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

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

Deliverable 6.6:
Final Report

SUBMITTED VERSION 1.0

Work Package 6: Synthesis of Results and Recommendations
Work Package Leader: Fachagentur Nachwachsende Rohstoffe e.V.

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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 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.

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' related to 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 analyzed with the objective of identifying the main barriers for 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 and fruitful CORE-JetFuel workshops that took place over the entire project duration, thereby safeguarding transparency of results and minimizing the risk of biased recommendations.

This Final Report first summarizes the main assessment results of the project in WP4 and WP5 in order to provide the factual basis for the subsequent recommendations as well as to establish a reference to the project work. Based on the assessment results as well as the project's recommendations to the European Commission, roadmaps were developed and are presented here. The developed roadmaps relate to R&D on feedstock and conversion technologies, to technical approval, production and deployment, and to strategic policy milestones and targets.

Lastly, a brief description of the assessment framework defined and applied in the course of the project is given.

This Final Report represents a concise overview of the work that has been conducted in the CORE-JetFuel project. Detailed elaborations of the assessment results can be found in the final reports of the different thematic domains[1]. In addition, the project's recommendations[2]

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[1] **D4.2**: Final Report on collection, mapping and evaluation of R&D activities in the field of feedstock production and sustainability; **D4.4**: Report on compilation, mapping and evaluation of R&D activities in the field of conversion technologies of biogenic feedstock and biomass-independent pathways; **D5.2**: Final Report Innovation on Technical Compatibility, Certification and Deployment; **D5.4**: Report on Compilation, Mapping and Evaluation of R&D Activities in the Field of Policies, Incentives and Regulation;

[2] **D6.3**: Report on Recommendations

as well as the suggested roadmaps[3] are described in detail in dedicated reports. CORE-JetFuel Deliverables are available online at: http://www.core-jetfuel.eu.

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[3] **D6.4**: Report on Roadmaps

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LIST OF ABBREVIATIONS

AFTF	Alternative Fuels Task Force
AJF	Alternative Jet Fuel
APR	Aqueous Phase Reforming
ARA	Applied Research Associates
ASTM	American Society for Testing and Materials
AtJ	Alcohol-to-Jet
BtL	Biomass-to-Liquid
CapEx	Capital Expenditure
CCE	Camelina Company España
CH	Catalytic Hydrothermolysis
CtL	Coal to Liquid
DG	Directorate General
DOE	Department of Energy
DSHC	Direct Sugar to Hydrocarbon (now called SIP)
EC	European Commission
EPA	Environmental Protection Agency
ETS	European Trading Scheme
EU	European Union
FAA	Federal Aviation Administration
FT	Fischer-Tropsch
FT-SPK	FT Synthetic Paraffinic Kerosene
FT-SPK/A	FT-SPK containing aromatics
GHG	Greenhouse Gas
GMBM	Global Market-Based Measure
HDCJ	Hydrotreated/Hydroprocessed Depolymerized Cellulosic Jet
HEFA	Hydroprocessed Esters and Fatty Acids
ICAO	International Civil Aviation Organization
ILUC	Indirect Land Use Change
ITAKA	Initiative Towards sustAinable Kerosene for Aviation
LCA	Lifecycle Analysis

LUC	Land Use Change
NISA	Nordic Initiative for Sustainable Aviation
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturers
OpEx	Operational Expenditure
PM	Particulate Matter
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
SIP	Synthetic Iso-Paraffins (formerly called DSHC)
SK	Synthetic Kerosene
SKA	Synthetic Kerosene with Aromatics
SPK	Synthetic Paraffinic Kerosene
SRC	Short Rotation Coppice
StL	Sun-to-Liquid
TRL	Technology Readiness Level
UCO	Used Cooking Oil
USDA	US Department of Agriculture
VO	Vegetable Oil
WP	Work Package

Introduction

One of the main objectives of the CORE-JetFuel project is to provide the European Commission with recommendations concerning its funding strategy with respect to R&D activities in the field of alternative aviation fuels.

In order to meet this objective, the project covered the entire biojet production 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 basic research, use-inspired 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 fuel research portfolio and allowed for indications in which areas of the field more research is required in the short, medium and long-term future.

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, GHG emission reduction potentials and costs of production. 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 analyzed and compared with the objective to identify the main barriers for the production and deployment of sustainable alternative aviation fuels.

This Final Report of the CORE-JetFuel project will first highlight the main assessment results of the four different thematic domains as well as recommendations based thereon. Lastly, roadmaps for the further development of production pathways, dismantling of political barriers for higher levels of deployment, as well as milestones in the technical approval of production pathways are given.

This Final Report represents a concise overview of the work that has been conducted in the course of the CORE-JetFuel project. Detailed elaborations of the assessment results can be found in the final reports of the different thematic domains[4]. In addition, the project's recommendations[5] as well as the suggested roadmaps[6] are described in detail in dedicated reports. CORE-JetFuel Deliverables are available online at www.core-jetfuel.eu.

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[4] **D4.2**: Final Report on collection, mapping and evaluation of R&D activities in the field of feedstock production and sustainability; **D4.4**: Report on compilation, mapping and evaluation of R&D activities in the field of conversion technologies of biogenic feedstock and biomass-independent pathways; **D5.2**: Final Report Innovation on Technical Compatibility, Certification and Deployment; **D5.4**: Report on Compilation, Mapping and Evaluation of R&D Activities in the Field of Policies, Incentives and Regulation

[5] **D6.3**: Report on Recommendations

[6] **D6.4**: Report on Roadmaps

1 Main Results

1.1 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. Utilizing the different feedstocks available today for the production of alternative aviation fuels is linked to various challenges of environmental, technological, social as well as economic challenges. Taking these challenges into account, the evaluation of different types of feedstock was conducted by applying a set of assessment criteria that were established in the corresponding assessment framework in the beginning of the project.

1.1.1 Assessment of feedstock sources and supply chains

The most important assessment criteria that were applied to feedstock cultivation and further processing included: greenhouse gas balance of cultivation, transportation and processing, amount of fertilizer application, technical maturity of the cultivation process and required machinery (Feedstock Readiness Level or FRL), impact on local biodiversity as well as the risk of inducing indirect land use changes (iLUC).

Due to the numerous options theoretically available for bio-jet production, the assessment concentrated on those types of feedstocks that have, either proven their suitability for one of the five certified production pathways and are therefore actually utilized, or on so-called advanced types of feedstocks that potentially show a very good sustainability performance, but are not produced at commercial scale for the aviation sector at the moment. In addition, the CORE-JetFuel Consortium agreed to narrow down the scope of the assessment work to the European context, i.e. feedstock cultivation

Corresponding to the main feedstock groups that have been identified by the CORE-JetFuel Consortium, the following feedstock sources have been assessed:

- Biogenic Oils and Fats
  - Microalgae
  - Camelina
  - Used Cooking Oils (UCO)
  - Rapeseed
- Lignocellulosic Biomass
  - Short Rotation Coppices (SRC)
  - Switchgrass
  - Agricultural Waste and Residues
  - Forestry Waste and Residues

The main assessment results are briefly outlined below:

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 biojet 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 limited 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. The transportation cost and GHG related emission could be limited, in case of decentralized pretreatment conversion units implanted close to the resource, such as torrefaction or fast pyrolysis plants.

