CORE-JetFuel

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

WP6: Synthesis of Results and Recommendations

Due date: 31.08.2016
Actual submission date: 27.10.2016

Grant Agreement no.: FP7-605716
Call identifier: FP7-AAT-2013-RTD-1

Information submitted on behalf of CORE-JetFuel

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This project has received funding from the European Union’s Seventh Programme for research technological development and demonstration under grant agreement No 605716

CORE-JetFuel

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D6.4: Report on Roadmaps

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 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.

In order to meet this objective, the project covers the entire renewable jet fuel 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 potential of the end-product, GHG emissions emerging from feedstock production and conversion, and the like. In addition, an analysis of deployment initiatives, currently certified and soon to be certified production pathways was undertaken in the course of the project.

Based on the twofold assessments outlined above, a Report on Recommendations has been elaborated featuring the most important assessment results, an identification of those areas of renewable jet fuel R&D that require additional efforts, and most importantly, potential courses of action for the respective R&D fields.

Based on these recommendations as well as the project results, the Report at hand establishes roadmaps for different time horizons, namely 2020, 2035 as well as 2050. The suggested roadmaps hereby correspond to the project's thematic domains mentioned above. First, graphical R&D roadmaps for renewable jet fuel feedstocks and conversion technologies are given that indicate according to the CORE-JetFuel assessments the need for research efforts in this field in the short-, medium- and long-term future. Subsequently, corresponding short- to long-term production and deployment targets for the beginning of the value chain, i.e. feedstock production and conversion technologies are presented.

Moving on to graphical roadmaps and milestones concerning the approval, production and actual deployment of renewable jet fuels, the report concludes by stating strategic milestones with respect to policies that either address renewable jet fuels or aim at including them in legislation.

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TABLE OF CONTENT

LIST OF FIGURES AND TABLES

Document Information

Project Title	CORE-JetFuel
Deliverable nature	R
Dissemination Level	PU
Start Date of the Project	01.09.2013
Duration	36 months
Contractual Delivery Date	30/06/2016
Actual Delivery Date	27/10/2016
Status	Submitted
Contractual	Yes
Version	1.0
Total Number of Pages	29
Work Package Number	6
Work Package Leader	FNR
Lead Beneficiary of Deliverable	FNR, BHL

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

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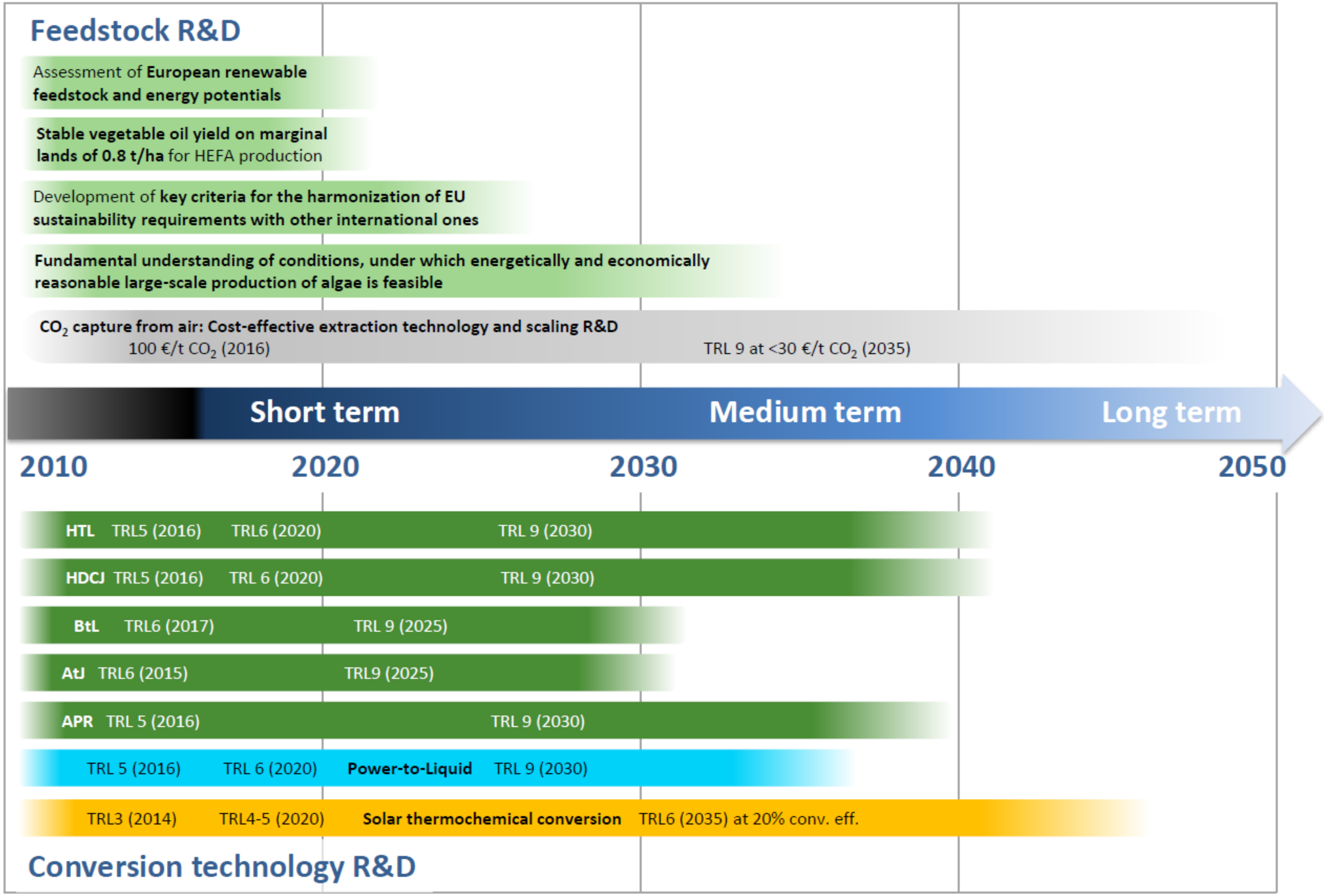
1 R&D Roadmaps

1.1 Graphical R&D Roadmap for Feedstock and Conversion Technologies



1.2 Feedstock and Sustainability

In order to reach the GHG emission reduction targets of the aviation sector, a reliable and sustainable supply of (biogenic) feedstocks will be essential in the short-, medium- and long-term future. The CORE-JetFuel project therefore analyzed a variety of different feedstock options with respect to their sustainability performance, technical maturity of cultivation and further processing as well as their sustainable availability in Europe. Based on these assessments and on discussions held with experts in the field, roadmaps for the time horizons 2020, 2035 and 2050 are outlined below. It has to be mentioned, though, that particularly the projections for 2050 are subject to some degree of uncertainty due to various political and technolgical factors linked to feedtsock cultivation and their utilization for renewable jet fuel production and other bioenergy applications.

