CORE-JetFuel

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

Work Package 5, D5.2:
Final Report on Technical Compatibility, Certification and Deployment

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Johannes Michel
- Coordinator-
Fachagentur Nachwachsende Rohstoffe e.V. (FNR)
j.michel@fnr.de
Tel.: +49 (0) 3843 – 69 30 – 250
Fax: +49 (0) 3843 – 69 30 – 102

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

Deliverable 5.2:
Final Report on Technical Compatibility, Certification and Deployment

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Document Author: A. Quignard

Work Package 5: Technical Compatibility, Certification
and Deployment"
Work Package Leader: SENASA
Task Leader: IFPEN

PROJECT PARTNERS

FNR – Fachagentur Nachwachsende Rohstoffe e.V., Germany

BHL – Bauhaus Luftfahrt e.V., Germany

SENASA - Servicios y Estudios para la Navegación Aérea y la Seguridad Aeronáutica SA, Spain

IFPEN – IFP Energies Nouvelles, France

WIP- WIP Renewable Energies, Germany

AGI – Airbus Group Innovations

EXECUTIVE SUMMARY AND CONCLUSION

Biojet fuel qualification and pathways

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

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

1. ASTM D7566 Annex A1, initially developed for natural gas and coal, based on feedstock gasification, followed by Fischer-Tropsch (FT), called Hydroprocessed Synthetized Paraffinic Kerosene (FT synthesis and hydrotreatement/hydrocracking of the obtained wax), or FT-SPK and certified in 2009, with a maximum allowed amount of 50% in Jet A/A1,

2. ASTM D7566 Annex A2, based on oleagineous vegetable oils, animal fats, used cooking oils or lipids from microalgae, called Hydroprocessed Esters and Fatty Acids or HEFA-SPK, certified in 2011, with the same maximum blending ratio of 50% in Jet A/A1,

3. ASTM D7566 Annex A3, related to a process developped by Total/Amyris producing only a unique type of product called farnesane (an iso-paraffin with 15 carbons) from hydroprocessed fermented sugar, was approved in June 2014. Formerly called DSHC (Direct-Sugar-to-HydroCarbon), it was renamed Synthetic Iso-Paraffins (SIP). Blends are permitted with a limitation up to 10% in JetA/A1, because of the specificity of the fuel corresponding to a pure chemical compound and not to a complex mixture of hydrocabons with a continuous distillation curve,

4. ASTM D7566 Annex A4, FT-SPK/A synthesized jet fuel or FT-SPK with Aromatics (alkylated mono-aromatics), was added to ASTM D7566 in November 2015. FT-SPK/A is corresponding to a fuel obtained from the alkylation of light mono-aromatics proceeding from a narrow naphtha cut rich in benzene from CTL with light olefins. This process is proposed by Sasol with a maximum allowed amount of 50% FT-SPK/A in Jet A/A1, but today the fuel (aromatics) is not proceeding from biomass,

5. ASTM D7566 Annex A5, ATJ SPK (Alcohol to Jet Synthesized Paraffinic Kerosene) proposed by Gevo from isobutanol deshydratation and oligomerization to a mixture of C_{12} and C_{16} isoparaffins, was very recently approved on April 15th, 2016, with a maximum allowed amount of 30% in Jet A/A1, probably because it is not corresponding to a complex mixture of hydrocabons with a continuous distillation curve. It is limited up to 30% in conventional jet fuel (refer to SIP).