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: 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)[7]	45 – 550 g CO_2 eq./MJ[8]	Open Pond: 5 – 25g/m^2/day PBR: 60 – 650 g/m^2/day[1]	9.200t (2015)[9]	Europe: 41Mt/y (technical potential)[10]
	Camelina	35 – 45% dry weight)[11]	Cultivation: 40.2 g CO_2 eq./MJ Oil extraction: 12.3 g CO_2 eq./MJ[12]	0.34 2.24 t/ha – 2240kg/ha[5]	500 – 2000t/ha[5]	N/A
	UCO	N/A	RED: 0 g CO_2 eq./MJ up to collection	N/A	Europe: ~1 Mt/y[13]	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/y (2015)[14]	Europe: 22.4 Mt/y (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[15]	France: 2.4 Mt/y Italy: 1.2 Mt/y[16]	Germany: 9.5 Mt/y (on ‘very suitable’ land)[9]

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[7] Petrick et al., 2013
[8] Bauen et al., 2009
[9] Rocca et al., 2015
[10] Skarka, 2015
[11] Moser, 2010
[12] Miller/Kumar, 2013
[13] Spöttle et al., 2013
[14] USDA FSA, 2016
[15] Tubby, 2002
[16] Aust et al., 2013

	Switchgrass	Heating value at 15-25% moisture content: 16.8 – 19.1 MJ/kg[17]	Cultivation: 17.6 – 39.7 g CO_2 eq./MJ	18 – 25 t/ha[18]	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)[19]	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 MJ/kg[10]	RED: 0 g CO_2 eq./MJ up to collection Transportation: 8.25 kg CO_2 eq./MJ[10]		67.6 Mt/y[12]	Europe: 9.2 Mt/y (sustainable availability)[12]

In addition to the feedstock assessment itself, the most prominent sustainability certification schemes, namely the RSB EU RED as well as the ISCC EU were first described individually, then compared to each other and options for a higher level of mutual recognition / harmonization identified. It was found that 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, 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.

The same approach was applied to legally binding sustainability standards that entail mandatory sustainability criteria. Particularly for the global transport sector that is aviation, a higher level of harmonization of two of the most important standards, namely the European Renewable Energy Directive (RED) and the US-American Renewable Fuels Standard (RFS2) would be desirable. Since the envisioned harmonization would apply to mandatory sustainability requirements of biofuels in national legislation, it is not as easily achieved as for voluntary schemes. Nevertheless, there are areas that could potentially be streamlined, these include:

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[17] Zeller et al., 2013
[18] Elbersen et al., 2010
[19] Searle/Malins, 2016

- **Land conversion restrictions:** Agreement on a common reference date in the RED (currently 01.01.2008) and the RFS (currently 19.12.2007) – easy to implement, no impact on compliance. The current situation is that farmers who want to export feedstock to the US have to demonstrate that the land the feedstock is grown on had been in use for the same purpose prior to 19 December 2007.
- **Analysis of alternative jet pathway GHG emissions:** The GHG calculation methodologies in the RED and RFS2 share a common basis, although some differences exist. Irrespective of which GHG calculation methodology is applied, alternative aviation fuels should realize significant GHG emission reductions and meet current (and future) GHG emission reduction targets set in the two standards, irrespective of which GHG calculation methodology is used. In addition, all improvements on a fossil fuel comparator should be recognized and not limited by thresholds.
- **Agreement on a common (fossil) jet fuel comparator:** The fossil fuel comparator is a fundamental parameter in the calculation of GHG savings. Currently, both the RED and RFS2 entail a comparator for road transport fuel, but not for jet fuel. A necessary step would be to seek a common agreement on an appropriate comparator so that GHG savings are calculated on a consistent basis.

1.1.2 European portfolio of R&D projects related to feedstock production and sustainability

Lastly and accounting for the evaluation of R&D activities in the CORE-JetFuel thematic domain of “feedstock and sustainability” a mapping of European projects in this field was conducted. For this purpose, the Quadrant Model of Research, as depicted in Figure 1 and described in Section 4 was applied. 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.

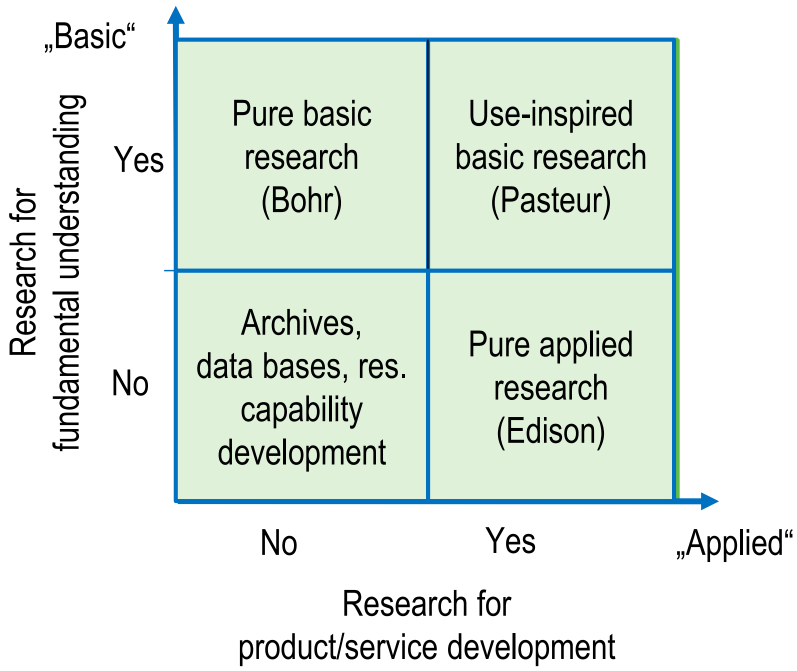
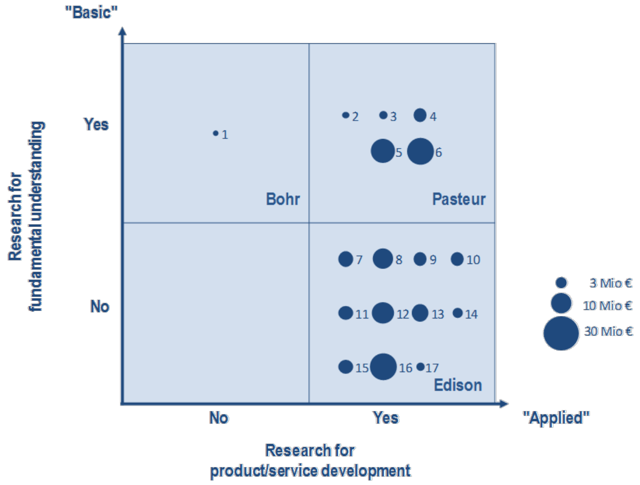


Figure 1: Quadrant model of research (Donald E. Stokes: „Pasteur‘s Quadrant – Basic Science and Technological Innovation“; The Brookings Institution, 1997)

In correlation with the project budgets, the Quadrant Model of Research gives valuable impression of the current European research portfolio in the field of feedstock and sustainability and allowed for conclusions regarding the question, where in the R&D landscape efforts should be concentrated. In line with the highly product-orientated field of research that is aviation, a clustering of R&D activities in Pasteur’s and Edison’s Quadrant was noticeable. In addition to applying Stokes’ Quadrant Model to the entire R&D landscape that was identified in the field of feedstock and sustainability, the model was also used to show the research portfolio of the different types of feedstock individually. Generally, it has to be noted that R&D activities in this area are very rarely concerned with solely the cultivation of one specific feedstock, but rather consider an entire value chain or parts of it, for example from cultivation to conversion or improving the logistics of a certain type of feedstock.



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.