1.2.1 Feedstock R&D Short-to Medium-term

Detailed and comprehensive assessment of renewable feedstock and energy potentials in Europe in high geographical resolution

In order to reach the GHG emission reduction targets established by the aviation sector and the RED, reliable data on the actual local feedstock / energy availability is of vital importance. This is not only for the reason that most assessments in this regard are of theoretical nature, which makes their validity questionable. Knowing the actual European feedstock production potentials is crucial also in light of the various application sectors competing for the same resources. A high geographical resolution of these potentials would furthermore allow for the creation of business cases including potential socio-economic benefits for the local population, and that take additionally into account most sustainable feedstock utilization, efficient use of existing infrastructure, most economically viable production routes and so on.

Stable vegetable oil yield of 0.8 t/ha on marginal lands for HEFA production /

In context of the limited available agricultural land that can be used for feedstock cultivation without the risk of inducing (indirect) land use changes, so-called marginal lands will play a vital role in contributing to bioenergy feedstock production in the medium- to long-term. As the yields that can be achieved on these lands are currently subject to considerable variations, researching and developing ways to stabilize yields and thereby increasing the economic viability of feedstock grown on marginal lands will be an important task in the near future – particularly from an investment point of view of fuel producers. Incentives could be generated by favoring such feedstocks through double-counting mechanisms.

Development of key criteria for the harmonization of EU sustainability requirements with other international ones

Particularly for the aviation industry, a highly competitive sector that is operating on a global scale, the variety of voluntary schemes as well as the different national legislations in place concerning biofuels pose considerable challenges. Hence, the creation of a level playing field for the aviation industry, i.e. harmonizing sustainability certification schemes (and standards) is of great importance to the sector and should be implemented in the short-term. 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

1.2.2 Medium- to Long-term

Fundamentally clarified, under which conditions energetically and economically reasonable large-scale production of algae is feasible

Microalgae are supposedly a very promising feedstock for biofuel production due to their high growth rate and lipid accumulation capacity. Their cultivation, however, particularly in closed photobioreactors (PBR) is still at an early stage and shows unfavorable GHG balances and net energy ratios (NER). In the short- to medium-term, it therefore needs to be clarified under which conditions microalgae cultivation is economically and energetically feasible in Europe and what the scale-up potentials of their production is / can be expected to be. When these questions are answered, increased efforts will be required for increasing the FSRL of microalgae cultivation in PBRs from pilot to demonstration scale. In addition, lipid extraction methods need improved in terms of achievable oil yields, energy-intensity and ultimately costs.

CO_2 capture from air: cost-effective extraction technology and scaling R&D

Capturing CO_2 from air for example via chemicals called ‘amine’ and subsequently converting it in fuels is considered to have a significant potential to contribute to keeping global warming under the 2°C target. However, major concerns exist regarding the economic viability of anime-based technologies, particularly with respect to their scale-up potential. It is for this reason that in the medium-term, research efforts should focus on researching different extraction technologies and making them cost-effective.

1.3 Conversion Technology R&D and Radical Concepts

A broad range of technologies for converting feedstock into liquid fuels are currently under development. The current level of technological maturity of these technologies varies from experimentally proven concepts at laboratory scale to full industrial operation. The conversion technologies presented in the R&D Roadmap (Section 1.1) are not yet fully developed and require substantial R&D efforts to progress towards industrial deployment. The deployment phase is than illustrated in the Roadmap for Production and Deployment in Section 2.1.The Roadmap on R&D (as well as the Roadmap on Production and Deployment) covers the following conversion technologies:

- Hydrothermal liquefaction (HTL)
- Pyrolysis (hydroprocessed depolymerized cellulosic jet, HDCJ)
- Gasification / Fischer-Tropsch synthesis (Biomass-to-Liquid conversion, BtL; this also includes conversion of waste materials, i.e. Waste-to-Liquid, WtL)
- Alcohol-to-Jet (AtJ) conversion
- Aqueous phase reforming (APR)
- Power-to-Liquid (PtL) conversion of CO_2 and water
- Solar-thermochemical (StL) conversion of CO_2 and water

1.3.1 Short-term

With the exception of solar-thermochemical conversion, all conversion technologies covered by the roadmap have at least reached pilot scale (TRL 5) or even demonstration scale (TRL 6). In particular, AtJ and BtL have been (or will be shortly) demonstrated in industrially relevant operational environments. For the thermochemical processes HTL and pyrolysis (HDCJ) a technological maturity corresponding to TRL 5 has been estimated, with HTL being possibly slightly less developed, particularly with respect to the upgrading of the intermediate bio-crude and the treatment of the aqueous phase formed in large quantities as a waste stream (for details, refer to D4.4[1]). Both technologies can be expected to reach demonstration scale in the short-term future.

The production pathways PtL and StL are distinct in this roadmap, as these concepts enable the production of renewable fuels without utilization of biomass feedstock. While the actual and projected short-term development of PtL is similar to HTL and pyrolysis, the StL technology has only recently left a laboratory environment as is on its way towards validation in a relevant operational environment (then corresponding to TRL 4-5).

1.3.2 Medium-term

Going from short to medium-term future and with the exception of StL, all conversion technologies can be expected to reach industrial maturity (TRL 9). However, the roadmap is based on technology

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[1] CORE-JetFuel Deliverable 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 (Final report)”

assessment, while technology development towards industrial scale operation strongly depends on the economic boundary conditions, the projection of which is outside the scope of CORE-JetFuel.