Today, only the HVO technology (called HEFA if partially or mainly dedicated to biojet fuel production) is industrially available and currently used in several countries mainly for biodiesel production: USA, Finland, Italy, The Netherlands, Singapore, and, in short time, probably early 2018, France. The capacity is or will be close to 3 million t/y, but currently for diesel production only, with the exception of the Altair HEFA plant (Paramount, California) producing biodiesel, but also biojet fuel for United Airlines since March 2016. The HEFA technology is ready to use, but not yet implemented today at industrial scale, with the exception of the AltAir plant in California, producing biojet fuel for United Airlines, since March 2016.
Another possibility is the so-called Green diesel or High Freezing Point / HFP HEFA, which is made from the same materials. Green diesel (UOP-ENI/Boeing) can use HEFA current industrial units producing renewable diesel at low concentration (less than 5%, and more probably less than 2-3 % v/v) in the final jet fuel blend with petroleum jet fuel. Green diesel / HFP HEFA could be certified in 2017, but there is no recent information from the last ASTM D02 June meeting. Nevertheless Green diesel from HVO units or HEFA jet fuel produced from new grass-roots[1] units cannot compete with petroleum based jet fuels at current crude oil price (UIS$/bbl 50), without significant subsidies. For biojet fuel, it is even more difficult than for ground transportation fuels, because there is no possible incentive based on a reduced tax (no tax) and because the cost of the feedstock is not necessary well known, since it is not yet at a large scale production (i.e. camelina and jathropha), or at a low cost but at a limited available quantity, such as Used Cooking Oils (UCO) or animal fats.

FT-SPK from natural gas and coal is at industrial level (i.e. Sasol in South Africa producing commercial FT-SPK jet fuel or Shell in Qatar or from demonstration/semi-industrial plants in China), but not yet for biojet fuel from ligno-cellulosic biomass, where it is currently mainly at demo level with the objective of being used at industrial level from 2020.

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

The Gevo ATJ-SPK route is in the early stage of industrial production of isobutanol, but the production of ATJ-SPK is currently not at commercial scale.

The FT-SPK/A synthesized jet fuel proposed by Sasol, basically from CTL, could be adapted to future processes producing bio-light olefins, such as olefins from a BTL process or

[1] New unit built on a green-field, meaning from scratch

obtained from alcohols fermentation and deshydration, or olefins directly obtained from fermentation, and from light aromatics from biomass conversion processes, such as catalytic pyrolysis. With the scheduled development of biofuel processes, it could be possible, in the mid/long term, to produce biobased alkylated mono-aromatics.

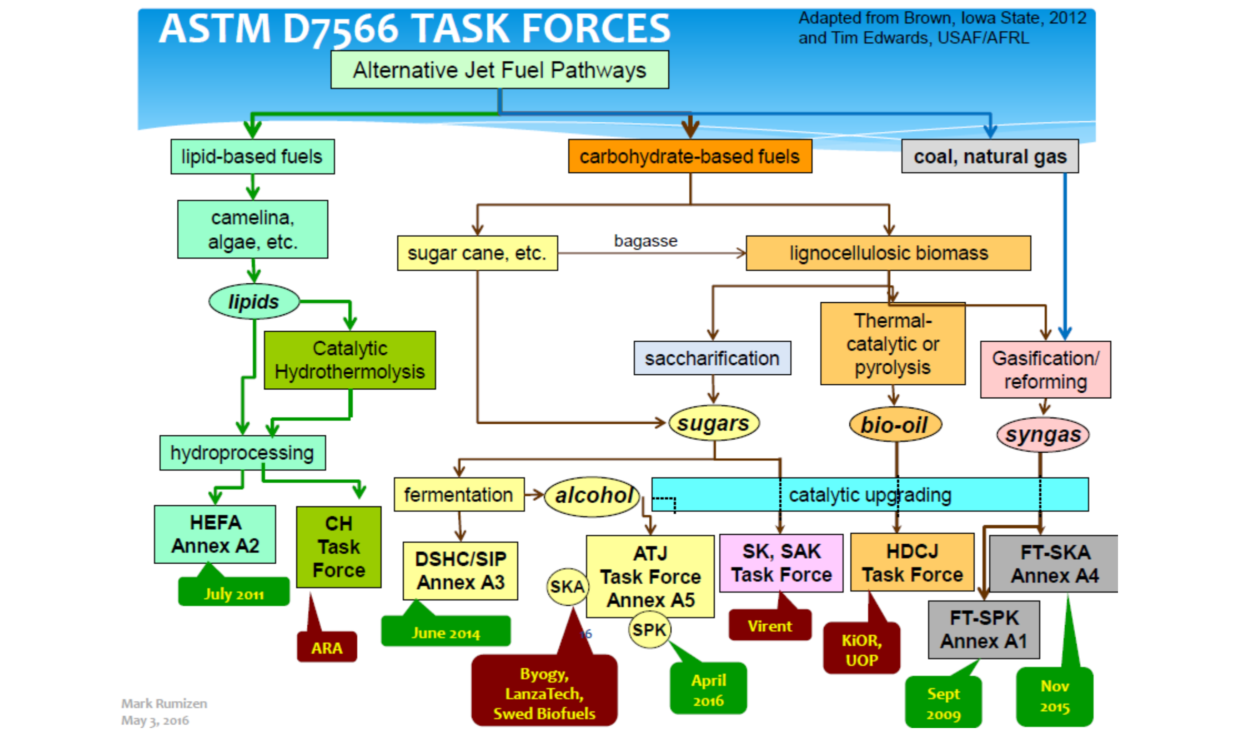
Because of the lack of aromatics in renewable jet fuels from most of the processes stated above, there are also other processes that were developped to get a closer chemical structure to the one typically observed in Jet A/A1. These pathways produce synthesized kerosene-containing aromatics, such as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