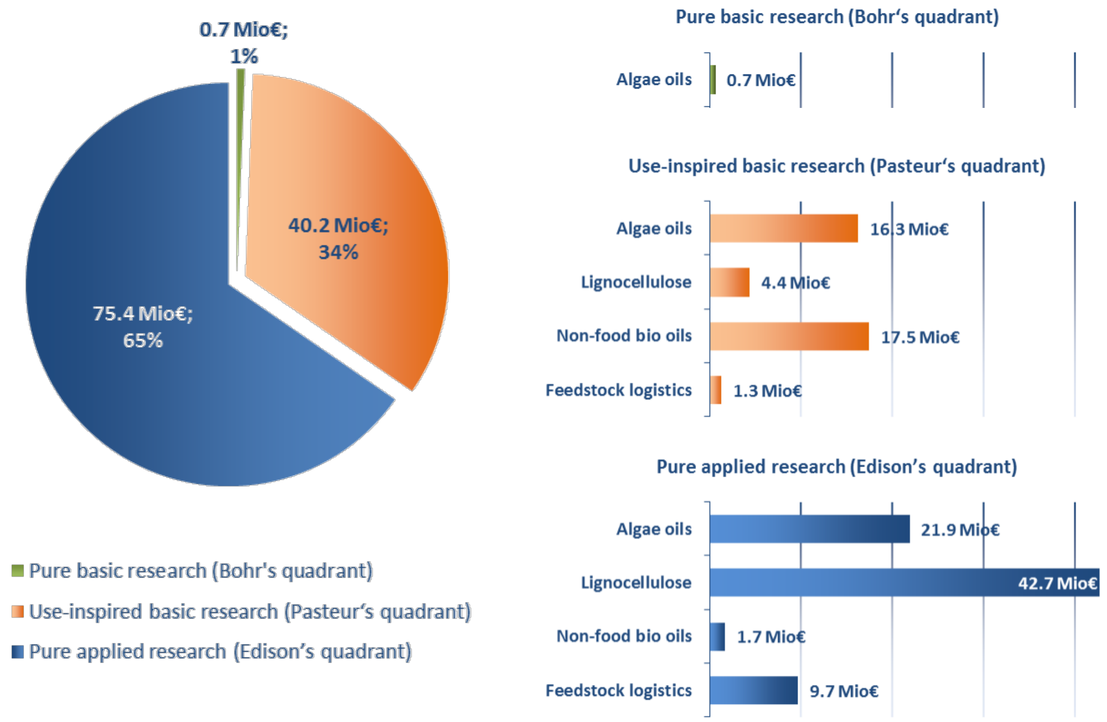


Figure 3: R&D portfolio identified by CORE-JetFuel in the area of feedstock & sustainability / quadrant-specific funding volumes

However, especially in case of microalgae, and to some degree in case of SRC, research efforts are also put in generating a deeper and more holistic understanding of plant genetics, solar radiation efficiencies as well as other vital characteristics and influencing factors without necessarily aiming at technology applications. On the other hand and again especially in case of microalgae, research of the considered projects is particularly concerned with making the cultivation and production processes more efficient in terms economic viability and energy efficiency (including the according reduction of GHG emissions) with the aim of reaching market maturity and deployment. In case of lignocellulosic biomass and residue materials, a lot of research and demonstration effort is placed on improving the logistics of making this type of feedstock available and transporting it to the processing site.

In conclusion, the R&D landscape in the field of feedstock and sustainability seems to be well-balanced, focus should be placed on bringing a larger variety of feedstocks to the market and to make use of the currently existing feedstocks that are at commercial scale.

1.2 Conversion Technologies, Radical Concepts and Holistic Assessment

As in case of feedstock production and sustainability (Section 1.1), the evaluation of the European R&D landscape on conversion technologies and radical concepts comprises of a holistic assessment at technology level (Sections 1.2.1 and 1.2.2) and a mapping of the corresponding European portfolio of thematically related R&D projects (Section 1.2.3).

1.2.1 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 (through the isoburanol route) 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, mainly for a question of high production cost for the SIP route..

1.2.2 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.

The main challenge encountered in the course of the technology assessment was the identification, collection and analysis of relevant information sources and data. The most important sources of information were technical reports and other scientific publications, such as peer-reviewed journal articles. In some cases, information and data were also acquired through direct communication with experts or consultation of companies' websites. For some, technically more advanced technologies, a wealth of scientific information was available, while for others the availability of data was very limited (if at all available) and sometimes restricted to non-traceable information provided by companies devoted to the development of proprietary technologies.

The quantitative comparison of technology options under such conditions of highly challenging. A comparison on a quantitative basis in principle requires harmonization of the considered data with respect to underlying assumptions and methods. However, considering the broad range of relevant technolgies and production pathways under consideration in CORE-JetFuel, was out of the scope of the project. Nevertheless, the technology assessment conducted in CORE-JetFuel yielded a highly valuable insight in the performance potentials of production pathways, as described in the following.

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)[20], is plotted versus the *production cost relative to the market value of conventional jet fuel* (denoted as γ)[21]. The ranges of uncertainty and variation in emission and cost are shown by the bars.

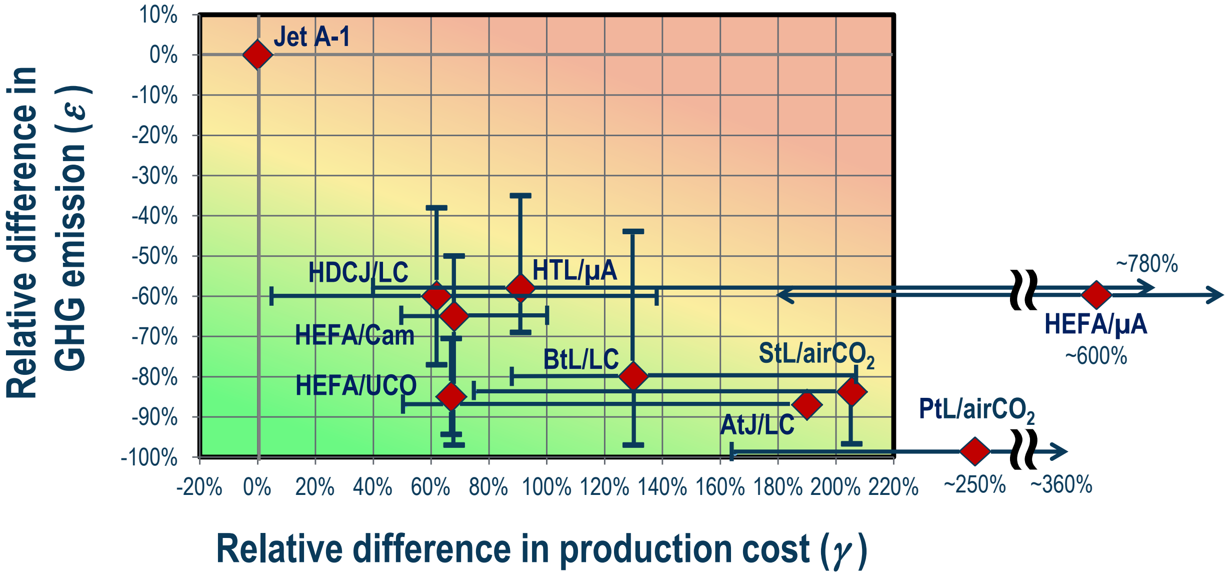


Figure 4: Specific GHG emissions vs. cost of production of analysed production pathways, each relative to conventional jet fuel. (HDCJ/LC: Hydroprocessed Depolymerized Cellulosic Jet from lignocellulosic feedstock; HTL/µA: Hydrothermal Liquefaction of microalgae; HEFA/µA, HEFA/UCO, HEFA/Cam: Synthetic 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.)

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[20] 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%).

[21] 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[22].

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, or much 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 exist at a significant share.

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[23].

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.