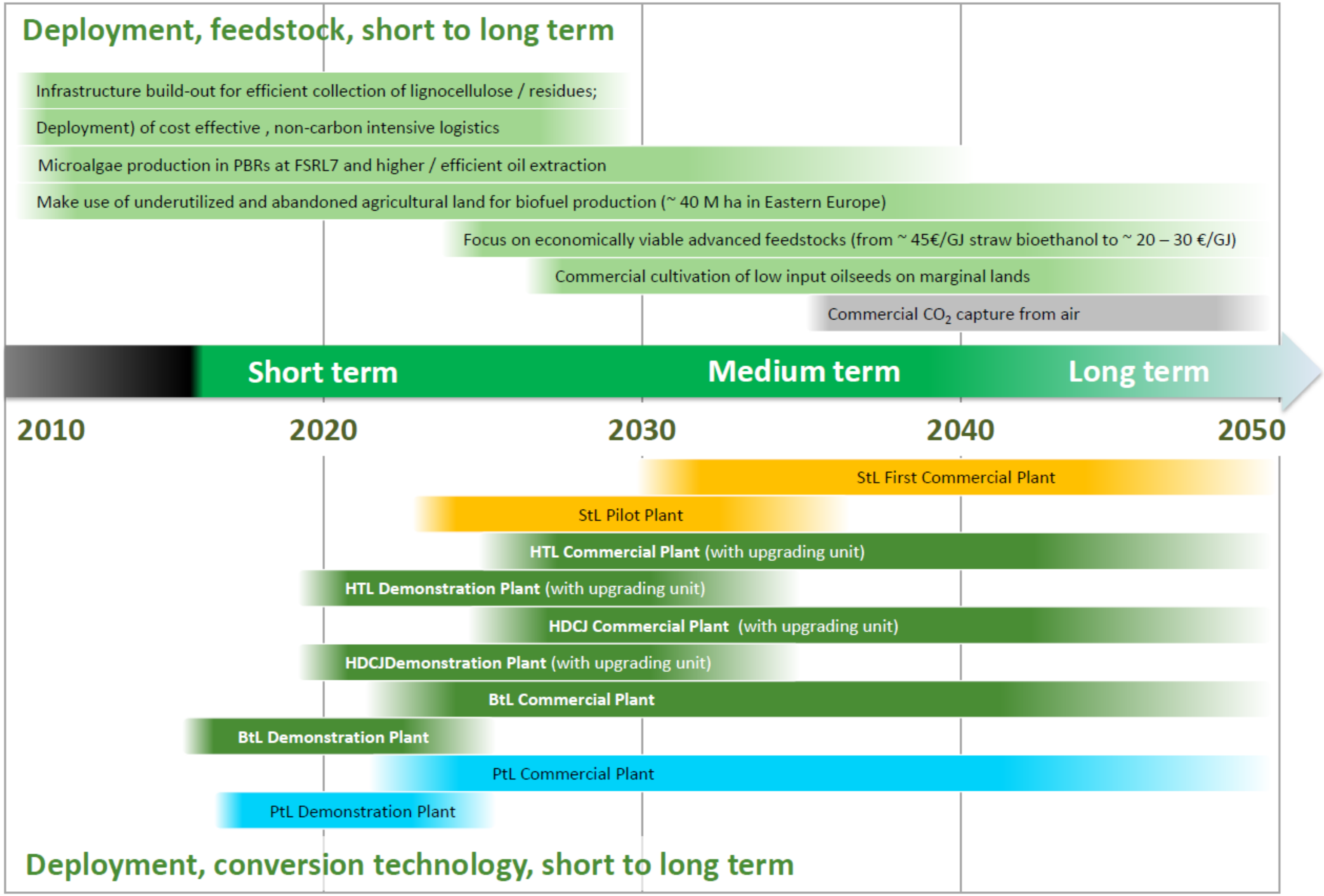
The StL technology is expected to further progress, reaching demonstration in relevant operational environments in the medium-term future. Importantly, successful progress of StL depends on the achievement of energy efficiencies of about 20% for the thermochemical conversion step.

1.3.3 Long-term

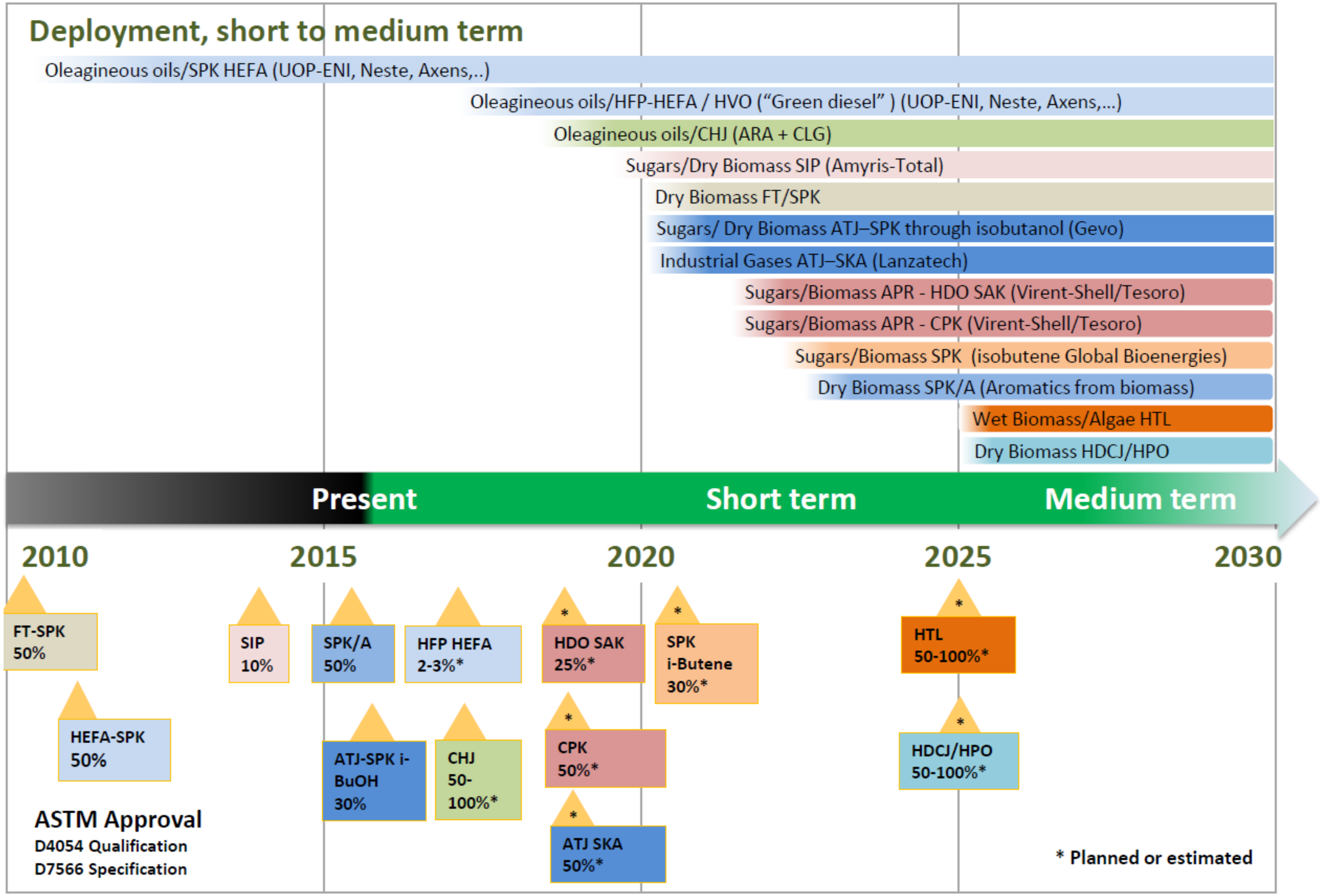
While all other conversion technologies show the potential to reach industrial maturity within the next 15 years, further progress of StL towards industrially relevant application depends on the achievement of important technical milestones, most importantly the above-mentioned energy efficiency that depends on a range of process parameters that require further improvements. Another issue of key importance is the supply of renewable CO_2 as feedstock via direct capture from air (see Section **Fehler! Verweisquelle konnte nicht gefunden werden.**).

