of future renewable energy technologies.

Well known are the generally used core metrics

- *costs of production* (used as metric for the potential economic competitiveness),
- the *technoloy readiness level* (representing an indicator of the maturity and therefore for the effort, time horizon and potential risk associated with the further development of a technology), and
- the *specific (life-cycle) GHG emission reduction potential of the unblended fuel relative to conventional jet fuel* (or the related carbon intensity).

Future technology assessment leads (a.o. objectves) to a better understanding of the possibilites for additional advances of respective technologies, and their future impact. In strategic decisions e.g. in the case of the development of future work programmes and funding strategies, the potential impact of a future technology on European or global scale has to be taken into account. The term “potential” impact assumes that this impact is within the physical and/or technical performance limits of a technology assumung it is mature (TRL6-9) in the future, not the impact at the state of the art or at a future intermediate (<TRL6) decision point. This potential impact represents a potential “reward” for the risk and effort of maturing the technology and is therefore the necessary corresponding trade-off metric for risk and effort. ***We recommend to complement the set of core metrics with the following performance indicators:***

1. ***Greenhouse gas emissions reduction potential relative to future fuel emission impacts*** as shown in Figure 5 rather than exclusively focusing on the *specific* GHG balance as shown in Figure 4. This performance indicator reflects the fact that an advantageous specific GHG balance alone is not sufficient; such fuel would also have to be supplied in large quantities to have a real impact. Any strategy to achieve climate mitigation targets is obviously linked to both volumes of fuels and their carbon intensity. By relating the *absolute reduction potential* to the absolute fossil emission trend, the *relative potential impact* is obtained.

2. ***European substitution potential energy import*** which relates to a contribution to the future European supply security. By relating the *absolute energy production potential* to the absolute energy import trend, the *relative substitution potential* is obtained.

In addition, indicators for impact on competitive European industries as well as socio-economic benefits may be used in order to represent objectives of central importance in the context of renewable energies. The value and significance of other performance indicators such as Energy Return on Energy Investment (EROI) and Marginal Abatement Cost (MAC) are still under discussion and may be interesting to use in future assessments.

We recommend that the potential of achieving certain rewards associated with specific technologies for the production of renewable fuels are evaluated with respect to these objectives and criteria. ***Specifically, we recommend that the set of key performance indicators is complemented with the two indicators listed above, i.e. indicators for future potentials for climate impact and European energy supply security.***

2.2.2 Balance technology development risks with an adequate level of rewarding GHG reduction potentials

There are conversion technologies not yet mature enough to represent options for short-term industrial implementation. In addition, the knowledge base to advance these technologies may not be extensive enough to exclude certain risks of failure in their further development. The decision maker has to understand which technologies potentially present the greatest source of change, what is the right level of risk for the expected potential reward of technologies to develop, i.e. the balance of risk and reward needs to be observed.

According to the CORE-JetFuel main results (Figure 5), production pathways offering highest potentials for European production and, at the same time, the highest specific GHG emissions reduction potentials, are based on

- lignocellulosic feedstock (including waste streams) or
- on renewable, but non-biogenic technologies, such as Power-to-Liquid (PtL) and Sun-to-Liquid (StL).

Although the associated conversion technologies are not yet mature enough to represent options for short-term industrial implementation, it appears that these pathways are key to achieve large-scale reduction of GHG emissions of the entire aviation sector. Therefore, ***it is recommended to foster the technology developments where the risks are worthwhile in view of a high impact potential of GHG reductions, and consequently***

- ***to support the progress of conversion technologies based on lignocellulosic and/or waste feedstock,*** such as ***HDCJ, HtL and FT-SPK***,
- ***to support the progress of renewable non-biogenic pathways,*** such as the core conversion technologies of ***PtL and StL, and their aerial CO_2 supply technologies*** towards higher technological maturity to demonstrate their viability in an industrially relevant environment and
- ***to take measures to reduce risk and cost in order to leverage private funds and attract large industrial stakeholders to support these developments***, thus ensuring that there is sufficient financial commitment to overcome hurdles for industrialization and maximizing the success probability in the development chain.

It is emphasized that technologies depending on the supply of concentrated carbon dioxide (CO_2), such as PtL and StL, can only produce truly renewable fuels if CO_2 from renewable sources is used. For this reason it is recommended to support efforts dedicated to CO_2 extraction from air as key enabling technology.

2.2.3 Develop fuel technologies with simultaneous advantages in cost efficiency, scalability, sustainability and feedstock supply security

It is recommended to base the future strategy for R&I in aviation fuels on a holistic, multiple-criteria approach, developing fuels with simultaneous benefits in costs, scalability, sustainability and feedstock supply security. The visual representations of the main results in Figure 4 and Figure 5 reveals the “gap” existing for various technologies in terms of target performance (e.g. cost-competitive production, close-to-zero life-cycle emission and deployment-ready technology maturity) and the state of the art (Figure 4) or the state of maturity in relation to future performance potentials (Figure 5). To close this gap, research and development efforts in production technologies for renewable fuels should generally focus on

- reduction of cost to support economic competitiveness and market uptake,
- scalable production technologies, with each single technology showing potential to substitute at least 10% of the European jet fuel demand anticipated for 2050, while at the same time offering large specific GHG emissions reduction potentials,
- feedstock-flexible production technologies that enable efficient utilization of a broad range of feedstock types, thus reducing dependencies on single feedstock sources, minimizing risk of supply shortfall and increasing scalability.

In general, it has to be emphasized that improvements in terms of costs, scalability or GHG emissions must not compromise other important environmental or social aspects, such as water consumption, emission of pollutants, land use rights etc. To this end ***it is recommended***

- ***to set up and maintain a holistic standard reference of a multiple-criteria evaluator for future fuel technologies with***
    - ***single-criteria threshold conditions*** (defining specific reference performance potentials)**,**
    - ***single-criteria premise conditions*** (defining mandatory minimum required performance potentials) ***and***
    - ***multiple-criteria trade-off conditions*** (acknowledging the fact that certain trade-offs can exist with respect to individual performance indicators, e.g. cost of production and GHG balance)**.**

2.2.4 Maintain a balanced R&D portfolio to enable short-term innovation and to create long-term innovation opportunity

Based on the CORE-JetFuel findings, it can be concluded that it is important

- to ensure a healthy balance between
    - the use-inspired basic science on potentially impactful "high-risk" fuel production technologies (Pasteur's quadrant), thus creating future innovation opportunity and the required human capital, and
    - the development of more mature technologies (Edison's quadrant), thus reaping the possible first-mover benefits of short-term innovation, and
- to support the linkage between the two by integrating new knowledge of innovation opportunity into real technological innovation.[19]

While no general recommendation can be given with respect to the specific ratio of efforts dedicated to basic science, use-inspired basic research and technology development, the emphasis should be on the linkage between the two. The following conclusions can be drawn and recommendations can be given:

- Research in the field of renewable fuels itself is rarely "purely basic". However, research on fuel production technologies heavily relies on knowledge created in basic research in other thematic domains, e.g. physics, chemistry or materials science, and their inter-disciplinary approach. ***It is therefore recommended to support such basic research in other domains to create the knowledge base for future development of novel technologies and radical concepts.***
- Use-inspired basic research plays a very important role in the fuels-related R&I landscape, bringing results from other domains into the context of renewable energy and fuel production, validating technology concepts in laboratory environments and transferring them to technically relevant operational environments. ***It is therefore recommended to ensure that a sufficient share of R&I activities is located in "Pasteur's quadrant" of use-inspired basic research, forming the basis for future large-scale technology development projects.***

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[19] D. E. Stokes, Pasteur's Quadrant: Basic Science and Technological Innovation. Washington, D.C.: Brookings Institution Press, 1997, and
E. Arnold and F. Giarracca, "Getting the Balance Right – Basic Research, Missions and Governance for Horizon 2020", Technopolis Report 2012.

- Purely applied research towards product-oriented technology development is focused on the final step of development, maturing technologies from research labs to operation in industrially relevant environments and thus enabling subsequent commercial implementation. ***It is recommended to support purely product-oriented technology development projects for technologies that have proven their potential in terms of positive environmental impact, scalability, economic competitiveness and technical compatibility (drop-in capability);*** public support of such large-scale projects is important to minimize risks of investment and to enable the establishment of medium-term competitive industries in Europe and the long-term commercial supply of renewable fuels.

3 Technical Compatibility, Certification and Deployment

Before they can be used for commercial flights, aviation alternative fuels must demonstrate jet A/A1 technical compatibility and be approved by international standards, such as the ASTM qualification procedure ASTM D4054 and the jet fuel specification ASTM D7566.
ASTM qualification is a long and costly process, which is mandatory, before setting new jet fuel specifications and before the commercialization of the fuel can be pursued. It requires a large quantity of jet fuel, from about 38 to 380 m^3, several years, e.g. 2 to more than 5 years (or more), with a cost that can overpass US$10 million. Nevertheless this cost is relatively marginal, when comparing it to the mandatory step for the development of new biofuel processes: the construction, and operation for a few years, of a big size pilot plant or demo plant, to demonstrate the proces and to be able to scale it up, with costs typically in the range of US$ 100 to a few hundred millions.

3.1 Main Results

3.1.1 Renewable jet fuel current and future ASTM qualification and industrial production

By the end of April 2016 five different processes for alternative jet fuels have been already approved by ASTM, providing the technical specifications for these renewable jet fuels in 5 annexes A1 to A5 of the ASTM D7566-16: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons.