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

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

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

For a quick comprehensive overview, the pathways are illustrated in the following figure.



[Rumizen, May 2016]

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

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

Recommendations to the EC

Recommendations to the European Commission, issued from the CORE-JetFuel members, as well as from a dedicated phone meeting with the stakeholders and from the final project workshop held in Brussels in mid-June 2016, are detailed in a specific chapter of this report and briefly reminded below:

- Keep monitoring deployment / implementation initiatives with a critical expert analysis
- Develop initiatives connecting the stakeholders engaged in alternative aviation fuels
- Decrease the industrial risk to scale-up production
- Improve production costs and biojet fuel implementation / deployment
- Improve the understanding of the properties of biojet fuels
- Optimize and improve the use of ASTM D4054 process, through a better understanding between the chemical structure and the properties of the fuels and taking into account the feedback of the approved routes
- Pay attention to logistic and quality insurance.

Database

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 and distributed worldwide
The focus of this database is on “advanced alternative fuels” that could have an application in aviation. The production step of ethanol itself as an intermediate product feedstock for alcohol-to-jet is not included, but ATJ routes are considered. The file currently mainly includes announcements by industry or processes at large scale pilot plant or demo level.
The database is organized into two Excel sheets. A first sheet called “Announcements” provides all the data collected. A second sheet called ”short-term projections” is dedicated to the building of projections for a number of scenarios. The final objective is to have the right shared/controlled data to be able to build the alternative bio-jet fuel projection.

A group of ICAO/AFTF experts[2] is providing updates / announcements by setting a number of criteria. The group, under the leadership and secretariat of Volpe, with support of US FAA (Federal Aviation Administration), can then update the file and keep it updated on the AFTF website. Calls and face-to-face meetings within the group are performed all over the year in order to discuss and to quote, on a consensus basis between experts, the news, press releases and publications related to the evolution of existing projects, as well as new projects or project cancelations. This organization makes it possible to update the database in real time. Today the database is only available for ICAO members.

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

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[2] N. Brown (US FAA), R. Boyd (IATA), N. Jeuland (Safran), K. Lewis (Volpe, US DOT), L. Lonza (EC/JRC), R. Malina (MIT), A. Quignard (IFPEN), M. Starples (MIT), C. Velarde (ICAO, working in the Ministry of Transport of Indonesia)

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LIST OF ABBREVIATIONS

ABRETF	(Indonesia) Aviation Biofuel & Renewable Energy Task Force
AFTF	Alternative Fuels Task Force
aireg	Aviation Initiative for Renewable Energy in Germany
AJF	Alternative Jet Fuel
ANAC	Brazilian Civil Aviation National Agency
APR	Aqueous Phase Reforming
ARA	Applied Research Associates
ASCENT	Aviation Sustainability Center (cooperative aviation research organization co-leaded by Washington State University and the Massachusetts Institute of Technology)
ASTM	American Society for Testing and Materials
ASU	Air Separation Unit
ATAG	Air Transport Action Group
ATJ	Alcohol To Jet
BIC	Biofuels IsoConversion
BFCC	Biomass Fluid Catalytic Cracking
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAEP	Committee on Aviation Environmental Protection
CAP	Common Agriculture Policy
CH	Catalytic Hydrothermolysis
CHJ	Catalytic Hydrothermolysis Jet
C-JF	Core-JetFuel - Coordinating research and innovation in the field of sustainable alternative fuels for aviation
CLG	Chevron Lummus Global
CNG2020	a collective medium-term global aspirational goal of keeping the global net carbon emissions from international aviation from 2020 at the same level adopted at the 37th ICAO Session in 2010
CPK	Cyclo-Paraffinic Kerosene
CO2	Carbon Dioxide
COP 21	United Nations Climate Change Conference
DA	(US) Department of Agriculture
DBFZ	Deutsches Biomasse Forschungs Zentrum
DG	Directorate General