2 Approval, Production and Deployment

2.1 Graphical short- to long-term Production and Deployment Roadmap for Feedstock and Conversion Technologies



2.2 Graphical short- to medium-term Approval, Production and Deployment Roadmap



2.3 Feedstock Production and Deployment

2.3.1 Medium- to long-term

Infrastructure in place for efficient collection of lignocellulose / residues; Development of cost-effective, non-carbon intensive logistics

For advanced types of feedstocks such as lignocellulose or residue material to become available at large-scale on the one hand and economically viable on the other, their collection with the corresponding infrastructure has to be designed more efficiently in the medium-term. A first step in this direction is to make use of the locally available (advanced) feedstocks and organizing their conversion in a decentralized setup with small collection radius, thereby taking away large parts of the logistical challenges. 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.

Once these production chains have been established in the medium-term, decreasing production costs to approximately 20 – 30 €/GJ straw-based renewable jet will be the task in the long-term.

Microalgae production in PBRs at FSRL7 and higher accompanied by efficient oil extraction

Microalgae cultivation in PBRs takes most commonly place at lab-scale. Although PBRs appear to have several advantages compared to open pond systems such a higher biomass concentration and productivity, lower land and water footprints as well as a lower amount of CO_2 release to the atmosphere, particularly their energy requirements (and the GHG balance of cultivation) are at the current maturity level of the cultivation system unfavorable. In addition, most of the currently applied lipid extraction methods are not efficient in the case of microalgae. In the medium- to long-term, cultivation of microalgae has to take place in an operational environment (at small commercial scale) and therefore reach FSRL 7 if this aquatic biomass is to contribute to the production of renewable jet fuels.

Some experts are of the opinion that microalgae cultivation in PBRs will not permit the production of biofuels at reasonable price, even in the medium-term. Instead, new processes have allegedly to be "invented" for the utilization of microalgae for the energy applications. If this should be the case, it is even more important to clarify in the short-term, under which conditions energetically and economically reasonable large-scale production of algae is feasible.

Make use of underutilized and abandoned agricultural land for biofuel production

In line with the previously suggested roadmaps addressing feedstock potentials, i.e. utilization of marginal lands and efficiency increase in advanced feedstock collection, underutilized agricultural land particularly in Eastern Europe (approximately 40 M ha[2]) should be used for bioenergy production in the long-term. Although sufficient biomass is theoretically available, collecting it efficiently in abandoned areas is often neither logistically nor economically feasible. To unlock this potential, infrastructure in a decentralized fashion needs to be implemented, subsequently to which commercial biofuel feedstock

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[2] IEA, 2011

production should be focused on. Feedstock production on potentially polluted soils in these regions, however, should not be conducted and carefully checked previous to cultivation.

Commercial cultivation of low input oilseeds on marginal lands

Once stable oil yields have been achieved, the commercial cultivation of sustainable low input oilseeds (also in intercropping systems that further increase the sustainability of cultivation) should be pushed for in the medium- to long-term.

Commercial CO_2 capture from air

Once CO_2 has proven to be moderately cost-competitive and technological difficult have been overcome in the medium-term, commercial CO_2 capture from air should be focused on in the long-term. When the extraction process can be conducted economically and at sufficient scale, the CO_2 could serve as a feedstock for renewable jet fuels.

2.4 Conversion Technologies, Production & Deployment

This roadmap on production and deployment complements the R&D roadmap presented and described in Chapter 1. However, there is some overlap, as the phase of production and deployment starts before development is completed at TRL 9.

2.4.1 Short-term

The technologies Biomass-to-Liquid (BtL; gasification and FT synthesis) and Power-to-Liquids (PtL) can be expected to move towards demonstration scale production, i.e. the technologies are demonstrated in relevant operational environments.

In the short to medium-term future, hydrothermal liquefaction (HTL) and pyrolytic conversion (HDCJ), importantly both including upgrading and refining processes, can be expected to reach demonstration-scale production as well.

2.4.2 Medium-term

The thermochemical technologies for converting biomass into liquid fuel products, namely HTL, HDCJ and BtL), as well as the non-biogenic PtL technology show the potential to reach commercial-scale production in the medium-term future. The currently far less developed concept of StL conversion can be expected to advance pilot-scale production. Construction and operation of an StL pilot plant will yield deeper insight into the performance of key process steps and a knowledge base for strategic decisions regarding further development of the technology.