- **FT-SPK** (Fisher Tropsch Synthesized Paraffinic Kerosene): 2009 / blend at 50% content maximum
- **HEFA-SPK** (Hyroteated Esters of Fatty Acids Synthesized Paraffinic Kerosene): 2011 / 50%
- **SIP** (renewable Synthesized Iso-Paraffinic fuel from hydroprocessed fermented sugars from Alyris/Total: June 2014 / 10%
- (FT) **SPK/A**: FT-SPK plus mono-aromatics from alkylation of a benzene-rich cut (naphtha type) with light FT olefins (SASOL): Nov. 2015 / 50%
- **ATJ-SPK** (Alcohol To Jet Synthesized Paraffinic Kerosene from GEVO) from iBuOH + dehydratation + oligomerization +HDT (Hydrotreatment): April 2016

For the following pathways certification is foreseen in the short term:

- **BIC** (Biofuel ISOCONVERSION) process by ARA and Chevrion Lummus Global, renamed **CHJ** (Catalytic Hydrothermolysis Jet)
- **Green Diesel / HFP HEFA** (High Freezing Point HEFA) in 2016-2017, even if for this last route, the advancement of certification is not so clear without any news from ASTM since the end of 2015

For the following pathways certification is foreseen in the medium/long term:

- **APR** (Aqueous Phase Reforming) pathways (Virent/Tesoro-Shell) with two routes:
  - **HDO SAK** (HDO Aromatic Synthesized Kerosene) mainly aromatic

  - **HDO SK** (HDO Synthetized Kerosene), renamed **CPK** (Cyclo Paraffinic Kerosene) mainly naphthenic with more than 70% naphthenes
- **ATJ SKA** (Alcohol To Jet Synthesized Kerosene with Aromatics) and **ATJ SK** (ATJ Synthesized Kerosen) developped by Lanza Tech from industrial fermented waste gas:
  - **ATJ SKA** is a mixture of hydrocarbon with a chemicl structure similar to fossil jet fuel
  - **ATJ SPK** is mainly based on iso-paraffins
- **ATJ-SPK** from Global Bioenergies with a similar approach than GEVO but with a direct fermentation of sugars to isobutene
- **Pathways based on Fast Pyrolysis with / without catalyst** followed by hydrotreatement, with a chemical structure probably similar to fossil jet fuels:
  - **HDCJ** (Hydrotreated Depolymerized Cellulosic Jet developped by KiOR (KiOR bankrupcy in 2014)
  - **HPO** (Hydrotreated Pyrolysis Oil) developed by Envergent/UOP (no news from a long time).

Other routes are not yet close to the pre-industrial/demo level but could also be certified in the medium/long term.

There are a lot of pathways to produce renewable jet fuels from biomass and wastes, **but today, only the HVO** (Hydrotreatment of Vegetable Oils) technology (called HEFA if partially or mainly dedicated to renewable jet fuel production) **is industrially available and currently used in several countries mainly for biodiesel production: USA, Finland, Italy, The Netherlands, Singapore, and, in short term, probably early 2018, Franc**e. The capacity is today over 3 million t/y, but currently for diesel production only, with the exception of the Altair HEFA plant (Paramount, California) producing biodiesel and also renewable jet fuel for United Airlines since March 2016. **The HEFA technology is ready to use, but not yet implemented today at industrial scale, with the exception of the AltAir plant with a 40 Mgpy production**. Emerald fuel in Port Arthur, Texas could follow with a 88 Mgpy biodiesel production and with a development program to achieve >500 million gallons per year portfolio. Total La Mede biorefinery (scheduled to be started in 2018) could also produce renewable jet fuel is the market and renewable jet fuel cost is compatible. 5 other projects are scheduled in the US (Preston projects), with the 1st one under construction to be started in 2017 but there is currently no information on renewable jet fuel production..

FT-SPK from natural gas and coal is at industrial level (i.e. Sasol in South Africa producing commercial FT-SPK jet fuel or Shell in Qatar or from demonstration/industrial plants in China), **but not yet for renewable jet fuel from lignocellulosic biomass, where it is currently mainly at demo level with the objective of being used at industrial level from 2020** (refer to BioTfuel project in France with two demo plants underconstruction and a scheduled period of 2 to 3 years to demonstrate the pathway).

Nevertheless, two projects could be close to completion in the US.

- US Fulcrum project is well advanced with 147,000 tons of post-recycled Municipal Solid Wastes (MSW) converted into 11 Mgpy liquid fuels (jet fuel and diesel) & power, with agreements with Cathay Pacific and United Airline for supply of over 465 million gallons over 10 years (375 million gallons over 10 yearscorresponding to 2% of the current airline consumption). The full route is based on a first steam reforming gasification of the wastes manufactured and licensed by ThermoChem Recovery Inc.(TRI), followed by a FT technology licensed from Emerging Fuels Technology to produce a syncrude. Fulcrum incorporated the technologies to produce renewable electricity and fuels in a modular and scalable way with plants producing from 10 to 60 Mgpy. Fulcrum is in the process of building their first commercial plant located in northern Nevada's Tahoe Reno Industrial Center (TRIC). In 2014, the USDA awarded Fulcrum a $105 million

Biorefinery Assistance Program loan guaranteed through Bank of America to build the biorefinery. Abengoa was awarded an engineering, procurement and construction (EPC) contract in 2015 to build the Sierra BioFuels Plant. Fulcrum plans to have the biorefinery up and operational by the second half 2018. The plant should produce 800 bpd[20] syncrude that should be refined (hydrotreatment/hydocracking-hydroisomerization) in Tesoro Martinez 160,000 bpd Refinery in California. Fulcrum also has plan to build other biorefineries across the country (up to 8 by 2022).

- Another one looks well advanced too, in the US: RedRock Biofuels (Oregon) with 140,000 dry tons tof woody biomass converted into 12 Mpgy of renewable liquid transportation fuels (naphtha, jet fuel and diesel), with a 3 Mgpy Sustainable Alternative Jet Fuel (SAJF) offtake agreement from each of Southwest Airlines and FedEx, and $70 million DPA Title III award for ~$200 million refinery. The Red Rock refinery, was slated to begin construction in late 2015 and then in early 2016 (Lake view, Oregon), but no recent news of the current construction starting date was found on the web. The plant should conver (TCG global gasification + Velocys micro channel FT modular smale scale technology+ Haldor Topsoe hydroprocessing) approximately 136,000 dry tons of woody biomass from a 75 milles radius into at least 15 Mgp of renewable, liquid transportation fuels.
-

These two processes are still very challenging, with the industrial development of such a route (the gasification from biomass or from wastes as well a the FT steps) and need a rather long demonstration period to test and to improve the technology, as well as to demonstrate it (refer to the failures of KiOR demoplant in Missisipi or to Choren demoplant in Germany). The final biofuel true cost is also a main concern.

The SIP/DSHC technology is at industial level, but without commercial production today because of its cost. With the end of quota on sugars in Europe and, if there are still significant gains on the production cost, SIP SPK could be competitive with fossil fuels in the mid-term.

The Gevo ATJ-SPK route is in the early stage of industrial production of isobutanol, but the production of ATJ-SPK is currently not yet at commercial scale. Nevertheless the very recent Head of Agreement signed between Gevo and Lufhansa on Sept. 8, 2016 could make it for the bear future. The intention is to build a commercial hydrocarbon upgrading facility (from isobutanol) in the existing Gevo ethanol and isobutanol Luverne (Minnesota) plant, to enhance the isobutanol production and to transform it to isobutane and jet fuel, in order to be able to produce produce up to 10 Mgp of hydrocarbon fuel from 13 Mgp of isobutanol. If the project is carried out, it will approximately take 2 years for financing, engineering and construction. It will not be ready before end of 2018. In the HoA, Lufthansa intention is to purchase up to 8 Mpg of ATJ-SPK from Gevo, or up to 40 million gallons over the 5 year life of the off-take agreement. **So, after HEFA-SPK and FT-SPK, ATJ-SPK could be the next industrial production in the near future taking place in the US**.

The FT-SPK/A synthesized jet fuel proposed by Sasol, basically from CTL, could be adapted to future processes producing bio-light olefins, such as olefins from a BTL process or obtained from alcohols fermentation and deshydration, or olefins directly obtained from fermentation, and from light aromatics from biomass conversion processes, such as catalytic pyrolysis. With the scheduled development of biofuel processes, it could be possible, in the mid/long term, to produce biobased alkylated mono-aromatics.

[20] Equivalent to11 Mgpy on a basis of 330d/y operation of the unit

Because of the lack of aromatics in renewable jet fuels from most of the processes stated above, there are also other processes that were developped to get a closer chemical structure to the one typically observed in Jet A/A1. These pathways produce synthesized kerosene-containing aromatics, such as Synthetic Kerosene Aromatic or SKA jet fuels or jet fuels obtained from thermal or hydrothermal conversion of biomass with, or without catalyst, with a final refining step, such as hydrotreating / hydrocracking. Some of these new renewable jet fuels are being evaluated for ASTM qualification that may support longer-term goals of producing fully synthetic replacement fuels that could be used without blending:

- Direct thermal conversion of biomass or fatty material:
  - the Hydrotreated Depolimerized Cellulosic Jet also, called HDCJ route (KiOR) was supposed to be approved in 2014, but is currently in stand-by because of KiOR bankrupcy. Another route, called Hydrogenated Pyrolysis Oil (HPO) is very similar but still at the R&D level. So **HDCJ/HPO ASTM qualification should not be completed in the foreseeable future, if completed at all**,
  - the **CH or Catalytic Hydrothermolysis of lipids to a biokerosene, called ReadiJet^{TM}, developed by ARA** (Applied Research Associates) with CLG (Chevron Lummus Global), also called Biofuel ISCOCONVERSION (BIC) process, producing a renewable jet fuel with a chemical composition similar to petroleum-based jet fuel, is currently under the ASTM certicification process. **This route should be ASTM certified in the near future.**

- **Alcohols to Jet: ATJ-SKA** (Synthezised Kerosene with Aromatics) through industrial waste gas, rich in CO, gas fermentation to alcohols and alcohols conversion to bio-fuel (Lanzatech, Swedish biofuels) is another route under the ATSTM qualification. At this time only the ethanol production from industrial steel gas is demonstrated, but not the final conversion to renewable jet fuel. **The date of the ATJ-SKA qualification is not known** and there are no news from the qualification process in December 2015, as well as from the ATSM D02 meeting in June 2016.

- **Aqueous Phase Reforming / APR conversion of sugars and celulosic materials**, with two alternative pathways based on a preliminary APR conversion (Virent/Shell); **should be qualified by ASTM in the near future**:
  - Hydro-DeOxygenated Aromatic Synthesized Kerosene or HDO-SAK from cracking process to produce aromatic fuels,
  - Hydro-DeOxygenated Synthesized Kerosene called HDO-SK, recently renamed Cyclo-Paraffinic Kerosene / CPK, issued from condensation plus hydrotreating to produce distillate with about the same type of hydrocarbons that are present in fossil jet fuels.