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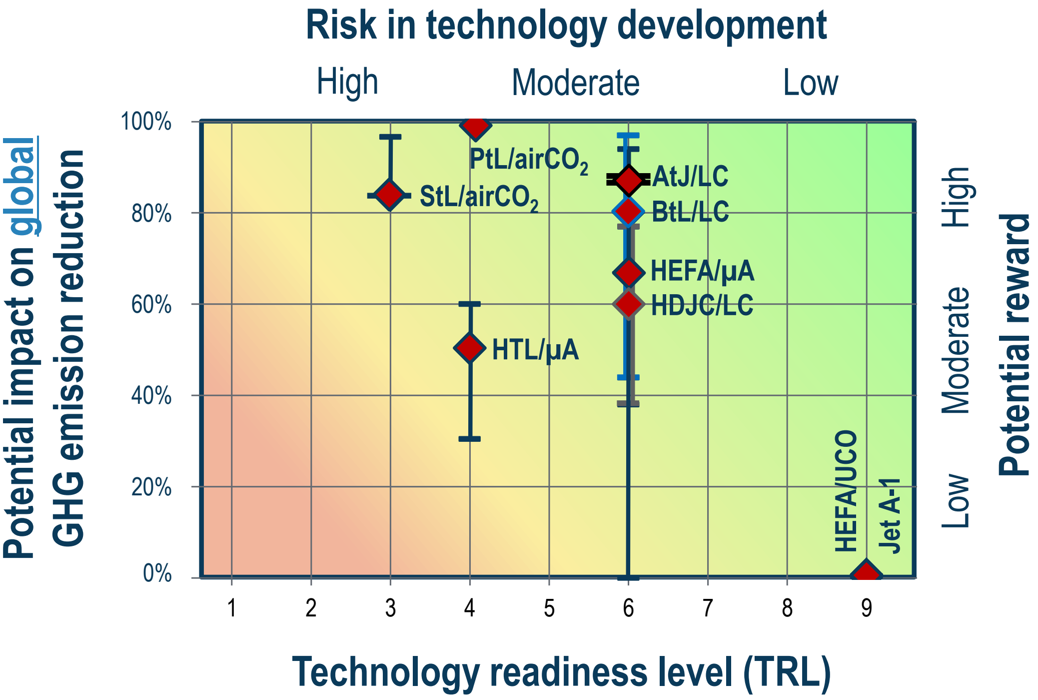
[22] Harmonization of assumptions and recalculation of the data sets would reduce the spread of data and would to enable a consistent quantitative comparison for a particular set of primary parameters. However such an analysis is out of scope of the CORE-JetFuel work.

[23] 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.

- 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.
- 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.



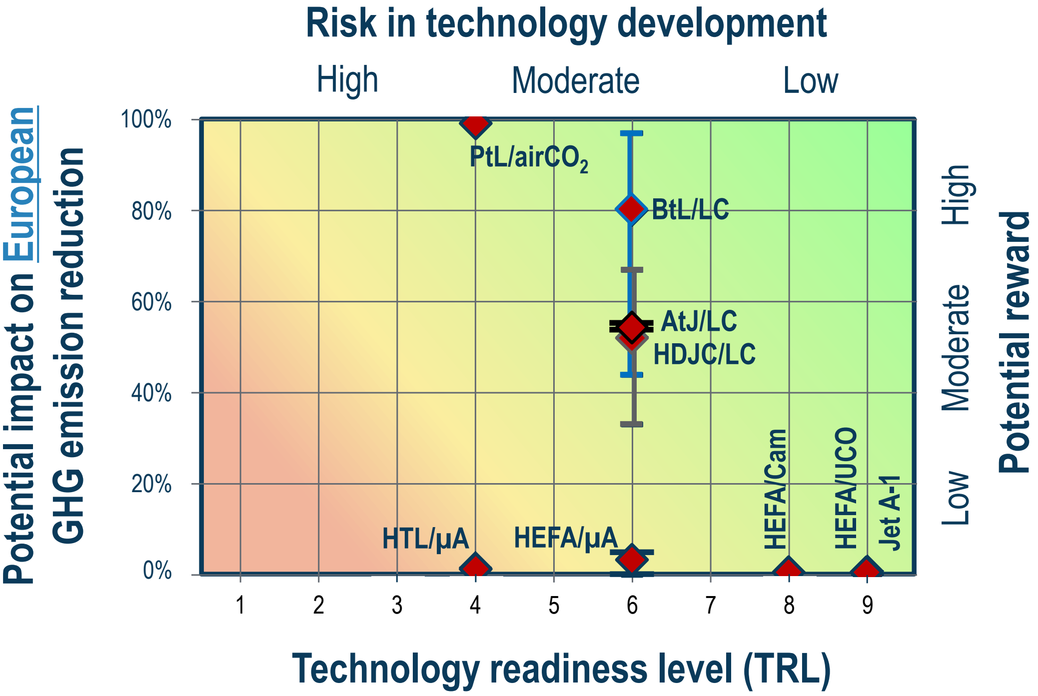


Figure 5: Greenhouse gas emissions reduction potential relative to future fuel emission impacts in the GLOBAL (top) and EUOPEAN (bottom) context, vs. current overall TRL of the analyzed production pathways (for explanation of abbreviations of pathways, see caption of Figure 4)

1.2.3 European portfolio of R&D projects dedicated to 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 (corresponding to 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 (mainly dedicated to ethanol production, not to the final fuel production).

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.

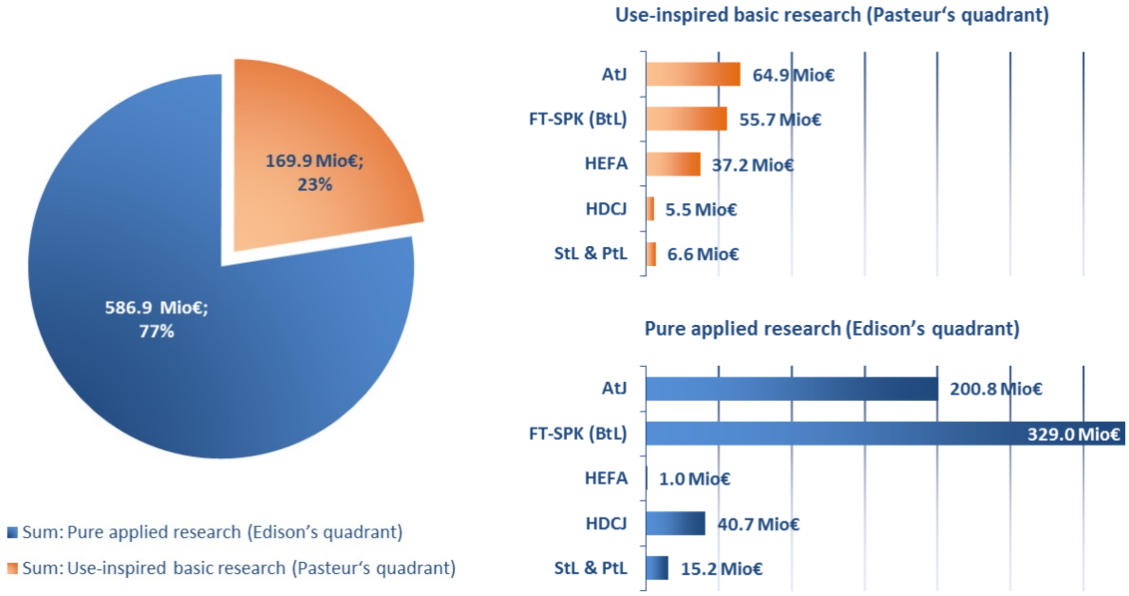


Figure 6: Summary of mapping results of European publicly funded R&I activities on conversion technologies and radical concepts. (Volumes given as total project costs, i.e. EU contribution plus residual costs)

1.3 Technical Compatibility, Certification and Deployment

1.3.1 Technical approval of synthesized jet fuel under ASTM

Biofuel certification process has been well studied. It includes the 5 already certified routes end of April 2016, as well as a lot of on-going certifications (with their inherent uncertainty level) for the short and medium term. This is an important task within this very complex alternative jet fuel world with a lot of stakeholders and a lot of uncertainty on the on-going project: possible bankruptcy, such as for KiOR or Solena for example, readjustment of the business models of some actors (such as more focusing on high margin products for chemicals, fine chemicals, human health or cosmetics than on biofuels) or the evolution of the balance between alternative fuels: gasoline, jet fuel and diesel.

That is the reason why, a recommendation to the EC is to continue the monitoring of deployment/implementation initiatives with a critical expert analysis to have an accurate overview on the most viable future pathways.