2.4.3 Long-term

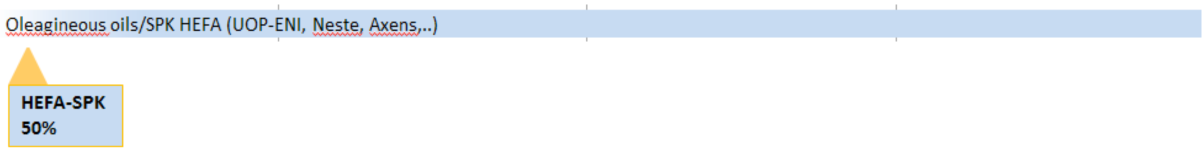
Assuming the potential of StL-based fuel production can be validated and demonstrated in industrially relevant operational environments, commercial-scale production could be realized in the long-term future. This also implies that a technology for direct capture of carbon dioxide from air is readily available, enabling a cost-efficient and renewable supply of CO_2 at the required large scale.

2.5 Approval Milestones

2.5.1 Overview

Today 5 pathways, mainly based on an iso-paraffinic biojet fuel, are certified and can be blended with fossil jet fuel from 10% to 50%, depending on the biojet fuel type and on the distillation curve range. About 4 to 5 pathways could be certified in the near future (2017-2020). About 3 more pathways could be certified in the medium term (2020-2025). Beyond 2030/2035 it is very difficult, and not reasonable, to make a prediction in this field. That is the reason why it is mandatory to follow-up ASTM certification in ASTM D02 / SC J spring and fall meetings. It is also important to continue a web / litterature/news (such as through biofueldigest), too follow-up dedicated presentation to biofuel conferences, as well as the ASTM certification, and to continue the monitoring of deployment and implementation of the biojet fuels. Another subject of interest is to follow-up ongoing and new projects, with a critical expert view. These data are gathered in the CORE Jet-Fuel/ICAO Excel Database, and are now updated within the ICAO expert group, under the leadership and secretariat of Volpe and support of FAA (US).

This roadmap is limited to a 2030 vision, since it predictions beyond 2025 – 2030 cannot be made with any degree of certainty. The upper part of the roadmap depicts the curent and future possible deployment of the pathways previously listed in chapter 3 “Certification Roadmap”.
The bottom depicts the ASTM approval according to ASTM D4054 with the current date of yet appoven 5 pathways described in annexes A1 to A5, as well as pathways that should be, or could be, approven in the short and medium term.
In order to make a link between the top and the bottom of the road map, and to visualize the necessary gap between ASTM approval and deployment (ASTM approval usually starts at TRL5 to 6), the same color code is used:



2.5.2 Short-term

For pathways that should be, or could be, approven in the short and medium term, the date of approval is only an estimated one.

- **Five pathways yet certified by ASTM in 2016.**
    - **FT-SPK** in 2009 blended with fossil jet fuel at 50% content maximum, only made of paraffins, mainly isoparaffins.
    - **HEFA-SPK**: in 2011 at 50% content max. (same chemical structure than FT-SPK).
    - **SIP**, initially called **DSHC** (Synthesized Iso-Paraffinic fuel from Hydroprocessed Fermented Sugars / Amyris), corresponding to an almost pure iso-C15 molecule: June 2014 at 10% content max.

  - (FT) **SPK/A**: FT-SPK plus mono-aromatics from alkylation of a benzene-rich cut (naphtha type) with light FT olefins (Sasol), with a chemical composition not very different from fossil jet fuel (15% cycloparaffin max.,20% aromatics max. and 65% paraffins min.): November 2015 at 50% content max.
  - ATJ-SPK from iBuOH (GEVO), mainly corresponding to a mixture of Iso-C12 and Iso-C16: April 2016 at 30% content max.
- **Two more could be certified in 2017** (no available date).
  - **Green Diesel**, now called High Freezing Point HEFA / **HFP HEFA** corresponding to a few percent (2-3% ?) of full biodiesel fraction directly blended with fossil jet fuel, without the need of a specific annex in D7566.
  - **CH,** now called **CHJ** / Catalytic Hydrothermolysis of lipid to bioJet fuel, by ARA/CLG: since it is a biojet fuel with chemical structure similar to fossil jet fuel, it could be used up to 100%.
- **Other pathways that could be certified by 2020.**
  - Pathways based on Aqueous Phase Reforming (APR) developed by Virent, with two routes.
    - Hydro-DeOxygenated Aromatic Synthesized Kerosene / **HD0-SAK** that could be blended up to 25%.
    - Hydro-DeOxygenated Synthesized Kerosene / **HDO-SK**, recently renamed Cyclo-Paraffinic Kerosene / **CPK**, mainly made of cyclo-paraffins (about 80%) and paraffins, that could be blended up to 50%.
  - Alcohol to jet pathway with Synthesized Kerosene with Aromatics / **ATJ SKA** (Lanzatech) from industrial was gas rich in CO.