There is no unique solution to encourage the production of renewable jet fuels and the best option will depend on many factors: on the region, feedstock sourcing, availability and price, tax structure, product slate, value of co-products, environmental impact (LCAs including or not including LUC and iLUC) and the like. Whatever is the considered renewable jet fuel process, the main challenges remain to reduce the cost of the feedstock and the production price, to develop the industry and to deploy the existing or close to be commercialized technological processes. For the mid- and long-term, advanced new conversion technologies, that are currently still at small pilot, big pilot plant or at demo unit level, further development to reach commercial scale and large-scale deployment by airlines will be necessary. Moreover, because of the intrinsec chemical structure of the biomass, the yields of biomass conversion to biofuels are pretty low, typically from 15 to 25 wt% on dried biomass, with even a lower yield if we focus on renewable jet fuel (range from 10 to 15 wt% on a dry biomass basis). This relatively low yield means that a very high amount is necessary to produce biofuels, introducing a possible constraint related to the biomass availability with the future demand and competition with terrestrial biofuels (road and rail). Currently the competition with marine and river transportation using biofuels to replace marine fossils fuels (marine gasoil and diesel, heavy distillate, light and heavy fuel oils, LNG etc.) is not foreseen to be at a significant level in the next 10 years.

From a general point of view, a crude oil price not too far or above $/bbl 100 (which is about twice the current price), would push forward the technologies that are, or will be in the medium term, at industrial scale, and reach price parity with conventional JetA/A1.

3.1.2 Database

An identification and information gathering the most promising deployment initiatives and industrial value-chains under development worldwide was performed.
Since it is a very important task, with a similar approach performed within the ICAO/AFTF (Alternative Fuel Task Force) group, the AFTF and the CORE-Jet fuel databases were merged in order to get a comprehensive database that is shared and distributed worldwide
The focus of this database is on "advanced alternative fuels" that could have an application in aviation. The production step of ethanol itself as an intermediate product feedstock for alcohol-to-jet is not included, but ATJ routes are considered. The file currently mainly includes announcements by industry or processes at large scale pilot plant or demo level.
The database is organized into two Excel sheets. A first sheet called "Announcements" provides all the data collected. A second sheet called "short-term projections" is dedicated to the building of projections for a number of scenarios. The final objective is to have the right shared/controlled data to be able to build the alternative renewable jet fuel projection.

A group of ICAO/AFTF experts is providing updates / announcements by setting a number of criteria. The group, under the leadership and secretariat of Volpe, with support of US FAA (Federal Aviation Administration), can then update the file and keep it updated on the AFTF website. Calls and face-to-face meetings within the group have been performed all over the year in order to discuss and to quote, on a consensus basis between experts, the news, press releases and publications related to the evolution of existing projects, as well as new projects or project cancelations. This organization makes it possible to update the database in real time. Today the database is only available for ICAO members.

This data base was made possible by the involvement of experts, not only from North America, but also from Europe and Indonesia. It should be underlined that a close cooperation, especially between North America and Europe, is necessary in that field.

3.2 Recommendations

3.2.1 Keep monitoring deployment / implementation initiatives with a critical expert analysis

The review of state of the art of deployment / implementation initiatives is a mandatory step to be aware of the numerous pathways that are currently used or could be used to produce renewable jet

fuels in the near, medium or long term. This review is strongly linked to the assessment of conversion technologies in Deliverable 4.4. “Report on compilation, mapping and evaluation of R&D activities in the field of conversion technologies of biogenic feedstock and biomass independent pathways.
An overwiew of current and short term renewable jet fuel productions is also very important to have an accurate picture of the technologies that are and will be capable to produce renewable jet fuels in the near future at an acceptable cost. An overview of deployment initiatives, about their viability and the participating stakeholders, including success stories is also important, as well as global overview of industry-driven projects and initiatives for the medium/long term. This overview should be updated quite frequently because there is a lot of changes in this field: on the current and new routes development, as well as at the level of policy (mainly US and European) evolution, in the changes in stakeholder or with the disapearing of even well advanced technologies such the one developped b by KiOR or Choren.

3.2.2 Develop initiatives connecting the stakeholders engaged in alternative aviation fuels

It is very important to develop initiatives gathering the stakeholders related to a dedicated renewable jet fuel pathway, such as the European ITAKA project[21] (HEFA from camelina) or the Lab’line for the future initiative[22] (SIP), to demonstrate the technical viability as well as assessing all the logistic issues, such as how to fill the tank of an aircraft in an airport, using the current Jet A1 airport hydrant system, or the social acceptance by passengers of using biofuels. Such initiatives could be pushed forward by the EC in the future for new pathways.

3.2.3 Decrease the industrial risk to scale-up production

It is also very important to decrease the industrial risk of producing renewable jet fuel within a highly moving world of fossil crude and fuel prices, by securing the production through long term contracts and/or partnerships with airlines, oil companies, national defense/civil administration, Government departments, such as done in the US could be favored by the EC. EC could also help new operations needed to be implemented at large scale in order to proof the industrial and commercial concepts. It is also important to develop at least a few renewable jet fuel in close cooperation with the oil industry and to try them.The stability of the EU regulations is also a main concern.
Amother main topic to dedrease the risk is to develop and to favour processes allowing the use of different types of feedstock (flexible processes) according to their costs and local or international availability. This is also a way to improve the production cost and to decrease the industrial risk.

[21] http://www.itaka-project.eu/default.aspx

[22] http://corporate.airfrance.com/fr/developpement-durable/labline-for-the-future/

3.2.4 Improve production costs and renewable jetfuel implementation / deployment

Because the initial cost of renewable jet fuels from the 1st industrial units is always much higher than when the process is fully optimized after the start-up and production of a few industrial units, it is also necessary to get the help of National State Members and /or the EC to introduce new renewable jet fuels fuels, as made for other means of transport biofuels,but without the possibility of incentives through tax discounts due to the absence of tax on jet fuel.
Because of its chemical structure, biomass composition is far away from the suitable chemical composition required for drop-in jet fuels, mainly based on an isoparaffinic structure with a limited amount of monoaromatics and mononapthenes. It results in low weight yield of biomass to renewable jet fuel, typically within the 5-15 wt% range (corresponding to 10-25 wt% total biofuel –naphtha, jet fuel, diesel yield). This is the main driver explaining the higher, or much higher, cost of renewable jet fuel v/s fossil fuel. It is the reason why any study to reduce the carbon losses and to improve the final yield to biofuels is very important. It is true for all the steps of the pathway: biomass production, biomass pretreatment, primary conversion process, secondary refining process, optimization of recyling flows, optimization of energy use and balance, gains in separation systems and energy consumption.These studies are of great importance to decrease the production cost as well as to increase the carbon and energy balances and to decrease the GHG footprint. This type of study could be supported by the EC.

Improving the yield and the energy balance will automatically improve the overal GHG balance with a higher recovery of the carbon of the feestock into biofuel. This type of study could be supported by the EC.
Carbon taxes may also be an option to promote competitiveness of these new technologies.
Another point of interest is to try to develop and to favour processes that can directly co-process biomass and fossil feedstock (for example gasifying biomass or waste with heavy fossil feedstock, such as petroleum coke or very heavy petroleum ends) or processes that can produce a biocrude/bio-oil that could be co-refined in an existing oil refinery on existing or revamped conversion units, such as aFluid Catalytic Cracking (FCC) or an Hydrocracking unit.

Other points of interest to decrease the cost of pathway close to the industrialization, or yet under indutrialization, are (not peculiar to the bomass to biofuel conversion processes but specially important for any complex pathway and scheme involving a lot of steps):

- the inventory of technical bottlenecks according to the different pathways and potential progress margin,
- the improvement of the energy balance for the fuel pathway (each step of the processes) with, as far as possible, the development of the use of other types of renewable energy.

3.2.5 Improve the understanding of the properties of renewable jetfuels

A lot of R&I efforts are still needed and required to understand the properties of alternative jet fuel blends based on detailed chemical analysis, at qualitative level first (molecule identification) and finally at quantitative level. The analysis of chemical properties has qualitative aspects with respect to the identification of specific molecules as well as quantitative aspects aiming at a reasonably precise prediction of properties. It should be the aim of such analysis of the alternative jet fuel to identify the most critical aspects of the certification process (i.e. red/green light for specific parameters).

Furthermore, some properties (cold flow such as freezing point and viscosity, as well as thermal and oxidation stability) of blended fuels are “non-additional” and may not be easily calculated from the ratio and properties of the blending components. The efforts have to be focused on such properties and also on combustion properties.

3.2.6 Optimise and improve the use of ASTM D4054 process [23]

ASTM qualification of alternative fuels is sufficient to guarantee safety of operations. It is a robust process to guarantee than the new fuel will comply with all requirements related to compatibility, quality and safety.

Fuel analysis is a good means to **support** the qualification process, but shall **not replace** the qualification process. Such support may serve to reduce costs and time needed for the qualification process, as well as to reduce the time for the overall development of a new pathway and to be able to judge in advance at a relatively low TRL how the new synthetic fuel may comply with final fuel requirements for aircraft.

Certification of chemical properties instead of pathways is not considered easier and it is agreed (refer to stakeholder telephone conference April 4th, 2016) that including a new Annex for each certified pathway in ASTM D4054 qualification remains mandatory, especially for safety issues.

Detailed fuel analysis is a good means to support the qualification process, but shall not replace this one. It will serve to reduce costs and time needed for the qualification process, as well as to reduce the time for the overall development of a new pathway and to be able to judge in advance, at a relatively low TRL, how the new synthetic fuel may comply with final fuel requirements for aircraft use.

Nevertheless, experiences gathered on the ASTM qualification of alternative jet fuels will make the certification of new pathways easier and faster. To make it as shorter and efficient as possible, as well as to reduce the cost, it is also important to focus in advance on the most critical issues for the certification and to take into account the feedback from previous certifications, as done in the SIP pathway. Currently iso-paraffinics are quite well known from the first certification efforts and this knowledge can help to reduce time for new renewable jet fuels certification based on this chemical structure. In that sense, a good understanding / modeling of relationship between chemical analyses and final fuels requirements is very important and can help to flag a red / green light on some of the relevant properties

Major cost factors within the qualification process of a new pathway are the high costs for the construction of demonstration facilities able to produce sufficient quantities of fuels for engine testing. The reduction of fuel quantity requirements is however seen critical as tests performed on smaller engines may not lead to trustworthy results acceptable to engine manufacturers. Not all the engines have exactly the same behavior with fuels. For example testing a small turbine, such as an APU unit, is not enough to extrapolate to the aircraft propulsion engines. It is not only a matter of fuel combustion in a turbine but there are differences among engines, such as for example the impact of contaminants, and a Turbomeca engine will not necessary exactly behave as a Snecma engine. It is thus mandatory to perform test on true propulsion engine too. Furthermore, the construction of (rather large) demonstration facilities is a necessary step towards market introduction, as large-scale (beyond pilot) production of a fuel at consistent quality needs to be proven before commercialization.