ASTM certification process is a well-recognized process. It is a robust process to guarantee than a new fuel will comply with all requirements related to compatibility, quality and safety. It should not be replaced by another one, even at European level. A short ASTM certification process 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 involvement of all the OEM's (Original Equipment Manufacturers) and suppliers. Even if quite high, ASTM qualification costs are not regarded as "show-stopper" 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. Any study that make possible a better understanding of the properties of the fuels, such as cold flow, stability and combustion properties…, should be pushed forward. Another concern is to pay attention to logistic and quality insurance because these topics are not covered by ASTM certification and qualification.

1.3.2 Database construction

An identification and information gathering of 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 worldwide. The focus of this database is on “advanced alternative fuels” that could have an application in aviation. The database currently mainly includes announcements by industry or processes at large scale pilot plant or demo level. It is a unique database where the collected information regarding alternative jet fuel projects, as well as classification and comments by the group of expert, are stored. Currently the database is managed by a group of ICAO/AFTF experts providing updates / announcements by setting a number of criteria under the leadership and secretariat of Volpe, with support of US FAA (Federal Aviation Administration) This group can then keep it updated and alive on the AFTF website. Today the database is only available for ICAO members.

1.4 Policies, Incentives and Regulation

Information regarding worldwide ongoing policies and national initiatives has been collected to get to know the different ongoing options that could eventually contribute to the scale up of aviation alternative fuels. On the basis of the work carried out for that task, a detailed analysis of the following policies and regulations has been elaborated:

- ICAO level political discussions
- Relevant European level legislation: EU Renewable Energy Directive, Fuel Quality Directive and EU ETS
- Relevant state of transposition of European legislation and treatment of some European member states of national
- US Renewable Fuel Standard
- Californian Low Carbon Fuel Standard
- Brazilian National Alcohol Program (PROALCOOL)
- Australian Biofuels Act
- Indonesian Alternative Fuels and Renewable Energy for Airports Initiatives

This compilation of policies information was used as a basis to analyze possible ways forward for the EU. In particular, 5 possible measures were analyzed:

- Counting of alternative 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, for each of these proposed measures, specific conclusions have been drawn.

Regarding the possibility of counting of renewable jet fuels towards the obligation of fuel suppliers in several EU Member States (opt-in), although the sole impact of this measure has been evaluated to be low, it is considered by stakeholders a necessary step before proposing more ambitious measures. This measure is encouraged to be implemented on the EU states that have not adopted it already, since it is a measure which is fairly easy to implement, does not require a significant investment and creates confidence for investment.

Regarding the use of market-based Measure (MBM) with revenue generation to be geared towards innovation in the aviation sector, there is currently uncertainty on the short term development of the EU ETS and therefore, it is premature to give final recommendations without knowing the details of the system and how the implementation of a GMBM will affect European MBMs. However, several actions can start to be considered in the definition of the European medium-term strategy for aviation alternative fuels. In the case of the implementation of a GMBM 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 on alternative fuels. Alternatively, 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, or even create offsetting projects that involve the aviation sector.

Regarding the discussion of proposing a separate mandate for aviation alternative fuels, the outcomes of the project workshops show that it is still a topic where there is not a strong consensus among the collaborating stakeholders. Implementing a separate mandate for aviation alternative fuels requires significant time as well as production capacity. 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. In fact, 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.). Secondly, any mandate for aviation renewable fuels would have to be developed within the context of a MBM or the EU ETS.

Regarding the option of stimulating innovation and projects in the supply chain, this strategy would be in line with the current FP7/H2020 strategy. Support from national administrations would also be beneficial very beneficial, especially in order to invest directly on local development (i.e. local agricultural development or industrial production). One of the conclusions of all the stakeholder workshops and debates is that support shouldn’t be limited to one single technology, since it is considered that there is no winning technology, but rather that diversification is still important in terms of supply chain development. However, support is not only needed in the actual supply chain but also in the coordination with related topics and projects (i.e. with projects related to fuel/engine systems) in order to find synergies. Another option would be to try to attract private investment through financing options for first mover/early adopter grants, off-take agreements facilitated by national administrations or even facilitating access to loan guarantees.

Regarding the possibility of facilitating cooperation between major airports / airlines, it has been observed that such initiatives in previous experiences have given very positive results. It is recommended that institutional support is given by national authorities in order to act as facilitators to reach the cooperation agreements. The European Commission can promote an airport-led initiative primarily through its communication with sector organizations, selected airports and the aviation society at large. In fact, it would be interesting to analyze in further detail which airports would be optimal for such pilot experiences, based in their logistics system, geographical situation and level of activity.

In addition to the previously mentioned policies, it is a recommendation of the project that some financing options could also be explored in addition to giving direct support to projects, since it may still seem unattractive from private investors if further security to their investments is not assured. The risk of failure of a project needs to be decreased in order to incentivize investments. Purchase agreements that guarantee demand for a certain period could be a way of de-risking such investments. Incentives could be introduced for production/consumption.

2 Recommendations

2.1 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 (LUC).
- 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 the high cost of the feedstock.
- Logistical challenge with the collection of ligno-cellulosic biomass.

HOW

- Develop small-scale conversion plants with the collection of the biomass nearby.
- Coordinate the networks of supply chains for business model of renewable 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.

Harmonize sustainability certifications to converge on international scheme recognized by everybody

WHY

- All renewable fuels 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

- Harmonize 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.

2.2 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 ligno-cellulosic 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.

2.3 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 prove the industrial and commercial concepts.
- Consolidate the European regulations to avoid a backward step.
- Develop and favor 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 are always higher or much higher than well established and optimized 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%), penalizing 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 (refer to 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 behavior 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.

Optimize and improve the use of ASTM D4054 process

WHY

- Fuel analysis, even very detailed at molecular level, is 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 detailed 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.

2.4 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 fuels for road transport are 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 renewable fuels and renewable jet fuels.
- Inform Member States and the public about the possibilities for a renewable jet fuel opt-in in national biofuel policy.
- Analyze 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 (t CO_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 such as the Bioport Holland 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.
- Analyze 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 funding.

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 authorization 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.
- Stabilize the fuel policy (Europe, but also US) 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 analyze 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 using 2 million tons of alternative fuels per year for aviation, perspectives and continuation of the European Advanced Biofuels Flightpath initiative

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.