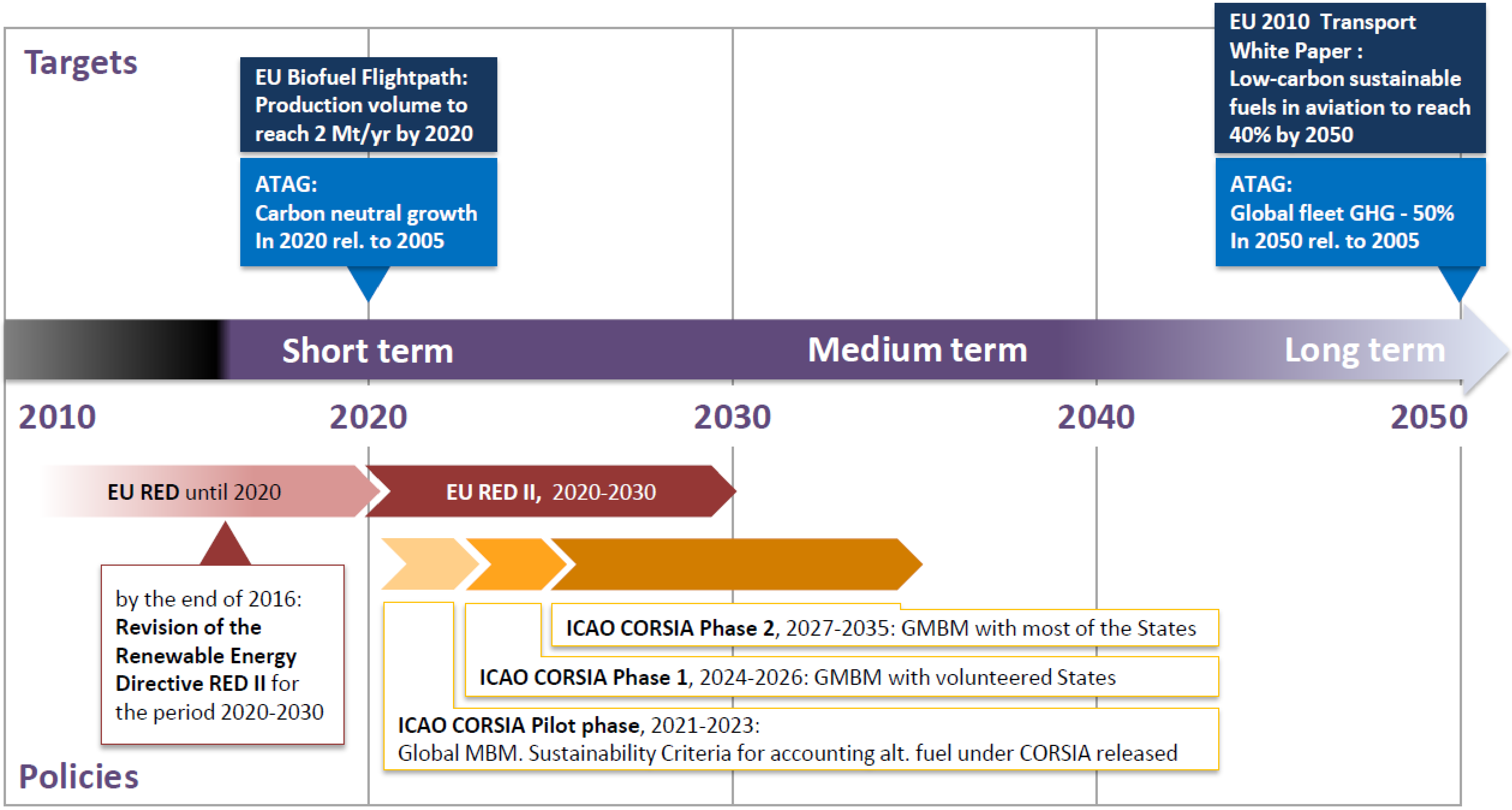
2.5.3 Medium-term

- Other pathways that could be certified by 2035.
  - Hydrotreated Depolymerized Cellulosic Jet / **HDCJ** and Hydrogenated Pyrolysis Oil / **HPO** from catalytic or non-catalytic fast pyrolysis.
  - Macro-algae / wet biomass Hydrothermal treatment (**HTL**) to produce a biocrude followed by a final hydrotreatement / hydroconversion, can also be another pathway, but it is too early to predict a date.
  - Global Energies pathway similar to Gevo, but through a direct gas fermentation of sugars to Isobutene (in place of isobutanol), followed by conversion to isoparaffin type biojet fuel, (it should be a blend of iC12 and iC16 as for Gevo), with probably up to 30% biojet fuel.

For the prediction of new pathways that could be certified beyond 2035, it is not relevant to give even guidelines because of the high uncertainty of the development of new pathways and on the production cost, such as Solar to Liquid / StL, Power to Liquid / PtL, and even more for non-drop-in fuel pathways, such as liquid methane or hydrogen.

3 Strategic Milestones, Targets and Policy Roadmap

3.1 Graphical strategic Milestones, Targets, and Policy Roadmap



3.2 Policy Roadmap

In order to reach significant volumes of alternative fuels production, the CORE-JetFuel has listed a number of short and medium term milestones that will need to be acomplished. These milestones and conclusions have been obtained from the stakeholder inputs, experiences obsterved in other regions and analysis of the existing regulations. Long term milestones have not been included in this list since it has been considered that it would be an exercise that would not be rigorous without knowing the level of technology development that the industry will reach in such long term. When the industry and the market are more mature, a re-evaluation of the potential policy measures described by CORE-JetFuel in WP5 will need to be carried out again. (i.e.: the establishment of mandates).

3.2.1 Short-term

EU Biofuel Flightpath

Reaching the production volume of 2 Mt/yr. will be a difficult objective to reach by 2020, but at this point in time new post 2020 goals should be set. 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.

Other short-term policy targets include:

- All Member States should incorporate the possibility of counting biojet fuels towards the obligation of fuel suppliers (opt-in)
- It should be clarified how the GMBM will affect EU ETS and if it is the case, how the two systems will coexist and how aviation alternative fuels will be treated.
- Biomass production potential and availability in Europe should be clear. Compendium of European resources for the production of sustainable transportation fuels for short, medium and long-term time frames, detailing the availability of sustainable feedstock and renewable primary energy.
- An agreement should be reached at ICAO level in terms of sustainability criteria of alternative fuels to be accounted under a GMBM.
- European network that works in promoting deployment initiatives should be established.
- Establish mechanisms financing/de risking mechanisms for early adopters.
- Develop initiatives by connecting the stakeholders engaged in alternative aviation fuels to push sustainable pathways
- Decrease the industrial risk of producing biojet fuel by securing the production through long term contracts and/or partnerships with airlines, oil companies, national defense/civil administration, Government departments

3.2.2 Medium-term

Revision of the Renewable Energy Directive RED II

The proposal for revision of the RED is still to be defined and the consequences of its application for aviation alternative fuels will need to be reevaluated.

ICAO CORSIA Pilot Phase, Phase I and Phase II

The impact on the implementation of the CORSIA on aviation alternative fuels is currently uncertain, since a decision on how alternative fuels are to be credited in the system is still to be defined, although there is certainty that regulated parties will receive a credit for its use. In any case, several experts consulted during the course of the project forecast that the direct impact on deployment will be low if the level of industrial development of the market does not improve, and that market forces alone will not be sufficient to generate a significant demand. ICAO, through CAEP is also working in the definition of sustainability criteria for sustainable alternative fuels under the CORSIA and in the definition of a guidance document on potential policies and coordinated approaches for the deployment of sustainable alternative fuels for aviation. The outcome of this work will be important in order to have a common understanding of the sustainability criteria in all ICAO Member States, as well as to understand the possibilities that states have to implement policy measures to promote aviation alternative fuels.