[23] Refer to stakeholder telephone conference April 4th, 2016: ” Discussion on ASTM Qualification of biojet fuels & relationships and prediction of detailed characterization/standard properties”

It is stated that certification costs are not regarded as bottleneck for the development of alternative aviation fuels.

3.2.7 Pay attention to logistic and quality insurance

The logistics of alternative fuels may have a negative impact on the quality assurance of blended fuels. The current ASTM qualification process does not cover potential problems originating from logistics aspects and the presence of new players, and the ASTM certification process may need to be adjusted.
An other key element is contaminants with a lack of understanding of their effects and there is a need for research in this area. This is not a question of qualification but a question of quality insurance and to be able to check that the production is performed in a good way.

To sum-up the specific recommendations to the European Commission from the April 4th, 2016, stakeholder meeting related to ASTM qualification of renewable jet fuels & relationships and prediction of detailed characterization/standard properties, these are the identified specific topics where the support at EU level for R & I projects would be needed:

- Understanding of the impact of contaminants of alternative jet fuels on fuel properties and materials.
- • Understanding and trying to model complex chemical and physical phenomena such as thermal and oxidation stability of fuel bases as well as on the final commercial blend.
- • Understanding of the impact (on fuel properties, contaminants,…) of using new feedstock (e.g. algae) for the production of already certified jet fuels (e.g. HEFA).
- • Quality assurance of the full supply chain (including logistics aspects) of alternative jet fuels, as well as blend with fossil jet fuel, especially for the jet fuel on which we have not so many analytical data and survey (i.e. Chinese or Russia) plus understanding and modeling existing fossil fuel refined in Russia and China.
- • Inclusion of full chain quality assurance in the certification process.
- • Studying the possible evolution of fossil jet fuel and blends with renewable jet fuels with lower sulfur and aromatic content.
- • Impact of new jet fuel structure on dielectric constant.

Moreover, in this highly moving world, especially in the field of biofuels and renewable jet fuels, new processes and/or new initiatives are announced quite each month, some project may also disappear, firms may face to bankrupcy (Ii.e. KiOR or Solena) or may be purchased by other firms and it is compulsory to get a comprehensive and updated view of the state of maturity of each announcement (Lab. scale, Pilot unit, Demo unit, Industrial Production). This is the reason why a database was built in cooperation with Core-JetFuel project and AFTF/ICAO.

3.2.8 Recommendation sum-up

Renewable jet fuels need to fulfill all ASTM requirements and need to be suitable for all applications. Adaptation of engines for the use of alternative fuels is complicated and takes time, engines are constantly improved for existing fuels, but shall not be adapted for future fuels and new fuels need to comply with the existing system.

Keep monitoring deployment / implementation initiatives with a critical expert analysis (Data base): an identification and information gathering the most promising deployment initiatives and industrial value-chains under development worldwide towards biofuels and renewable jet fuels was performed into an Excel database shared with ICAO, who will keep it updated on the AFTF website under the leadership and secretariat of Volpe, with the support of US FAA (Federal Aviation Administration). No specific action required from the EC.

Decrease the industrial risk to scale-up production: decrease the industrial risk of producing renewable jet fuel by securing the production through long term contracts and/or partnerships with airlines, oil companies, national defense/civil administration, Government departments, such as done in the US could be favored by the EC. Favouring the development of flexible process routes towards different type of feedstock is also a good way to improve the biofuel production cost and to decrease the industrial risk.

Improve production costs and renewable jet fuel implementation / deployment: the low weight yield of biomass to renewable jet fuel, typically within the 5-15 wt% range, is the main driver explaining the higher, or much higher, cost of renewable jet fuels v/s fossil fuel. It is the reason why any R&I study to reduce the carbon losses and to improve the final yield to biofuels is very important for all the steps of any pathway and could be supported by the EC. It is also important to notice that increasing the yield will automatically improve the overal GHG balance with a higher recovery of the carbon of the feestock into biofuel. Carbon taxes may also be an option to promote competitiveness of these new technologies.

Improve the understanding of the properties of renewable jet fuels: a lot of R&I efforts are still needed and compulsory to understand the properties of alternative jet fuel blends based on detailed chemical analysis, at qualitative level first, and finally at quantitative level. It should be both beneficial to shorten the ASTM qualification as well as the development of new routes well suited for jet fuel production. For a safe operation of engines precise knowledge about fuel composition and properties is also needed The efforts shall be focused on cold flow, stability and combustion properties.

Optimise and improve the use of ASTM D4054 process: this is a robust process to guarantee than the new fuel will comply with all requirements related to compatibility, quality and safety.

A short ASTM certification processes of about two years is possible, if data are available on time and if everything is well scheduled and prepared with a good cooperation and involvment of all the OEM's (original Equipement Manufacturers) and suppliers (refer to Total/Amyris feedback with the SIP route). Even if quite high, ASTM qualification certification costs are not regarded as bottleneck for the development of alternative aviation fuels, since the cost of the construction and operation of a demo plant is much higher and usually represent by far the highest cost. Nevertheless the ASTM process should be improved through a better knowledge of fuel chemistry and relationship with properties of usage. This better knowledge could also be a way to get new fuels reducing pollutant emissions. EC should support such projects (refer to the previous recommendation).

Pay attention to logistic and quality insurance: the logistics of alternative fuels may have a negative impact on the quality assurance of the blended fuels. The current ASTM qualification process does not cover this aspect. For example a key element is contaminants with a lack of understanding of their effects in the final commercial blend. Specific topics where the support of EC for R & I projects would be needed were listed:

4 Policies, Incentives and Regulation

Aviation biofuels have generated a relevant policy discussion in the latest years. Being one of the industrial sectors that is experiencing a stronger growth in the last decades, the reduction of aviation emissions has become an important issue and aviation biofuels have been considered within the measures for its abatement. In fact, ICAO has included aviation alternative fuels in the basket of measures to contribute to reducing international aviation net CO2 emissions. However, to be able to contribute towards such an objective, the level of development and market penetration of alternative fuels needs to increase significantly. In fact, the level of market penetration is still relatively low compared with road transportation biofuels.

The possibility of achieving emissions reductions in the aviation sector by using exclusively technological measures has been determined to be limited and not enough to achieve the ICAO emission reduction objectives. With a future perspective of continuous growth, alternative fuel is one of the measures that is being analyzed as having potential for reduction and to achieve such objectives. In fact, due to this, ICAO CAEP created the Alternative Fuels Task Force (AFTF) with the mission of assessing the potential range of emission reductions from the use of alternative fuels in aviation up to 2050, and recently, a subtask within this group exclusively dedicated to assessing and evaluating policy options.

In the European context, a number of targets and policy instruments exist concerning biofuels (which have been analyzed in Deliverable 5.4 of this project), including the Renewable Energy Directive and the Fuel Quality Directive. In addition to this, the Biofuel FlightPath initiative was introduced in 2011 with the objective of targeting 2 Mt annual production of fuel derived from renewable sources by 2020. Alternative renewable jet fuel is currently produced in small quantities and usually under purchase agreements/ small-scale deployment projects, and due to several reasons, there is not a sufficient demand that could justify a continuous production. Although the number of flights performed using alternative fuels is growing every year, this target is currently considered difficult to achieve with the current levels of development of the industry and for this reason a higher level of ambition would be required at the political level to promote aviation alternative fuels. To date, no long term binding targets specific for aviation exist, neither at European nor at international level.

In this regard, when defining the future policy, it needs to be considered that aviation has no alternative to liquid fuel for the short-term futures, unlike ground transportation or power generation. Therefore, if aviation is to tackle its growing volume of emissions (due to the growth of the sector), it must look at replacing fossil fuels with a lower carbon alternative. Currently, such alternative is mainly limited to drop in alternative fuels.

According to Kousoulidou & Lonza (2016), a study that analyses fuel demand and CO2 emissions evolution in Europe toward 2030, when comparing projected demand volumes of alternative aviation fuels with currently available projections in terms of supply available in Europe, it seems that dedicated renewable jet fuel production will not be sufficient to meet demand. The study does appoint, however, that there uncertainty surrounding the implementation of market based mechanisms (comparable to the EU ETS) and the possible full implementation after 2017 make the secenario-based projections of possible costs for HEFA/HVO quite unreliable.

These predictions show that, first, a clear strategy needs to be created at EU level to define what level of deployment is wanted in Europe, and secondly, that the policy action needs to be congruent and in line with such strategy. Further policy action will be required if the European Union's strategy is committed to support aviation alternative fuels. It also depicts that policy stability will be a key for investments to happen and the lack of a more defined strategy may slow down deployment in Europe with respect to other regions.

4.1 Recommendations

Two main objectives need to be considered in this set of recommendations: first, the general target for the transport sector for 2020 which is to achieve 10% share of renewable energy and secondly, the 2 MT of biofuel target set by the Flightpath 2020 for the same year. However, the progress until 2015 towards the achievement of both these objectives has been slow with a projection of only 5.7 % renewable energy in transport in 2014 (European Comission, 2015). One of the main reasons for this has been the uncertainty caused by delay in finalization of the policy to limit the risks of indirect land-use change, and the lower progress in deployment of advanced biofuels. There has recently been a the political agreement on limiting the impact from indirect land use change has resulted in the modification of the RED. In this regard, there is a risk that the trajectory towards the previously mentioned targets may become steeper, especially for those Member States that where already progressing slowly. The regulatory uncertainty, the adversity of stakeholders towards assuming the risk and administrative barriers can continue to impact private investments in the alternative fuel sector in Europe, and even more in the aviation sector, which may require additional measures to be taken.