DGCA	Directorate General Of Civil Aviation, Indonesia
DLA	(US) Defense Logistic Agency
DOE	(US) Department Of Energy
DPA	(US) Defense Protection Act
DSHC	Direct Sugar to HydroCarbons (now called SIP)
e.g.	exempli gratia, for example
EASA	European Aviation Safety Agency
EC	European Commission
ENAC	Italian Civil Aviation Authority
EPA	Environmental Protection Agency
ETS	Emission Trading Scheme
EU	European Union
F2F2	Farm to Fly 2.0; initially founded in April 2013(called Farm to Fly 1.0) by USDA, Airlines for America (A4A) and Boeing, with the addition in April 2014 of FAA (Department of Transport/DOT/FAA) and then DOE (August) (recalled Farm to Fly 2.0) + Business Aviation Associations + CAAFI's Industry sponsors: public/private initiative to enable commercially viable, sustainable biojet fuel supply chains in the U.S, that are able to support the goal of one billion gallons of biojet fuel production capacity and use for the Aviation Enterprise by 2018
FAA	Federal Aviation Administrative (USA)
FAO	Food and Agriculture Organization
FCC	Fluid Catalytic Cracking
FLS	Fermentation of Lignocellulosic Sugar
FPA	Fuel Process Assessment (performed by ICAO/AFTF)
FT	Fischer-Tropsch
FT-SK	FT Synthetic/Synthesized Paraffinic Kerosene
FT-SPK/A	FT SPK base with the addition of alkylated mono-aromatics
GHG	Green House Gas
HBBA	High Biofuel Blends in Aviation
HDCJ	Hydrotreated/Hydroprocessed Depolymerized Cellulosic Jet
HDO SK	Hydro-DeOxygenated Synthetic/Synthetized Kerosene
HDT	HyDroTreatment
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
i. e.	it est
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IGAC	Indonesia Green Aviation Conference
IINAS	International Institute for Sustainability Analysis and Strategy
ILUC	Indirect Land Use Change
INRA	Institut National de la Recherche Agronomique
IPCC	Intergovernmental Panel on Climate Change
ISAFF	Italian Sustainable Aviation Fuel Forum
ISCC	International Sustainability and Carbon Certification
ISEAL	International Social and Environmental Accreditation and Labeling
ISEAS	Integrated Seawater Energy and Agriculture System
ITAKA	Initiative Towards SustAinable Kerosene for Aviation
JRC	Joined Research Center (o the European Commission)
LAX	Los Angeles International Airport
LCA	Life Cycle Assessment
LNG	Liquefied Natural Gas
MIT	Massachusetts Institute of Technology
M gpy	Million gallons per year
MSW	Municipal Solid Waste
M usg	Million US gallons
OEM	Original Equipment Manufacturers (refer to ASTM D4054 Qualification Approval new jets fuels & additives)
NABC	National Advanced Biofuels Consortium
NISA	Nordic Initiative for Sustainable Aviation
PNPB	Brazilian National Biodiesel Program
PNNL	Pacific Northwest National Laboratory
R&D	Research and Development
RED	Renewable Energy Directive
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number

RPN	Renewable Paraffins and Naphthenes
RSB	Roundtable on Sustainable Biomaterials
R&D	Research and Development
SAJF	Synthetic/ Synthesized 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
SUSTAF	Sustainable Alternative Fuels
UCO	Used Cooking Oil
VO	Vegetable Oil
WEC	World Energy Council
WGS	Water Gas Shift
WP	Work Package
WWF	World Wide Fund for Nature

Introduction

In June 2011 the European Commission initiated the Advanced biofuel Flightpath Initiative aiming at producing two million tonnes of biofuels per year by 2020, setting therefore ambitious targets to deploy alternative fuels for aviation. As in the medium-term aviation technology will remain dependent on the availability of liquid hydrocarbon fuel, the alternative fuels to be developed will need to be fully compatible with current aircraft and infrastructures ("drop-in" strategy).