Strategic targets

In addition to the short term Flightpath objective, three more objectives have been included in the graph. First, carbon neutral growth objetive in 2020 rel. to 2005 and the global fleet GHG reduction of 50% in 2050 relative to 2005. For the completion of these two goals the introduction of aviation alternative fuels will be essential, since, as analysed by ICAO, the potential of other in-sector measures is limited and will not be sufficient. In addition, the EU 2010 Transport White Paper establishes that low-carbon sustainable fuels in aviation need to reach a share of 40% by 2050. In order to accomplish these objectives, additional policy measures to promote alternative fuels will be needed. However, long term policy options have not been included in the roadmap graph since it is very difficult to evaluate at the present stage the options that could be implemented in a market that has a very uncertain development due to the changing scene in terms of technological options. Policy options will need to be reevaluated (for example, the establishment of specific aviation mandates) depending on the level of matureness achieved by the market and the industry. In these regard, the guidance document on potential policies and coordinated approaches from ICAO will be essential.

Other medium-term targets include:

- Aviation alternative fuels should be integrated in an European alternative biomass policy, there should be an integrated biomass policy for a smart use of the resources.
- The establishment of a mandate should be reconsidered and evaluated based on the technical deployment and technology progress.
- Develop initiatives by connecting the stakeholders engaged in alternative aviation fuels to push sustainable pathways
- Decrease the industrial risk of producing biojet fuel by securing the production through long term contracts and/or partnerships with airlines, oil companies, national defense/civil administration, Government departments

4 Appendix

This appendix features supplementary information to the graphical roadmaps and corresponding descriptions on Feedstock R&D and production outlined in Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.** and 2.3 of this report. While the majority of milestones and targets stated below have already been described in more detail, some have not been included in the graphical roadmaps in the beginning of the report (and therefore not described).

4.1 Feedstock and Sustainability

4.1.1 Short-term (2020)

- Detailed cartography of the available feedstock and potentials for aviation biofuels
- Integrated biomass policy put in place for a smart use of the resources and the soils (arbitration when needed) with the selection of the most suitable ones to support according to the location (European or not) (from 2025).
- Stable oil yield of 0.8 t/ha on marginal lands for HEFA production
- New practices to decrease the costs of sustainable feedstock production
- Stabilization of camelina seed yield at 2 t/ha for sufficiently scalable and economically viable biojet production
- Fundamentally clarified, under which conditions energetically and economically reasonable large-scale production of algae is feasible
- Establishment of production targets for microalgal biomass
- Clear definition of the term “marginal land”
- Use of sustainability certifications harmonised at international level
- For lignocellulosic biomass as well as agricultural waste and residues: Infrastructure put in place for the efficient collection and pretreatment of the feedstock up to the (bio)refinery
- New applications identified, using the same types of feedstock to boost and make profitable the production by proposing co-products with high added-value
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4.1.2 Medium-term (2035)

- Commercial cultivation of low input oilseeds on marginal lands
- New types of feedstock usable for drop-in aviation alternative fuels (new micro-organisms, use of CO2 and/or other carbonated gases and solar power).
- Harvesting, collection and pretreatment systems for advanced feedstocks in place in order to maximize supply of intermediate bioenergy carriers by the minimization of costs per unit
- Large-scale utilization of lignocellulosic biomass and other advanced feedstock types
- Mobilisation of agricultural, forestry and waste biomass through the development of sustainable supply chains and efficient technology transfer
- Location of advanced biofuel plants alongside other industrial facilities producing lignocellulosic residues as by-product such as paper mills leading to a higher share of advanced biofuel production
- Focus on economically viable advanced feedstocks. In order to reach price parity with fossil fuels and therefore become interesting for the aviation industry, the price of straw-based ethanol has to decrease from ~ 45€/GJ to ~ 20 – 30 €/GJ)

- Microalgae production in closed photobioreactors at operational scale (Feedstock Readiness Level of 7 and higher) / utilization of waste gases from industry for algae cultivation[3]; Integration of microalgae production with other renewable energy technologies
- Annual UCO availability increase to 3 Mt by advancing collection from private household
- Utilization of technical production potential of agricultural residues (straw) shown in Figure 1.