3 Roadmaps

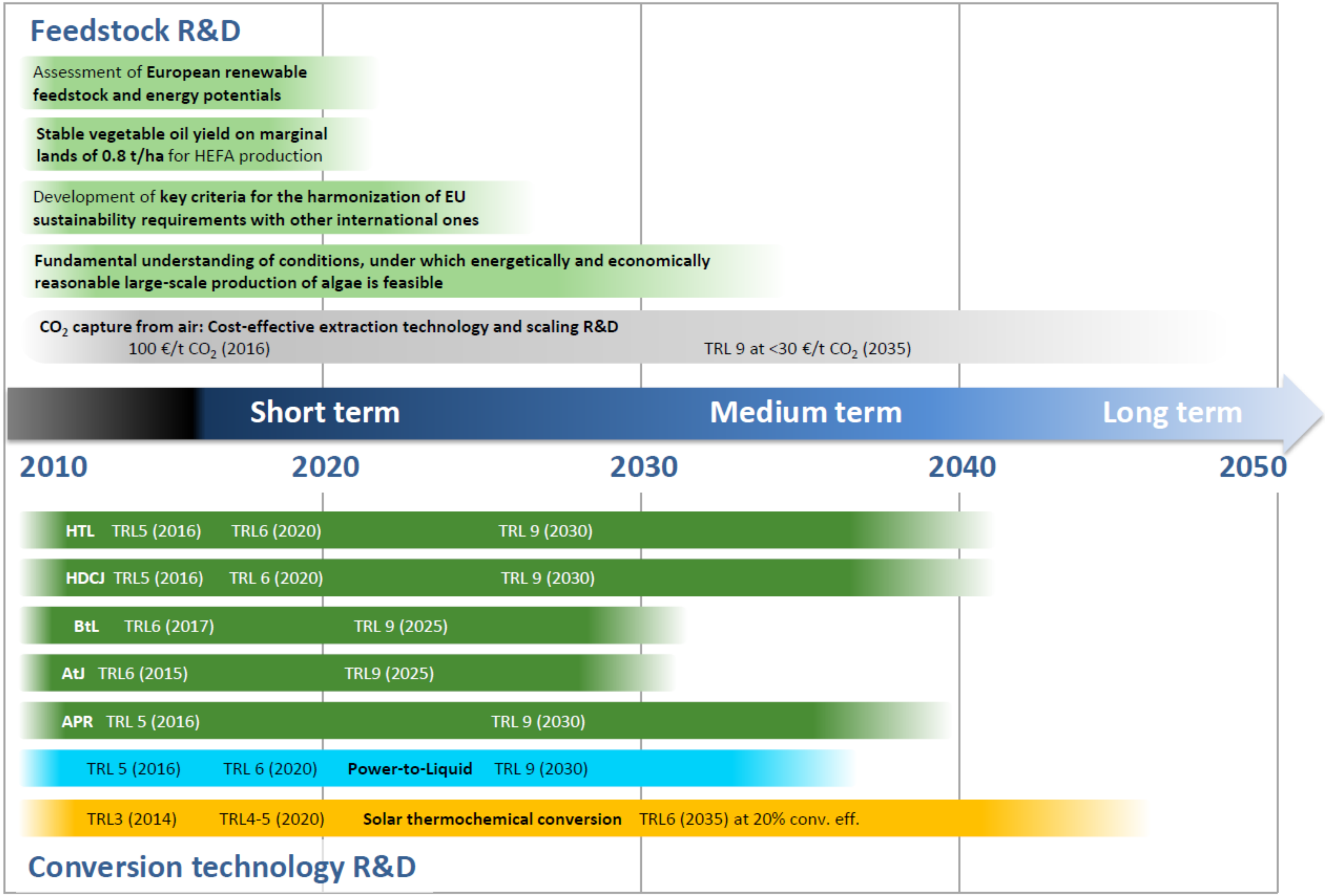
One of the main objectives of the CORE-JetFuel project is to provide the European Commission with recommendations concerning the re-orientation and re-definition of its funding strategy with respect to R&D activities in the field of alternative aviation fuels.

Based on the results of the compilation, mapping and evaluation of R&D activities, as well as of the assessment of selected production chains, recommendations have been drawn (see Section 2 above) and roadmaps established for short, medium and long term time horizons (from 2010 to 2050). The suggested roadmaps hereby correspond to the project's thematic domains in combination with the development cycle or strategic milestones with respect to feedstock and conversion technologies, namely:

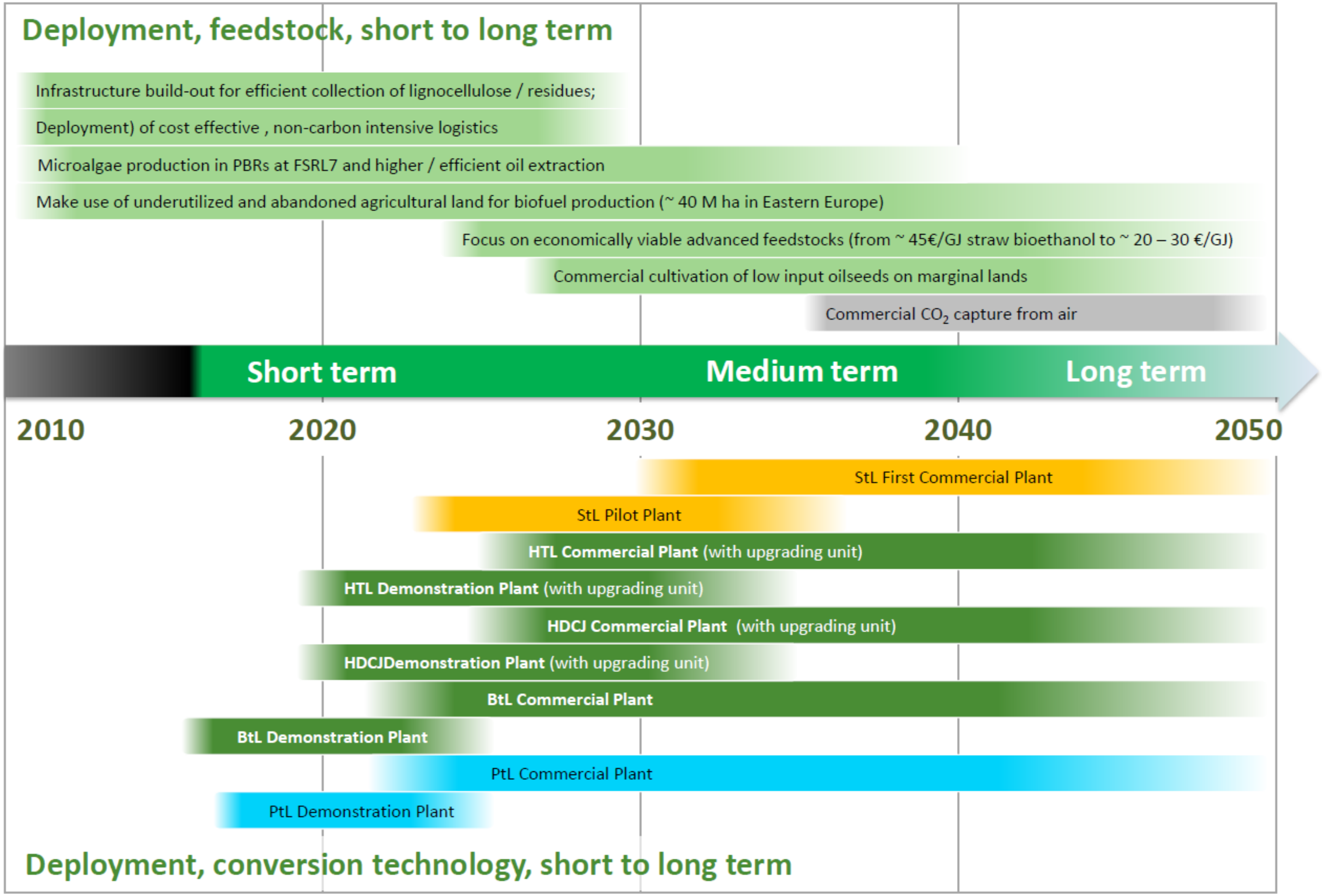
- Research and development on feedstock and conversion technologies
- Production and deployment of feedstock and conversion technologies (short to long term)
- Approval, production and deployment (short to medium term)
- Strategic milestones, targets and policies.

First, the R&D roadmap for feedstock and conversion technologies can be found in Section 3.1 followed by a corresponding short to long term production and deployment roadmap for feedstock and conversion technologies in Section 3.2. Third, a short to medium term roadmap for approval, production and deployment is depicted in Section 3.3. Lastly, strategic milestones and targets have been compiled in a policy and targets roadmap in Section 3.4. For further details and background information on these roadmaps, please refer to CORE-JetFuel Deliverable D6.4 "Report on Roadmaps".