Deliverable 5.4 was dedicated to the analysis of the existing policies as well as a review of the possible actions that could eventually be implemented in the EU in order to promote aviation biofuels uptake. One of the conclusions from this analysis is that there is no single policy that will enhance alternative fuel uptake, but rather a combination of several due to the various existing barriers for implementation. In addition, a combination of several favorable conditions will be required. In particular:

- Policy support and elaboration of a strategy with specific objectives and specific milestones to be achieved
- Institutional support, compromise with the development of aviation alternative fuels as well as an in depth knowledge by the administrations of the current barriers and willingness to provide assistance to overcome them. In this regard, the implication of the National administrations is key.
- Interest of the private sector at all phases of production and consumption of fuel, as well as a willingness to make investments
- Creation of a favorable environment, including institutional support of initiatives, stable policy framework and a solid European stakeholder network
- Reduction of investment risk
- Public awareness and understanding of the benefits and drawbacks of aviation alternative fuel

During the analysis carried out for WP5 of the CORE-JetFuel project, 5 possible measures have been analyzed.

- Counting of renewable jet fuels towards the obligation of fuel suppliers in several EU Member States (opt-in)
- Market-based Measure (MBM) with revenue generation geared towards innovation in the aviation sector
- Separate mandate for aviation biofuels

- Stimulating innovation and projects in the supply chain
- Cooperation between major airports / airlines

As a result of this analysis, as well as from the inputs obtained from the Core-JetFuel stakeholder workshops, economic incentives are also discussed below based on the inputs obtained and suggestions of the panel discussions. For each of these proposed measures, specific conclusions have been drawn.

4.1.1 Count renewable jetfuels towards the obligation of fuel suppliers in several EU Member States (opt-in)

Most Member States have designed national biofuel policies that only allow renewable jet fuels for road transport to be counted towards the mandate for renewable energy, which limits the capacity of stimulating alternative fuels for aviation. Although the RED directive was modified to allow aviation biofuels to account towards that objective, they are currently only included in the renewable energy for transport objectives in the case of the Netherlands. Fuel suppliers are not stimulated to produce and sell renewable jet fuel to comply with their obligations on renewable energy in transport. By stimulating other Member States to provide a level playing field for road biofuels and renewable jet fuels the value of delivering biofuels to the aviation sector would increase for fuel suppliers, thereby bridging the costs gap for the airlines.

Although the sole impact of this measure has been evaluated to be low, it is a necessary step before proposing more ambitious measures. This measure is encouraged to be implemented on the rest of the EU states since it is a measure which is fairly easy to implement and that does not require a significant investment.

In this regard, the Commission cannot demand Member States to change their national legislation, but could rather inform Member States about the possibilities to create a level playing field. This could be carried out through:

- Conferences and other public appearances to inform Member States and the public about the possibilities for a renewable jet fuel opt-in in national biofuel policy, including the meetings of the ECAC/EC EuroCAEP Group.
- In 2016 / 2017 an impact assessment on renewable energy in transport will be published to analyse different policy scenarios for the post 2020 period. The Commission could mention the inclusion of renewable jet fuels in overall biofuel policy as a good example, or analyse the case of the Dutch opt-in, to give attention to this possibility and inspire Member States to take similar action.
- By the end of 2017 the Commission will report to Parliament on the implementation of Directive (EU) 2015/1513, including a section on *"promoting sustainable biofuels after 2020 in a technology-neutral manner, in the context of the 2030 framework for climate and energy policies"*. The report could include a section on technology neutrality and a level playing field for bio energy end use by including a section on the opt-in for renewable jet fuels.
- The Concerted Action Renewable Energy Sources (CA-RES) is the official regular meeting between the European Commission and the Member States to discuss the implementation of the RED. CA-RES is an instrument of the Intelligent Energy Europe (IEE) Programme, which

supports the transposition and implementation of the RED. The working group on biofuels could be asked to discuss the opt-in for renewable jet fuels

- The Renewable Fuels Regulators Club (REFUREC) is the informal network of Governmental institutions responsible for regulating biofuels, meeting regularly to discuss the implementation of the RED. In light of the upcoming ICAO proposal on a market the Commission could initiate based measure for the aviation industry, in which the use of biofuels may play a significant role towards the achievement of emission limitation targets, a discussion with Member States during a REFUREC meeting.

4.1.2 Market-based Measure (MBM) with revenue generation geared towards innovation in the aviation sector

Currently, the aviation sector is included in the EU ETS. Within the EU ETS, regulated parties are able to buy allowances through an auctioning system which generates revenue. It is a competence of the EU Member States to determine the the use to be made of those revenues, although they should be used to tack climate change in the EU and third countries. One of the possible uses of this revenue could be to fund research and development in the field of alternative fuels.

In addition to the EU ETS, ICAO has agreed to work towards a GMBM that can help tackle aviation emissions. The final design of a GMBM defined at ICAO level is for the moment still under discussion and the way aviation alternative fuels could eventually account for lower emissions is for the moment uncertain, but it is intended to be defined during the current CAEP cycle. The GMBM is likely to be an offsetting scheme, with the details depending on ICAO's next General Assembly in 2016, where the 191 Member States will vote on adopting the Resolution. In a global offsetting scheme greenhouse gas (GHG) emissions can be offset through the reduction, removal or avoidance of emissions. Offsetting could be carried out using existing standard emission units (CERs…) or even through alternative fuel use. Alternatively, alternative fuel use could be accounted in order to reduce the total amount of emissions of a regulated party. These details are therefore still pending and the results of the negotiations can condition the aviation biofuel strategy in Europe.

Under this uncertain result, several actions can be considered in the definition of the European short-term strategy for aviation alternative fuels.

- In an offsetting system renewable jet fuel could be used to reduce the emissions from airlines activities by accounting with lower emission factors, as an alternative to buying other offsets. To maximise the impact of using renewable jet fuels it could be considered to account for renewable jet fuels s as having lower GHG emissions than conventional fuel. Currently, EU ETS assigns a zero emissions factor to alternative fuels as long as they comply with the FQD and RED sustainability requirements. This would require easily implementable accounting systems, currently under development at the ICAO CAEP groups.

- Another possibility is to stimulate renewable jet fuels through generating a revenue stream from an offsetting system. The revenue stream from an aviation MBM system could be used as a source for climate financing needed to limit the global temperature increase, or used for stimulating innovation in the aviation sector, including innovation at the alternative. In the case of an offsetting scheme one way to create a revenue stream could be by applying a transaction fee to each purchased offset unit (tCO_2). This is, however, an item to be defined at ICAO level as it will be part of the general definition of the system. In case there is revenue generation, it would be the individual States that would decide the use of it so this would be a decision at Member State level. These projects could include projects that stimulate innovation in renewable jet fuels.

4.1.3 Separate mandate for aviation biofuels

Due to the objective set to supply 10% renewable energy in transport in 2020, individual Member States have defined their own targets to contribute towards such objective. However, national authorities have focused their policies to achieve their individual objectives mainly through road transport. The establishment of specific mandates for aviation has been broadly discussed during the project meetings and discussions. Although there are some stakeholders that consider that it could be the most effective way to achieve a certain objective, others doubt of the secondary effects that may cause in industry if the production capacity is not sufficient to cover such demand. As such, there is not a strong consensus regarding this way forward among the collaborating stakeholders.

Implementing a separate mandate for aviation biofuels requires significant time as well as production capacity. Only certified sustainable renewable jet fuel should be eligible to be counted towards the mandate but currently, there are few cases of complete value chains that have been completely certified. As a result, it may be cautious to allow building up further capacity of production as well as experience in complete value chain sustainability certification of aviation fuels before establishing a specific mandate.

Introducing a separate mandate in an upcoming market does hold the potential risk of destabilizing the market, as a proper supply chain has to be established. A further risk is that a strong mandate would be difficult to apply unilaterally as it could lead to jet fuel consumption leakage to nearby countries that do not have the obligation.

In the case mandates are considered, establishing the actual volumes will be a challenging task. First of all, a detailed impact assessment of possible mandated volumes would be required (i.e. analyzing the potential production capacity, etc.) Objectives may increase with time but in any case, a low volume should be set in the beginning to avoid the mentioned effects. Secondly, any mandate for aviation biofuels would have to be developed within the context of a MBM or the ETS, in case the European Commission decides to extend the ETS to flights in and out of the EU. Another option could be that individual Member States impose a mandate on aviation biofuels, however, there might be EU free market barriers that stand in the way of unilateral action.

4.1.4 Stimulate innovation and projects in the supply chain

To reduce the costs for renewable jet fuel, innovation is needed throughout the supply chain. Policy making can be directed to the removal of existing barriers through direct funding support. One of the main outcomes that the partners have obtained from the project workshops is that there is no winning technology for aviation biofuels although there are different levels of readiness level. For that reason, it is still important the supply chain projects are diversified in terms of production pathways.

Policy makers can facilitate/provide funding to projects that scale-up the renewable jet fuel availability and integration of the supply chain. It is important that these investments are directed to increasing the potential production capacity since this is currently an issue at European level. Increasing the number of initiatives is important for the renewable jet fuel market to grow. It is important that any innovation project to be set must be in line with the general alternative fuel strategy for Europe.

Previous or ongoing experiences, such as the ITAKA project have delivered important knowledge on value chain deployment and experience to European stakeholders. ITAKA permitted to secure the fuel production but also to test an optimized business model all along the value chain (optimization of costs, identification of axes of progress, risks and potential opportunities) to develop the market for aviation in Europe. The ITAKA ambition has been extended to deploy the first fuel distribution platform at the level of airports (being Oslo airport the first biohub in Europe). This is an important achievement being a basis for future biohub initiatives in Europe.

However, support is not only needed in the actual supply chain but also in the coordination with related topics and projects. In fact, some stakeholders have shown concerns between the lack of connection between publically funded alternative fuel demo projects and other R&D projects concerned with the investigation of engines and fuel systems. Having this connection would allow to carry out tests of the new engine technology, not only with conventional fuels but also with the new alternative fuels. In fact, in the ongoing projects for deployment of alternative aviation fuels in Europe (i.e. ITAKA, Biorefly), the possibility of using a sample of the produced biofuel for its test in other fuels projects (i.e. SAFUG) has not been foreseen in advance. There is currently a lack of knowledge of the effects of the variability in the fuels composition that can be introduced with alternative fuels on the aircraft fuels systems and the alignment of these two types of projects could help in getting further knowledge and understanding the properties of different types of fuels.