Task T5.1 entitled “Technical compatibility, Certification and Deployment” is performed within the Work Package 5 (WP5) entitled “CORE-Jet-Fuel “Innovation Analysis”. The work within this WP5 is focussed on the identification, collection, mapping, analysis and evaluation of all relevant national, European and international innovations of sustainable alternative fuels for aviation, including technical certification, standardisation, deployment and policy measures, so that the sharing of information may lead to building relationships and public-private cooperation.

Before they can be used for commercial flights, alternative fuels must demonstrate such technical compatibility and be approved to international standards, such as ASTM fuel specifications. The ASTM qualification process is also reminded.

This report described the current and future processes approved or to be approved by the ASTM qualification procedure.

One of the targets of this WP is to have a tool to be able to make an independent assessment of the collected information to identify the needs of the aviation sector in the field of biofuels at European level, in order to visualize potential pathways of further promising and/or needed research achievements in the long-term.

Since it is a very important and time consuming work, with a similar approach performed within the ICAO/AFTF group (Alternative Fuels Task Force), the AFTF and the CORE-Jet-Fuell databases were finally merged in order to get a comprehensive worlwide shared base. The ICAO/AFTF assessment was perfomed in the AFTF WP2 Fuel Process Assessment (FPA). The main objective is to gather all the available and quite frequently (even if currently less frequent than a few years ago) changing public information related to biojet fuel processes at laboratory, pilot plant, demonstration or industrial level that are yet implemented, or to be implemented in the near future (2020) or in the long term (2035-2050).

The database and its assessment are briefly described in this report.

1 Outcomes of the ASTM qualification process and main pathways to biojet fuels

This chapter depicts the current and short term ATSM qualification process of biojet fuels and introduces the main pathways at industrial level, yet in production or to be in production in the very short term, as well as routes still at pilot plant at demo level for the mid-term or longer term.