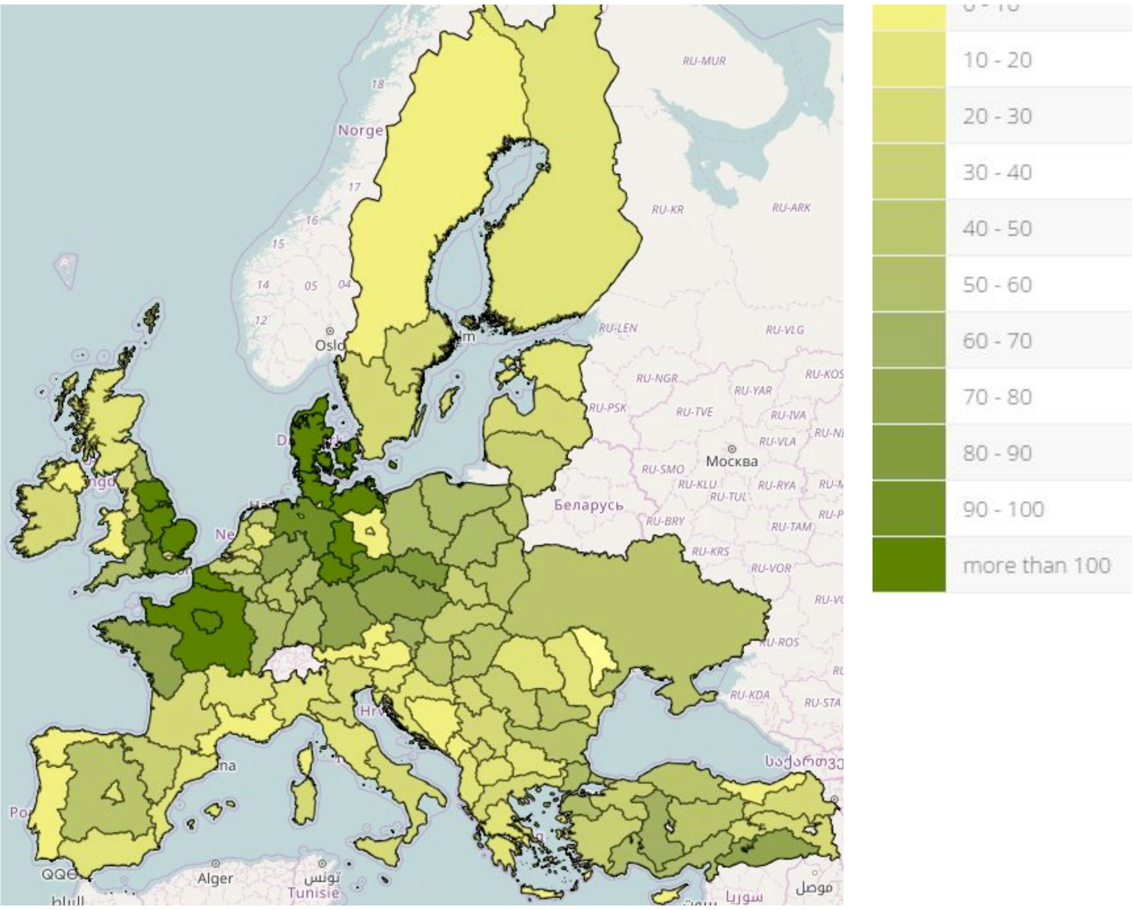

Figure 1: Technical Production Potential of agricultural residues (cereal straw) in t/km^2 in 2030 at NUTS1 level (http://s2biom.alterra.wur.nl/home)

Figure 1 shows the technical potential of straw in 2035. Utilizing this potential efficiently and cost-competitively will be critical if the aviation sector aims at producing sustainable renewable fuels based on this type of feedstock. The S2Biom tool was also applied to the technical potential of straw production in 2020, but did not show significant differences, which is why the corresponding graphical representation was not included in the short-term targets. It nevertheless underpins the short-term

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[3] In November 2014, the US Department of Energy (DOE) shifted its milestone of validating **production** of algae-based biofuels in open pond systems at total production costs of $3/GGE (~ 11€/l) (gasoline gallon equivalent) to validating **demonstration-scale** production of algae-based biofuels, clearly showing the difficulty of forecasting the development of (micro-)algae roadmap, particularly in terms of production volumes. This underlines the necessity of fundamentally clarifying under which conditions an energetically and economically large-scale microalgae production is feasible, as stated in the short-term algae targets (http://www.biofuelsdigest.com/bdigest/2014/12/28/the-does-shifting-worldview-for-biofuels-deployment-now-through-2030/)

need for efficient collection infrastructure that enables the large-scale utilization of straw as a renewable jet fuel feedstock.

4.1.3 Long-term (2050)

- Use of biogas such as bioCH_4 for non drop-in fuels.
- At an average yield of 15 t/ha of SRC, increase yields of BtL-SRC from 3100 litre of gasoline equivalent (lge)[4] per hectare in 2010 to 5200 lge in 2050. Average improvement of 1.3% per year
- 50% of feedstocks for advanced biofuels (and biomethane) obtained from waste and residues, equating to 1Gt of dry biomass globally, or 20 EJ
- Expansion of land use for biofuel production from 30 Mha in 2011 to 100 Mha globally, i.e. 6% of the total arable land
- Make use of the underutilized and abandoned agricultural land for biofuel production (~ 40 M ha in Eastern Europe alone)
- Renewable electricity-based fuels (Power-to-Gas, Power-to-Liquid)
- Sustainability is mandatory. Improvements in terms of costs or GHG emissions must not compromise other important environmental or social performance indicators, such as water consumption, emission of pollutants, land use rights etc.

Figure 2 shows the global demand for different types of biofuels and the corresponding land demand of biogenic feedstock projected by the IEA[5] until 2050. These projections are based on the assumption that 50% of advanced biofuels and biomethane are produced from waste and residues, requiring 1 Gt of residue material. Although objections might exist regarding the amount of residue-based biofuels, Figure 2 nevertheless shows the existing and projected competition between different application sectors for (advanced) feedstock types – an issue that is addressed in numerous CORE-JetFuel Deliverables.

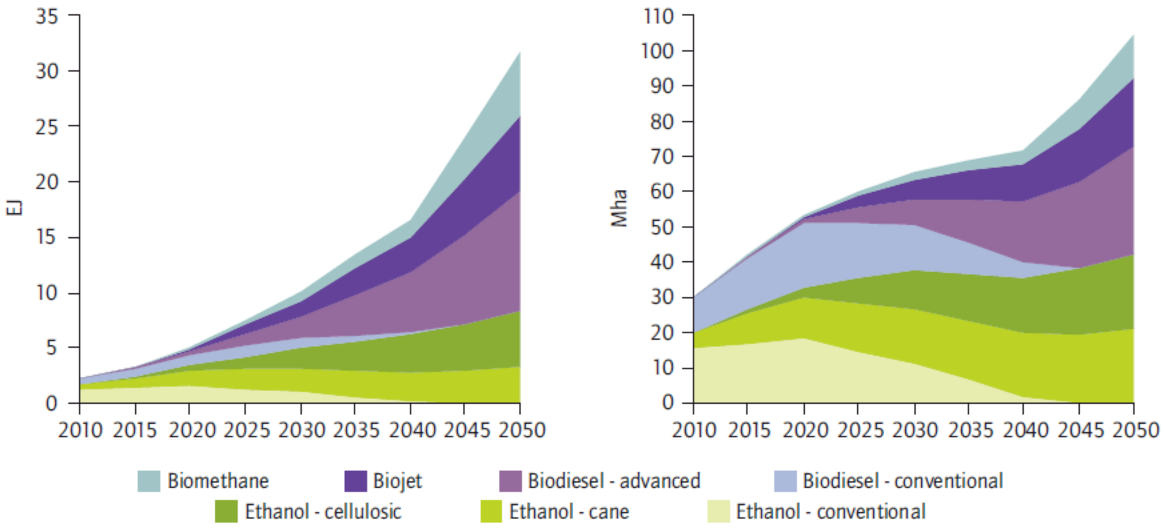

Figure 2: Demand for different types of biofuel (left) and resulting land demand until 2050 (IEA, 2011)

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[4] 1 liter of ethanol = 0.65 lge; 1 liter of biodiesel = 0.90 lde (liter of diesel equivalent); 1 liter advanced biodiesel = 1 lde (at an average yield of 15t/ha for woody crops from SRC

[5] http://www.iea.org/publications/freepublications/publication/biofuels_roadmap_web.pdf