In addition to publicly funded projects under EU programs such as Horizon 2020, support would also be valuable in terms of de-risking potential private investments. One of the main oucomes of the Core-JetFuel Final Workshop was that economic barriers could be addressed through financing options for first mover/early adopter grants, off-take agreements facilitated by national administrations or even facilitating access to loan guarantees.

4.1.5 Cooperation between major airports / airlines

Existing barriers and current market conditions make it challenging for individual airlines to push this aviation alternative fuels market forward. The ongoing Bioport Initiative in the Netherlands is an example of an an airport-led approach in which the airport uses its position in between fuel supplier, airlines and national government to optimize distribution and facilitate the supply.

This kind of initiative or similar initiatives mean that the airport acts as a demand aggregator, of different airlines and would therefore aim to deliver a certain quantity of renewable jet fuel through its fuel distribution systems. Instead of an individual airline having to set up dedicated supply chain to buy a certain amount of biofuel, the airport would supply a small percentage of biofuel to all aircraft taking off at the airport. This would allow for more efficient supply chains as well as larger volumes, both reducing the costs for biofuel significantly.

In this regard, one of the outcomes of the stakeholder consultation is that direct institutional support is needed since administrations can act as facilitators/promotors of these types of agreements. The European Commission as well as national administrations can promote airport-led initiatives primarily through its communication with sector organizations, selected airports and the aviation society at large. In fact, it would be interesting to analyses in further detail which airports would be optimal for such pilot experiences, based in their logistics system, geographical situation and level of activity. Furthermore, administrations could consider how to facilitate the forming of an airport-led initiative, e.g. by providing resources or funding.

4.1.6 Economic Support and Incentives

Significant deployment of renewable jet fuels is difficult to achieve with market forces alone. It is clear that while investments on other uses other than aviation seem to be more rewarding in economic terms, the level of aviation alternative fuel production will remain low. It is still unattractive from an economic point of view to make investments on aviation alternative fuels since the level of risk and the ease of obtaining a return on the investment is low, especially in comparison with other alternatives. Incentives and de-risking of investments have demonstrated to be an effective strategy both in off-take agreements in Europe and other regions. The risk of failure of a project needs to be decreased in order to incentivize investments. Purchase agreements or national/supranational financing programs could be a way of de-risking such investments.

It is the recommendation of this report to reduce the cost differential by tying economic benefits to the use of sustainable jet fuel. Incentives could be introduced for production/consumption. There are several options for this but a system similar to biotickets in the Netherlands could contribute to reducing the price gap. This would therefore be a market based measure in which the price of the unit of alternative fuel would vary depending on its demand. However, for a market based measure to be introduced, individual states would need to maintain national objectives after 2020 for alternative fuel use in the transport sector, even if there is no mandatory regulation at European level, otherwise, there will be no incentives to use. Another option to incentivize would be direct tax benefits for airlines that use alternative fuels.

Another way of de-risking investments are public-private partnerships, where the investment risk is shared and therefore lowered for individual stakeholders. These partnerships could be designed so conditions and requirements are fixed and secured independent of the changes on the regulatory process. For this purpose, the role of the national administrations/public organisms is key in order to act as facilitators to achieve agreements between the different stakeholders.

4.1.7 Create an Enabling Environment through Removal of Non-Economic Barriers

In addition to the economic barriers there are other elements from the policy and strategy perspective that need to be considered in order to create sufficient conditions for deployment.

According to the Report from the Commission on Renewable energy progress (2015), spatial planning, administrative and authorisation procedures for project developers are important factors affecting investment decisions for large energy infrastructure projects. In order to facilitate market access for new entrants and stakeholders in the market, transparency needs to be increased and coordination among involved authorities ensured. Therefore, the authorisation procedure for new renewable energy producers is an element that has already been identified by the Commission as a challenge to renewable energy on a general basis (not only for aviation). In addition, aviation has its own particularities that add to the previously mentioned barriers. In particular, there is a lack of experience in chain of custody control to comply with ETS eligibility criteria, an element that requires experience in terms of administrative work. Such experience is needed in order to learn how to simplify and streamline the work. Furthermore, chain of custody to demonstrate sustainability criteria and compliance will require improved and simplified procedures if a global MBM is to be implemented and aviation alternative fuels may be used to lower the emissions accounting of the regulated parties.

Another very important item to favor investments is policy stability. The creation of a secure environment for investments is absolutely necessary to help the industry develop. There is a common understanding among stakeholders that without a clear and reliable frame of reference, investment will be deterred, and therefore specific initiatives for the aviation sector will be delayed. For such, a possible solution is to guarantee that the criteria for eligibility of the final product will not vary for a certain period of time for investments made up to a certain date, so that if there is a legislative modification, the production can be continued under certain conditions to avoid that investments are lost. LUC consideration has been a controversial topic in this regard and it is still a highly debated topic which may generate certain mistrust for investors as well as diminished confidence of the final user (airlines).

In addition, institutional support needs to be perceived by stakeholders. This support may be the form of a national initiative or platform, not only at national level, but on a regional basis, taking advantage of the stakeholders that can participate in the deployment of a specific value chain in a broader region. Several European countries already have their national initiatives, but in some cases, in the latest years, the progress of the initiatives has slowed down due to the lack of direct financial support by the authorities. National/regional platforms should be strengthened, getting national authorities/administrations involved, at least to act as facilitators to reach purchase agreements between different stakeholders of the value chain.

Collaboration between national/regional platforms should also be assured in the form of a European platform. In fact, stakeholder exchange is a key element to create a common European strategy. European coordination on how aviation alternative fuels must be approached would be necessary in order to participate in a more coordinated manner at ICAO discussions. In fact, the ICAO CAEP group dedicated to alternative fuels, the AFTF, is currently working not only on an LCA methodology for alternative fuels, but also in trying define a common understanding on sustainability criteria as well as analyzing policy measures to help alternative fuels deployment. A common understanding and further coordination in this regard between the participating states would help to bring up proposals at ICAO level.

Along with institutional support, public perception of alternative fuels is also a key element in creating a favorable environment for deployment. For that confidence to be created, the sustainability of renewable jet fuel must therefore be convincingly demonstrated in order to avoid any environmental and social sustainability concerns. Airlines and industry representatives have expressed their concerns regarding the assurance of sustainability of a commercial biofuel. The industry, and in particular, the airlines are very exposed to the public opinion, and therefore want to make sure that any biofuel they use has a guarantee of compliance of all the sustainability criteria. This becomes a particularly delicate matter in a globalized industry that can purchase biofuel anywhere in the world and thus, under different regulations. In this regard, a good communication strategy with the public and NGOs is essential in order to avoid misinterpreted information to the public. It would be interesting to analyze public perception of aviation alternative fuels as well as creating public awareness of the possibilities of alternative fuel in the aviation sector. In fact, the Lab'line for Future project in France did carry out a survey to analyze public perception in France. This could be replicated on a larger spectrum.

Lastly, it is the recommendation of this report to focus efforts on continuing work on the assurance of sustainability criteria, as well as analyzing how these criteria could be harmonized in order to avoid any possible trading issues. There are currently a large number of national and voluntary sustainability schemes and additionally, there are significant differences on sustainability criteria with other states outside the EU where different regulations exist. As an international and global business, aviation's standards and requirements should have an international recognition. This becomes even more important if aviation alternative fuel is to be considered as having lower emissions in a GMBM. In fact, ICAO's AFTF is currently working on alternative fuels sustainability criteria. The EU and its member states should dedicate significant resources to cooperation and discussion in this task as it is of vital importance that the criteria are properly agreed and set to ensure the environmental integrity of any alternative fuel used by the industry. If there is no harmonization of these criteria, a possible solution would be to establish mutual recognition agreements with those non EU countries that produce significant quantities of alternative fuel.

4.1.8 Work towards the Feasibility of 2 MT of alternative fuels for aviation, perspectives and continuation of the Flightpath

On the previous section, it was suggested that more effort should be dedicated national initiatives in order retake their initial objectives. However, to reach the 2 MT objective it would be important to put together the effort of stakeholders from different European regions that have different potentials for developing the different steps of the value chain.

As such, work carried out by the Advanced Biofuels Flightpath should be continued. The future continuation of this initiative should therefore be carried out in the form of a coalition that focuses the efforts in building relationships, sharing and collecting data, identifying resources, and direct research, development and deployment of alternative jet fuels. As such, the coalition will need to focus on finding financing methods as well as sponsorship for specific projects and/or off-take agreements that will enhance deployment. Since the economic barrier is currently the most difficult to overcome, this stakeholder working group should dedicate an important effort on finding financial solutions to projects. There could be different working groups dedicated to financing and business, environmental issues, technologies, feedstock and R&D. In addition, the group should work on Identifying and promoting new opportunities in Europe to continue to sustain sustainable aviation fuels production and use.

In addition to this, aviation alternative fuels need to be further integrated in the European renewable energy policy. In fact, production of bio kerosene will in practice be accompanied by the production of biofuels for other means of transport. Accordingly, any project aiming to produce bio kerosene is affected by biofuel policy in other sectors. Developing a common integrated strategy along with other ways of transport which could also be the target for alternative fuel use would be important in order to prioritize feedstock use. The current availability of feedstock is limited and therefore it is important to have a strategy to define where this feedstock could be used, either for its environmental benefit or for economic reasons. This integrated strategy should include coordinated European strategy at international forums, including ICAO discussions relative to av. Alt. fuels.

5 Summary of Recommendations

This chapter synthetizes all the recommendations detailed above.