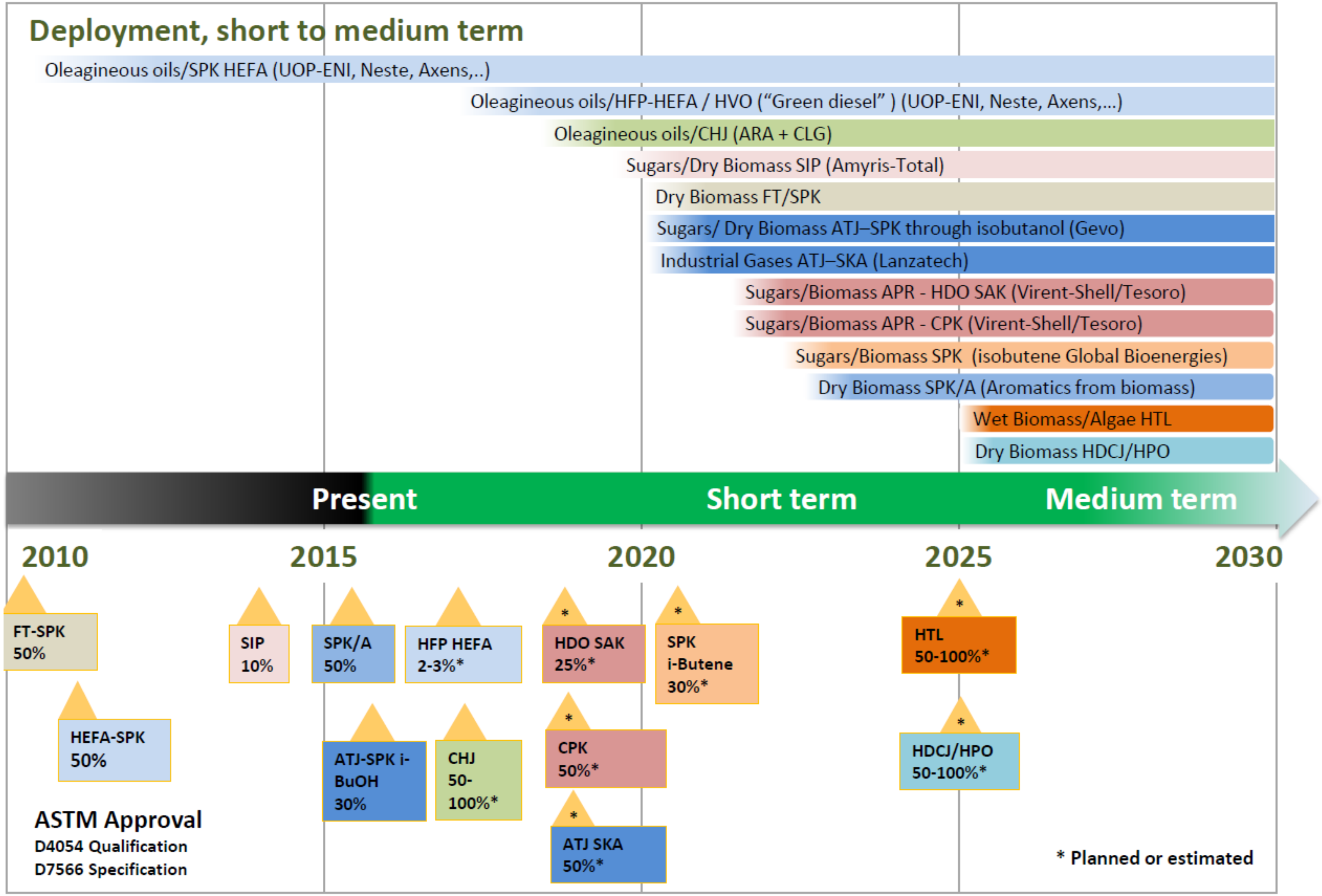
3.1 R&D Roadmap for Feedstock and Conversion Technologies



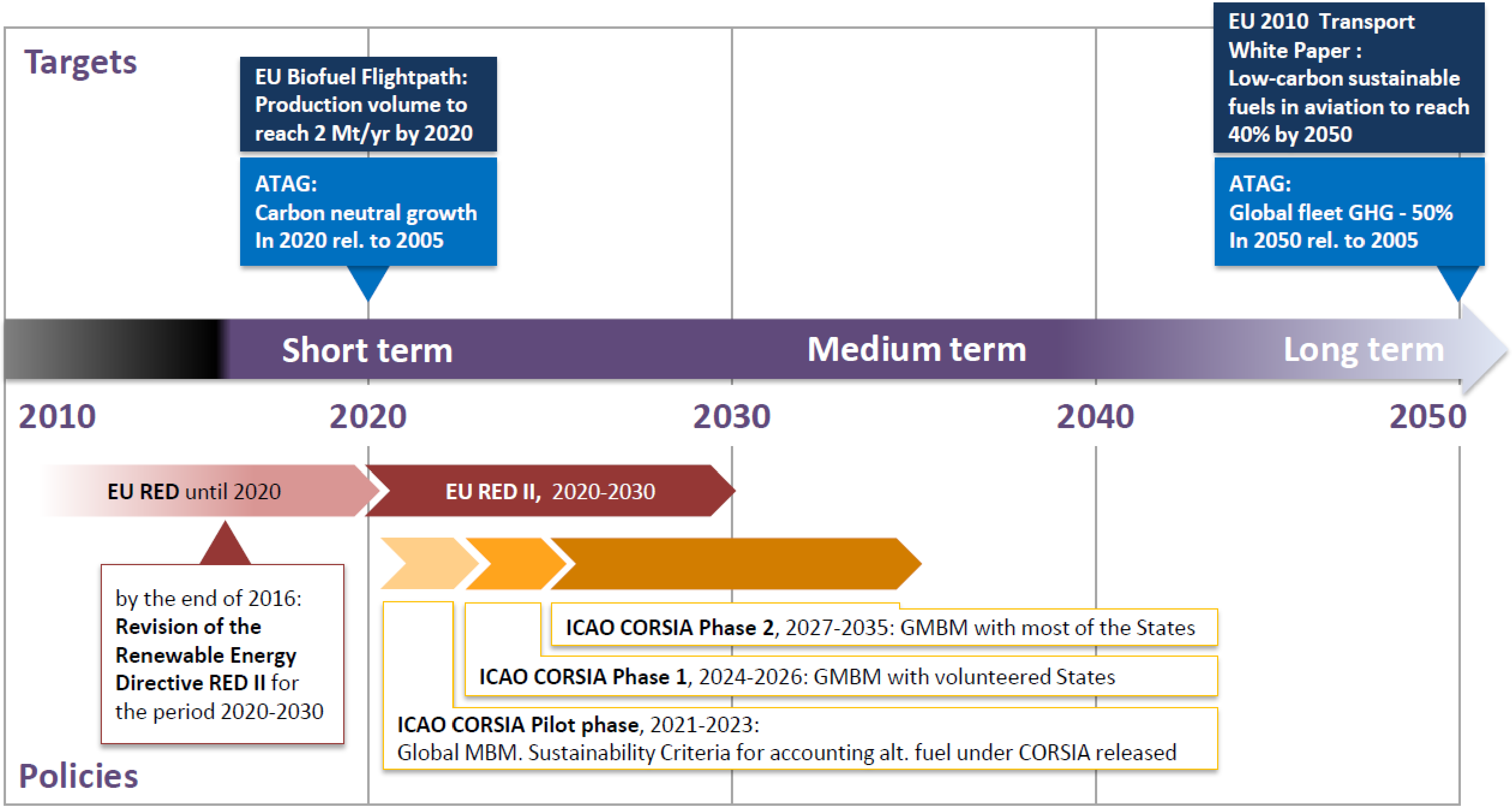
3.2 Production and Deployment Roadmap for Feedstock and Conversion Technologies



3.3 Approval, Production and Deployment Roadmap



3.4 Strategic Milestones, Targets and Policy Roadmap



4 Methodology

4.1 Identification of information acquisition sources and definition of procedures

The integration and participation of experts and other stakeholders is very valuable and important for the success of the entire CORE-JetFuel project, as knowledge gaps and other risks can be avoided effectively with the aid of a comprehensive network. It is a particular advantage of the CORE-JetFuel consortium that the individual partners bring in extensive but complementary networks that had been combined and continuously expanded. All experts and stakeholders had been clustered with respect to the fields of research (corresponding to the tasks within CORE-JetFuel Work Packages 4 and 5):

- Feedstock production and sustainability
- Radical concepts and conversion technologies
- Technical compatibility, certification and deployment
- Policies, incentives and regulation

A serious risk of knowledge gaps is caused by the fact that a great part of R&D effort in the field of alternative fuels is industry-driven. Consequently, a good part of promising technologies under development is proprietary and related information is thus not publicly available.