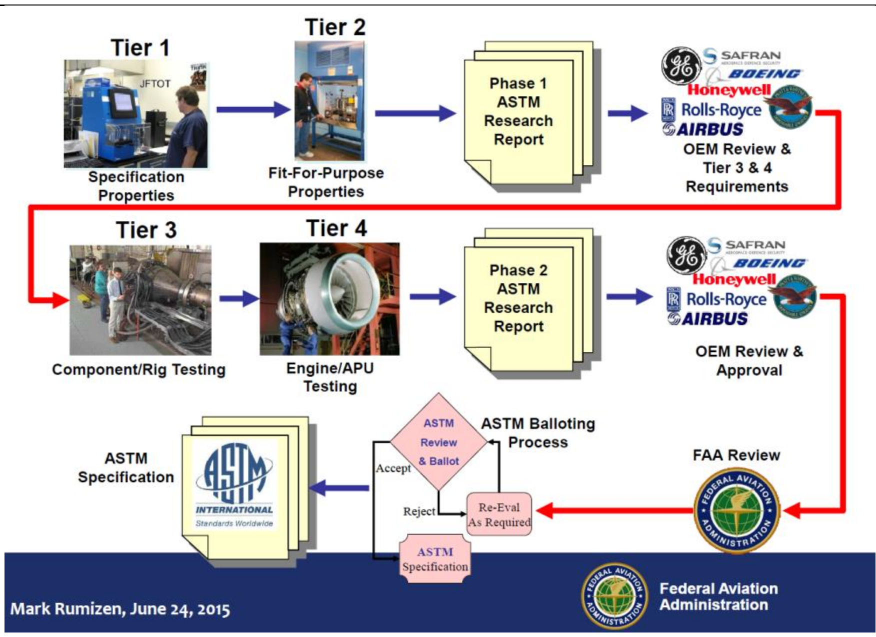
1.1 ASTM qualification

The qualification process is established in ASTM D4054-14 Standard: Guideline for the Qualification and Approval of New Turbine Fuels and Fuel Additives. This standard describes the steps, procedures and laboratory measurements required for a new jet fuel or a new jet fuel additive. Its purpose is "to guide the sponsor of a new fuel or new fuel additive through a clearly defined approval process that includes the prerequisite testing and required interactions with the engine and airframe manufacturers, standards organizations, and airworthiness agencies, such as the FAA (Federal Aviation Administrative / USA) and EASA (European Aviation Safety Agency). This practice also provides a basis for calculating the volume of additive or fuel required for assessment, insight into the cost associated with taking a new fuel or new fuel additive through the approval process, and a clear path forward for introducing a new technology for the benefit of the aviation community".

ASTM qualification is a long and costly process, that is a mandatory step, before setting new jet fuel specifications, as described in ASTM D7566-16 and its annexes, and before the commercialization of the fuel. It requires a large quantity of jet fuel, from 10000 to 100000 gallons (about 38 to 380 m^3) for the required mandatory tests, several years, e.g. 2 to 3 years, with a cost that can overpass US$10 millions.

ASTM qualification process and steps are described in Figure 1, Figure 2 and Figure 3.

For drop-in fuels (this is the case for all alternative Jet fuel, ASTM D7566) **there is no need, in the USA, of FAA Certification on engines, aircraft and aircraft flight manuals and ASTM Qualification directly results in FAA Certification since the operating limitation of the fuel is unchanged**. This is not be the case for non drop-in fuels with a new ASTM standard.



[Rumizen, May 2016]