5.1 Feedstock and Sustainability

Select and push for the most suitable types of feedstock or feedstock cultivation practices to mitigate the environmental impacts

WHY

- Aviation industry very concerned with only using advanced feedstock types showing a very good sustainability performance Objective of achieving GHG emission reduction targets for aviation sector
- A means to generate socio-economic benefits for the local population and to improve their acceptance by using such biomass for renewable jet fuel production

HOW

- Use a multitude of potential feedstock, needing investments to set up the value chains
- Promote advanced types of feedstock according to the location in the world

Assess the sustainable biomass availability in Europe and its geographical distribution

WHY

- Direct impact on the renewable jet fuel production costs
- Feedstock widely dispersed with availability not always economically viable due to long transport distances or cultivation costs

HOW

- Assess, with a uniform approach, the regionally available biomass potential including feedstock production costs
- Identify areas economically favorable for sustainable feedstock production with sound agricultural practices and restricted land use changes
- Take into account unforeseeable climatic conditions/aleas on the biomass production
- Take into account competition for other uses

Decrease costs of feedstock production by developing small-scale production sites and networks of supply chains

WHY

- Current actual cost of renewable jet fuels too far from the cost of fossil jet fuels due to generally the high cost of the feedstock
- Logistical challenge with the collection of lignocellulosic biomass

HOW

- Develop small-scale conversion plants with the collection of the biomass nearby
- Coordinate the networks of supply chains for business model of bio-jet fuel production

- Take advantage of synergies with the production of more valuable products using the same feedstock

Establish integrated biomass policy for a smart use of the resources with a special attention for aviation needs

WHY

- Competition for biomass between different application sectors (road transport, electricity, heating, cooling, biomaterials etc.), needing arbitrage for a real smart use of the feedstock according to the constraints of each sector
- Use of energy under liquid form inescapable for aviation sector for a long time
- Only option of using biogenic feedstock to decrease GHG emissions in the medium-term

HOW

- Assess the needs of biomass for each sector and introduce prioritization if needed
- Put in place integrated biomass policy taking into account all biomass application sectors
- Include a strategy for road transport sector on GHG emissions in this policy and also for wind and solar energy use

Harmonise sustainability certifications to converge on international scheme recognized by everybody

WHY

- All biofuels subject to sustainability requirements of the RED in Europe by using 'voluntary' certification schemes recognized by EC as RSB EU RED and ISCC EU, but this is currently not an international requirement.
- Need for higher level of mutual recognition/harmonization
- Larger degree of flexibility in the supply of biomass from producers already certified by one or the other schemes

HOW

- Harmonise the certification schemes to reduce the costs for the producers and finally the end-users
- Improve the databases with input data for LCA and other tools for certification to obtain comparative level of confidence on criteria regarding environmental aspects
- Work through CAEP ICAO working groups in order to reach an international agreement and dedicate resources to such groups from the EU MS.

Focus some research efforts on sustainable feedstock acceptable for aviation sector

WHY

- Few of European public projects solely concerned with a single type of feedstock and its production

HOW

- Focus R&D effort on several types of feedstock and their cultivation in order to improve plant genetics, solar radiation efficiencies, etc. and to make the production step more efficient, keeping in mind the final application and associated targets (GHG emission reduction in the long-term)

- Focus effort on higher production volumes with increase of the yield without collateral damage
- Focus on agricultural practices that enhance productivity using methods with low ILUC effect

5.2 Conversion Technologies, Radical Concepts and Holistic Assessment

Complement the set of key performance indicators with future potentials for climate impact and European energy supply security

WHY

- Advantageous *specific* GHG balance alone is no sufficient metric, as it does not yield an indication regarding the potential impact of a technology, e.g. a specific type of renewable fuel, could have on a sector's GHG emissions.
- In strategic decisions e.g. in the case of the development of future work programmes and funding strategies, the potential impact of a future technology on European or global scale has to be taken into account and with these metrics a better understanding of the possibilites for additional advances of respective technologies, and their future impact is obtained.

HOW

- The indicator ***"Greenhouse gas emissions reduction potential relative to future fuel emission impacts"*** represents a combination of the specific GHG emissions and the potential availability (the production potential) of a specific type of renewable fuel in relation to a sector's overall fuel consumption. It indicates the GHG emissions that are saved as a consequence of substituting the potential maximum share of the overall fuel consumed by the considered renewable fuel. By relating the *absolute reduction potential* to the absolute fossil emission trend, the *relative potential impact* is obtained.
- The indicator "***European substitution potential energy import"*** relates to a contribution to the future European supply security. By relating the *absolute energy production potential* to the absolute energy import trend, the *relative substitution potential* is obtained.
- The term "potential" impact suggests that this impact is within the physical and/or technical performance limits of a technology assumung it is mature (TRL6-9) in the future, not the impact at the state of the art or at a future intermediate (<TRL6) decision point.

Balance technology development risks with an adequate level of rewarding GHG reduction potentials

WHY

- Some production pathways are key to achieve large-scale reduction of GHG emissions of the entire aviation sector. Therefore, it is recommended to foster the technology developments where the risks are worthwhile in view of a high impact potential of GHG reductions.
- The decision maker has to understand which technologies potentially present the greatest source of change, what is the right level of risk for the expected potential reward of technologies to develop, i.e. the balance of risk and reward needs to be observed.

HOW

- Support the progress of conversion technologies based on lignocellulosic and/or waste feedstock, such as HDCJ, HtL and FT-SPK,
- Support the progress of renewable non-biogenic pathways, such as the core conversion technologies of PtL and StL, and their aerial CO_2 supply technologies towards higher technological maturity to demonstrate their viability in an industrially relevant environment.

Develop fuel technologies with simultaneous advantages in cost efficiency, scalability, sustainability and feedstock supply security

WHY

- Single-criteria improvements should not compromise a holistic solution.
- Simultaneous improvements in terms of costs, scalability and GHG emissions are necessary and should not compromise other important environmental or social aspects, such as water consumption, emission of pollutants, land use rights etc.

HOW

- Base the future strategy for R&I in aviation fuels on a holistic, multiple-criteria approach, developing fuels with simultaneous benefits in costs, scalability, sustainability and feedstock supply security.
- Base the future strategy for R&I in aviation fuels on scalable production technologies, with each single technology showing potential to substitute at least 10% of the European jet fuel demand anticipated for 2050, while at the same time offering large specific GHG emissions reduction potentials,
- Base the future strategy for R&I in aviation fuels on feedstock-flexible production technologies that enable efficient utilization of a broad range of feedstock types, thus reducing dependencies on single feedstock sources, minimizing risk of supply shortfall and increasing scalability.
- Set up and maintain a holistic standard reference of a multiple-criteria evaluator for future fuel technologies with:
    - single-criteria threshold conditions (defining specific reference performance potentials),
    - single-criteria premise conditions (defining mandatory minimum required performance potentials) and
    - multiple-criteria trade-off conditions (acknowledging the fact that certain trade-offs can exist with respect to individual performance indicators, e.g. cost of production and GHG balance).

Maintain a balanced R&D portfolio to enable short-term innovation and to create long-term innovation opportunity

WHY

- A well-balanced R&D portfolio is crucial
    - to enable short-term industrial implementation of mature technologies,
    - to pave the way for less mature technologies to progress from laboratory-scale research towards demonstration in industrially relevant environments,
    - to enable novel and radical concepts offering large long-term potentials (“high risk / high gain” concepts) to be researched at laboratory-scale, thus creating future innovation opportunity and developping, retaining and attracting the required highly skilled human capital.

HOW

- Support basic research in other scientific domains, such as physics, chemistry, biotechnology etc.
- Support engagement of industrial stakeholders in use-inspired research and technology development, thus ensuring that industrially important issues are addressed and minimizing risk of failure.
- Larger number of R&D activities needed in the use-inspired research domain (Pasteur’s quadrant), forming the technology base for subsequent industrialization.

- Support large-scale technology development projects to de-risk the final develop step towards industrial maturity.

5.3 Technical Compatibility, Certification and Deployment

Continue the monitoring of deployment/implementation initiatives with a critical expert analysis to have an accurate overview on the most viable future pathways

WHY

- Identification of the pathways able to reach an acceptable renewable jet fuel price at mid term

HOW

- Assess of the conversion technologies of different types of feedstock through the numerous pathways currently used or planned to produce renewable jet fuels in the near, medium or long term
- Make an frequent overview of deployment initiatives and industry-driven projects, about their viability and the participating stakeholders
- Collaborate with international stakeholders (i.e. through ICAO working groups), in order to understand progress and deployment initiatives carried out in other world regions.
- Follow the evolution of the policy which determines the emergence of further initiatives and conversely brake some will to invest in such production

Develop initiatives by connecting the stakeholders engaged in alternative aviation fuels to push sustainable pathways

WHY

- Important to demonstrate the technical viability of sustainable pathways, to assess all the logistic issues, notably in the airports and to make sure of the social acceptance by passengers of using biofuels

HOW

- Push forward such initiatives gathering the stakeholders in the future for new pathways with suitable communication
- Continue to provide financing for R&D projects.

Decrease the industrial risk to scale-up production

WHY

- Necessity to secure the production through long term contracts and/or partnerships with airlines, oil companies, national defense/civil administration, Government departments

HOW

- Support such production, as in USA, and new operations needed to be implemented at large scale in order to proof the industrial and commercial concepts
- Consolidate the European regulations to avoid a backward step

- Develop and favour flexible processes allowing the use of different types of feedstock according to their costs and local or international availability.

Improve production costs and renewable jet fuel implementation/deployment

WHY

- Initial cost of new renewable jet fuel production units always much higher than well established and optimised plants
- Absence of tax on jet fuels in comparison with road transport fuel (no possible incentives by this means)
- Low weight yield of biomass to renewable jet fuel (5-15 wt%) penalising the final fuel cost

HOW

- Support newly developed renewable jet fuels by imagining and implementing an incentive procedure, preferably with the support of main airports (such as in the NL), such as the incentives that supported biofuels for the road transport sector in their establishment in the European market
- Support R&I studies to reduce the carbon losses at all the steps of the processes and to improve the global yield and the energy balance of the full pathway with the use of other types of renewable energy, allowing also the improvement of the overall GHG balance
- Identify technical bottlenecks according to the different pathways and potential progress margin
- Favor processes that can directly co-process biomass with fossil feedstock, such as the gasification 1st step of the Fisher-Tropsch pathway, or processes that can co-process secondary products from biomass conversion in existing petroleum refineries, such as fast catalytic or non-catalytic pyrolysis oil, also called bio-oil (for example co-processing a few percent of fast pyrolysis bio-oil with a petroleum vacuum gasoil in a conventional Fluid Catalytic Cracking unit) or bio-crude from the hydrothermal liquefaction (HTL) of wet biomass (that could be processed in existing hydrotreating/hydroconversion units), in order to both decrease CAPEX and OPEX

Improve the understanding of the properties of renewable jet fuels by identifying the most critical characteristics before launching the certification process

WHY

- A lot of R&I efforts still needed to understand the properties of alternative jet fuel blends based on detailed chemical analysis to predict the behaviour of the new fuels and push the development of new routes well suited for jet fuel production

HOW

- Put focus on the most critical fuel characteristics, as freezing point, viscosity, thermal and oxidation stability, and on combustion properties
- Link alternative fuels projects that are publicly funded with engine-related projects in order to allow carrying out fuel testing of new blends.