Secondly, the diverse system of different funding levels in Europe that in turn results in a complex network of projects on European, national and sub-national level. The vertical and horizontal interrelation between these funding levels is merely regulated, there are no data bases relating to the entire European R&D landscape. It is therefore difficult to cover the entire landscape in its whole complexity.

While the CORE-JetFuel consortium's extended and widespread network to national and international experts, initiatives and key stakeholders enables a comprehensive evaluation, an exhaustive in-depth cover of the entire landscape cannot be guaranteed.

4.2 Mapping of R&D activities

The next step, following the identification and collection of actions, is the mapping of actions where the collected and selected activities are two-dimensionally sorted, thus being placed on a landscape or map that is defined by two coordinates representing certain properties. This placement on a map already involves some sort of qualitative assessment, as the specific coordinates defining the location of each action on a map have to be determined, and that involves, in most cases, a translation or interpretation of available information.

As described in Section 1.1.2, the identified project and activities are mapped according to the so-called "Pasteur's Quadrant"[24] model of research. In this model, the two dimensions of the landscape are defined by the orthogonal coordinates "Research for product/service development" and "Research

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[24] Donald E. Stokes: „Pasteur's Quadrant – Basic Science and Technological Innovation"; The Brookings Institution, 1997

for fundamental understanding". The landscape is divided into four quadrants (see Figure 1), depending on whether the mapped activities are product-oriented ("applied"), i.e. aiming at solutions for current and specific challenges, or focused on fundamental understanding ("basic") or both in nature. Additionally, the associated budgets are implemented as third dimension (see Figure 1) in order to illustrate the distribution of investment between Bohr's, Pasteur's and Edison's quadrant activities.

In a first step, the relevant projects are selected, evaluated (as described above) and listed with their associated scope (basic and/or applied) and funding volume (see the table inserted in Figure 2 in Section 1.1.2. In a second step, the table content is mapped onto the basic-and-applied quadrant scheme (see Figure 2).

4.3 Assessment framework for risk and reward evaluation

The assessment work in CORE-JetFuel is based on a multiple-criteria approach. In the assessment, two fundamentally different types of alternatives have to be considered: Projects and activities on one hand and technologies on the other. While both aspects have to be separately addressed, they are still interdependent and therefore cannot be regarded in an entirely separate way. While it is of great importance with respect to future funding strategies to assess the potential of technologies instead of specific projects, it is nevertheless also important in this regard to relate a technology's potential (in the light of certain goals and criteria) to the corresponding R&D landscape. In other words, it has to be evaluated to which extent a certain technology has been and is already worked on, how much funding has been spent, how the spent funding relates to the achieved progress and how the achieved progress relates to the technology's potential. On the other hand, the potential of a certain project cannot be properly evaluated without profound understanding of the technology it is focused on.

Within a multi-criteria approach the impact of the performance of a given alternative with respect to individual criteria is traceable, thus offering a deeper insight through a detailed analysis of individual aspects or relations between individual or combined criteria. Here we suggest a selection of two-dimensional projections of such aspects as reporting elements. The two-dimensional plots represent the performance of alternatives with respect to two selected criteria and visualize possible tradeoffs. In this way, a wealth of valuable information can be extracted from the multi-criteria assessment approach. The criteria and associated metrics (performance indicators) are listed in Table 2:

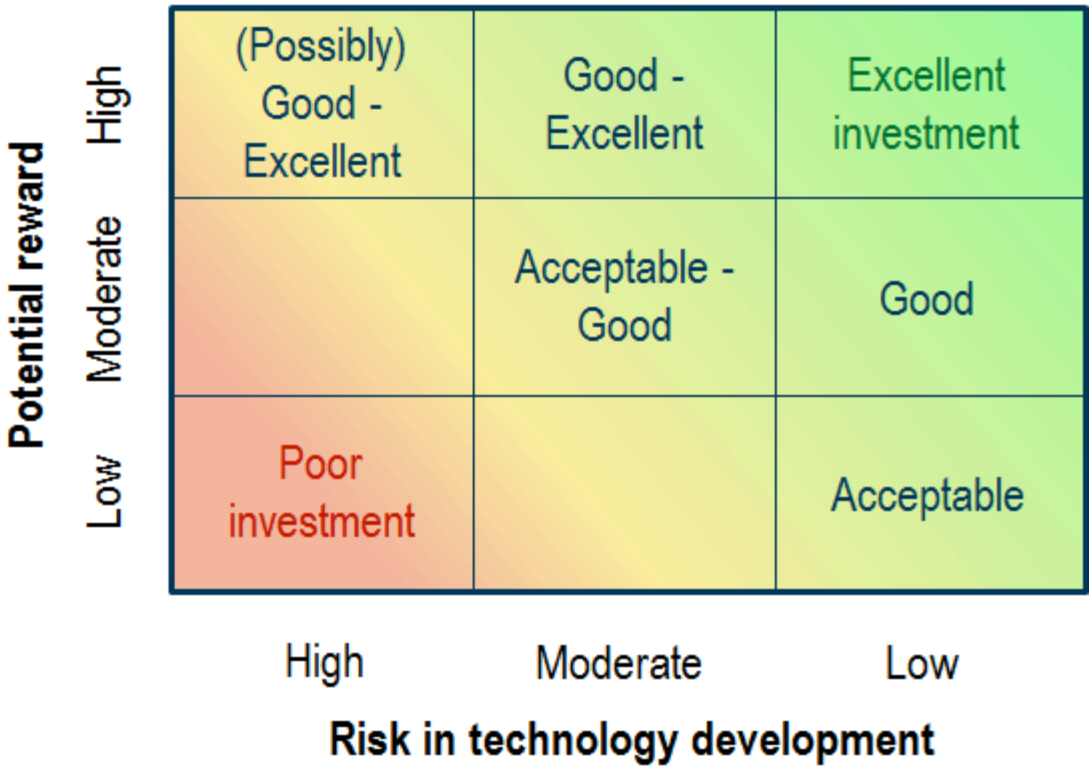
Table 2: Assessment criteria and associated metrics (performance indicators) applied in CORE-JetFuel.

Criterion	Metric	
Technical maturity	Technology Readiness Level	TRL (1-9)
Feedstock production maturity	Feedstock Readiness Level	FSRL (1-9)
Conversion technology maturity	Conversion Technology Readiness Level	CTRL (1-9)
Economic competitiveness	WtT production costs relative to spot price in 2013	γ [%]
***European* substitution potential**	Production potential relative to European demand in 2050	σ_{EU} [%]
***Global* substitution potential**	Production potential relative to global demand in 2050	σ [%]
specific GHG emission reduction	Specific lifecycle GHG emissions relative to conventional jet	ε [%]
Potential impact on *European* GHG emission reduction	Total impact on GHG emissions relative to conventional jet at European deman in 2050	ψ_{EU} [%]
Potential impact on *global* GHG emission reduction	Total impact on GHG emissions relative to conventional jet at global deman in 2050	ψ [%]

Based on a subset of performance indicators from Table 2, trade-offs are analyzed in terms of the

- relationship between risk and potential reward (see Figure 5 in Section 1.2.2).
- relationship between cost and benefit (see Figure 4 in Section 1.2.2).

A two-dimensional plot of potential rewards vs. associated risks (Figure 7) illustrates the distribution of risks in a given technology portfolio. It provides a means for identifying activities where the relation of risk and potential reward indicates excellent or poor R&D funding or investment.



Potential reward \ Risk in technology development	High	Moderate	Low
High	(Possibly) Good - Excellent	Good - Excellent	Excellent investment
Moderate		Acceptable - Good	Good
Low	Poor investment		Acceptable

Figure 7: Schematic illustration of the principle of a risk-reward analysis.

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