Optimise and improving the use of ASTM D4054 process

WHY

- Fuel analysis not enough to guarantee safety of operations requested in the ASTM certification process but can contribute to reduce costs and time with assessment at low TRL
- High costs due to the construction of demonstration facilities able to produce sufficient quantities of fuels for engine testing

HOW
- Focus in advance on the most critical issues for the certification from detailled fuel analysis and take into account the feedback from previous certifications
- Improve good understanding / modeling of relationship between chemical analyses and final fuel requirements for aviation use with reduced GHG emissions
- Maintain good cooperation and involvement of all the OEM and suppliers during the ASTM certification process to save time and costs

Pay attention to logistic and quality insurance due to presence of new players and the blending with fossil jet fuels

WHY
- Potential risks on the quality of blended fuels that could be due to logistics aspects and the inexperience of new players

HOW
- Adjust if needed the ASTM certification process, including the robustness of the production process, the quality assurance of the full supply chain and the effects of contaminants, coming from alternative jet fuels, on fuel properties and materials
- Check the impact of using new feedstock for the production of already certified jet fuels (e.g. Micro-algae for HEFA)
- Study the possible evolution of fossil jet fuel and blends with renewable jet fuels with lower sulfur and aromatic content.
- Check the impact of new jet fuel structure on dielectric constant
- Maintain a comprehensive and updated view of the state of maturity and level of confidence of each new pathway with new players launched on the market

5.4 Policies, Incentives and Regulation

Push for counting of renewable jet fuels towards the obligation of fuel suppliers in several EU Member States (opt-in)

WHY

- Only renewable jet fuels for road transport to be counted towards the mandate for renewable energy in most of national policies limiting the capacity of stimulating alternative fuels for aviation
- Fuel suppliers not stimulated to produce and sell renewable jet fuel to comply with their obligations on renewable energy in transport

HOW

- Stimulate Member States to provide a level playing field for road biofuels and renewable jet fuels
- Inform Member States and the public about the possibilities for a renewable jet fuel opt-in in national biofuel policy
- Analyse the case of the Dutch opt-in, to give attention to this possibility and inspire Member States to take similar action
- Include a section on technology neutrality and a level playing field for bio energy end use including renewable jet fuels in the report to Parliament on the implementation of Directive (EU) 2015/1513, by the end of 2017
- Take into account the opt-in for renewable jet fuels in the official regular CA-RED meetings
- Initiate MBM for the aviation industry in the frame of REFUREC meetings

Push for Market-based Measures (MBM) with revenue generation geared towards innovation in the aviation sector

WHY

- Possible for the EU Member States to use the revenue from EU ETS to fund R&T on aviation alternative fuels
- Agreement from ICAO to work towards a GMBM as potentially an offsetting scheme, that can help tackling aviation emissions (final design still under discussion)

HOW

- Use of renewable jet fuel as offsetting solution to reduce the emissions from airlines activities as an alternative to buy other offsets
- Stimulate renewable jet fuels by generating a revenue stream from an offsetting system to limit the global temperature increase
- Create a revenue stream by applying a transaction fee to each purchased offset unit (tCO_2) to fund projects that stimulate innovation in renewable jet fuels (decision at Member State level)

Stimulate innovation and projects in the supply chain

WHY

- Necessity to reduce the costs of fuel production and to remove existing barriers
- Support needed to de-risk potential private investments

HOW

- Use of direct funding support for innovative and diversified supply chain projects allowing renewable jet fuel availability increase, as for ITAKA allowing the deployment of the first fuel distribution platform at the level of airports
- Remedy the lack of connection between publically funded alternative fuel demo projects and other R&D projects concerned with the investigation of engines and fuel systems

Stimulate cooperation between major airports/airlines and fuel producers

WHY

- Existing barriers and current challenging market conditions for individual airlines to push this aviation alternative fuels market forward

HOW

- Develop and promote airport-led approach as Bioport Initiative in which the airport uses its position between fuel supplier, airlines and national government to optimize distribution and facilitate the supply with a small percentage of biofuel to all aircraft taking off at the airport
- Analyse which airports would be optimal for such pilot experiences, based in their logistics system, geographical situation and level of activity, and support with direct institutional fundings

Develop economic support and incentives

WHY

- Still unattractive from an economic point of view to make investments on aviation alternative fuels due to level of risk and the low return on the investment
- Necessity to de-risk the investments

HOW

- Develop purchase agreements or national/supranational financing programs to de-risk such investments
- Introduce incentives for fuel production and consumption, as the use of biotickets in the Netherlands to reduce the price gap or direct tax benefits for airlines that use alternative fuels
- Promote public-private partnerships, where the investment risk is shared, with national administrations/public organisms as facilitators to achieve agreements between the different stakeholders

Create an enabling environment through removal of non-economic barriers

WHY

- Spatial planning, administrative and authorisation procedures for project developers affecting investment decisions for large energy infrastructure projects
- Lack of experience in chain of custody control to comply with ETS eligibility criteria
- Slowing down of initiatives due to the lack of direct financial support by the authorities

HOW

- Facilitate market access for new entrants and stakeholders in the market with an improved coordination among involved authorities
- Improve and simplify the procedures for the chain of custody to demonstrate sustainability criteria and compliance if GMBM implemented
- Stabilise the fuel policy to favor industrial investments and eventually maintain them under certain conditions when already committed if there are changes in the regulations
- Strengthen National/regional platforms with the involvement of National authorities/administrations, to facilitate purchase agreements between different stakeholders of the value chain
- Put in place an European platform to contribute to a common European strategy for alternative fuel deployment and to be more coordinated for ICAO proposals and discussions
- Improve and analyse the public perception and therefore the communication to create a more favorable environment for deployment with demonstration of the compliance with all the sustainability criteria
- Focus efforts on continuing work on the assurance of sustainability criteria, as well as analyzing how these criteria could be harmonized at international level in order to avoid any possible trading issues, by dedicating significant resources to cooperation and discussions on these aspects, or otherwise establish mutual recognition agreements with those non-EU countries that produce significant quantities of alternative fuels.

Work towards the Feasibility of 2 Mt of alternative fuels for aviation, perspectives and continuation of the Flightpath

WHY

- Important to put together the effort of stakeholders from different European regions that have different potentials for developing the different steps of the value chain

HOW

- Continue the work performed in the frame of Advanced Biofuels Flightpath in the form of a coalition that focuses the efforts in building relationships, sharing and collecting data, identifying resources, and direct research, development and deployment of alternative jet fuels
- Dedicate stakeholder working groups on finding financial solutions to projects and on the identification and promotion of new opportunities in Europe to continue to support sustainable aviation fuel production and use.
- Integrate aviation alternative fuels in the European renewable energy policy
- Have a European strategy coordinated with ICAO discussions to define where the feedstock could be used for fuel production, either for its environmental benefits or for economic reasons

6 Bibliography

Alberici, S. et al. (2014): Assessment of sustainability standards for biojet fuel, Final report. http://www.ecofys.com/files/files/ecofys-2015-assessment-of-sustainability-standards-for-biojet-fuel.pdf

Arnold, E., Giarracca, F. (2012); "Getting the Balance Right – Basic Research, Missions and Governance for Horizon 2020", Technolopolis Report 2012.

Bauen A. et al. (2009): Aquafuels Project Deliverables 3.3 and 3.5 Lifecycle assessment and environmental assessment. http://www.aquafuels.eu/attachments/079_D%203.3-3.5%20Life-Cycle%20Assessment%20and%20Environmental%20Assessment.pdf (last visit: 28.04.2014)

European Comission. (2015). Report from the Comission to the European Parliament, the Council, the European Economic and Social Comitee and the Comitee of the Regions. Renewable Energy Progress Report.

FAO (n.y): Contribution of poplars and willow to sustainable forestry and rural development. http://www.fao.org/docrep/008/a0026e/a0026e02.htm (last visit: 11.08.2016)

Junker, F. et al. (2015): Biofuel Sustainability Requirements – The Case of Rapeseed Biodiesel. GJAE (2015), Number 4, The Political Economy of the Bioeconomy.

Kousoulidou, M., & Lonza, L. (2016). Biofuels in Aviation: Fuel demand and CO2 emissions evolution in Europe toward 2030. *Transportation Research Part D*, 166-181.

Kretschmer B. et al. (2012): Mobilising Cereal Straw in the EU to feed Advanced Biofuel Production. Report produced for Novozymes. IEEP: London.

Lundquist, T.J. et al. (2010): A Realistic Technology and Engineering Assessment Of Algae Biofuel Production. http://www.energybiosciencesinstitute.org/media/AlgaeReportFINAL.pdf (last visit: 28.04.2014)

Moser, B.R. (2010): Camelina (Camelina sativa L.) oil as a biofuels feedstock: Golden opportunity or false hope? Lipid Technology December 2010, Vol. 22, No. 12.

Rösch, C., Maga, D. (2012): Indicators for Assessing the Sustainability of Microalgae Production. Technikfolgenabschätzung – Theorie und Praxis 21. Jg., Heft 1, Juli 2012. https://www.tatup-journal.de/downloads/2012/tatup121_roma12a.pdf

Searle, S.Y. / Malins, C.J. (2016): Waste and residue availability for advanced biofuel production in EU Member States. Biomass and Bioenergy xxx (2016) 1 – 9.. https://www.researchgate.net/profile/Stephanie_Searle/publication/292077886_Waste_and_residue_availability_for_advanced_biofuel_production_in_EU_Member_States/links/56b0b2cb08ae9c1968b919bb.pdf (last visit: 11.08.2016)

Skarka, J. (2015): Potentiale zur Erzeugung von Biomasse unter besonderer Berücksichtigung der Flächen- und CO_2 – Verfügbarkeit. digbib.ubka.uni-karlsruhe.de/volltexte/documents/3494163 (last visit: 11.08.2016)

Stokes, D.E. (1997): Pasteur's Quadrant: Basic Science and Technological Innovation. Washington, D.C.: Brookings Institution Press, 1997.

USDA (2016): Oilseeds and Products Annual 2016.
http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Oilseeds%20and%20Products%20Annual_Vienna_EU-28_4-1-2016.pdf (last visit: 10.08.2016)