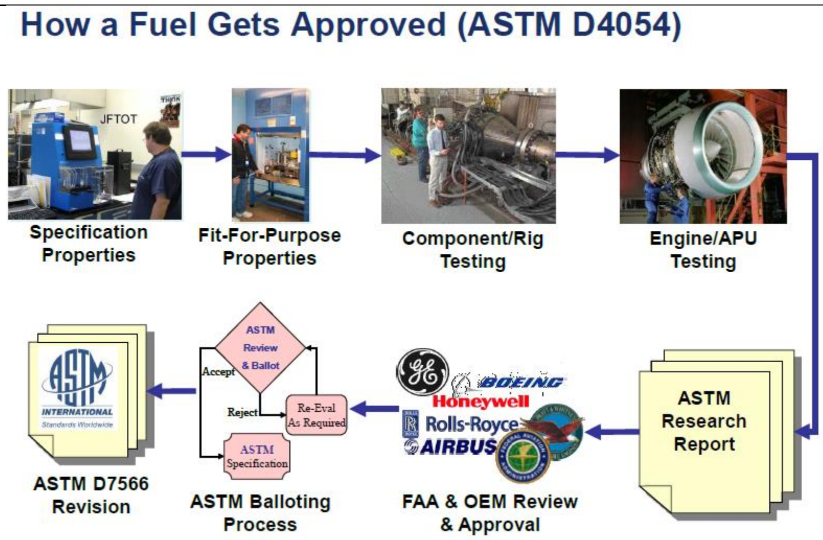
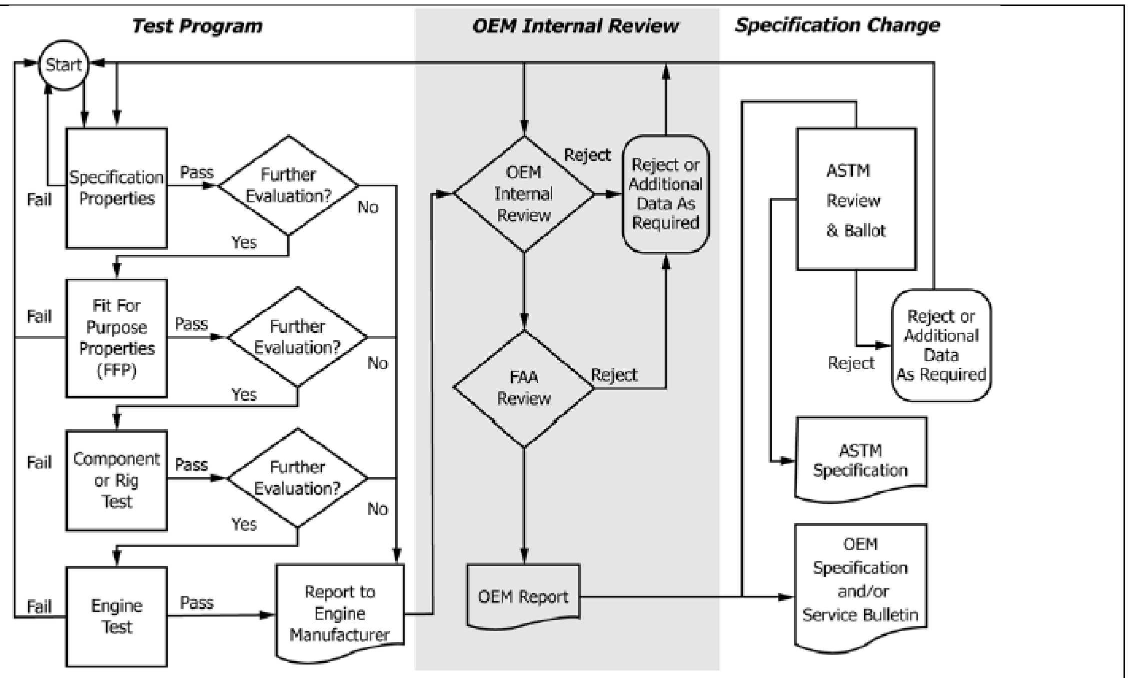
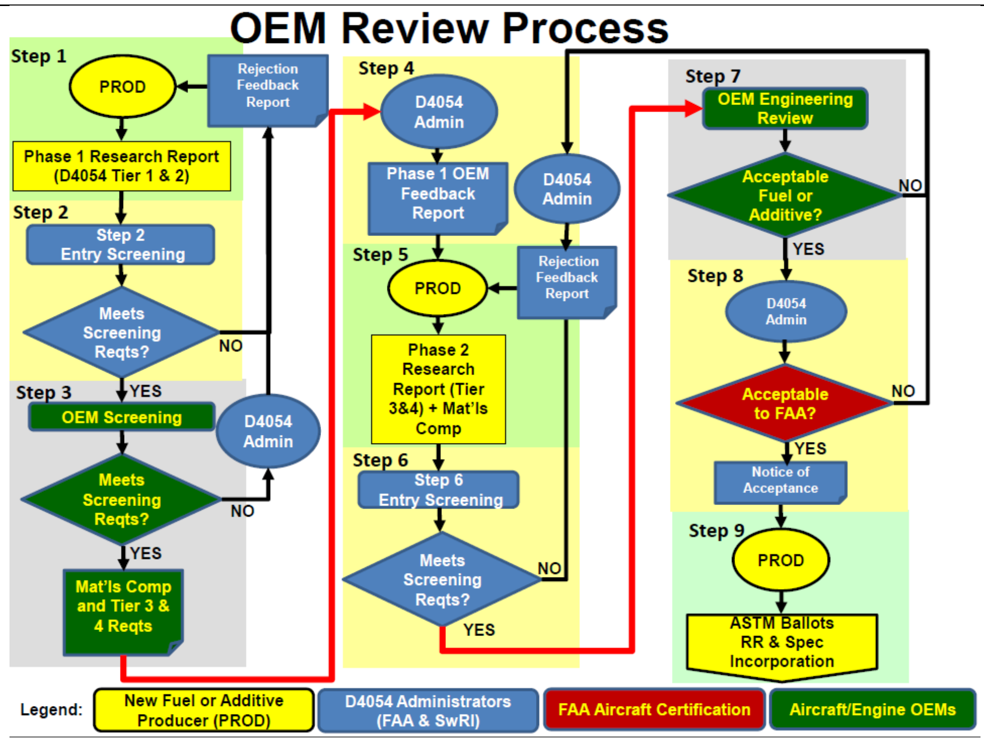


Figure 1: ASTM D4054 qualification main steps

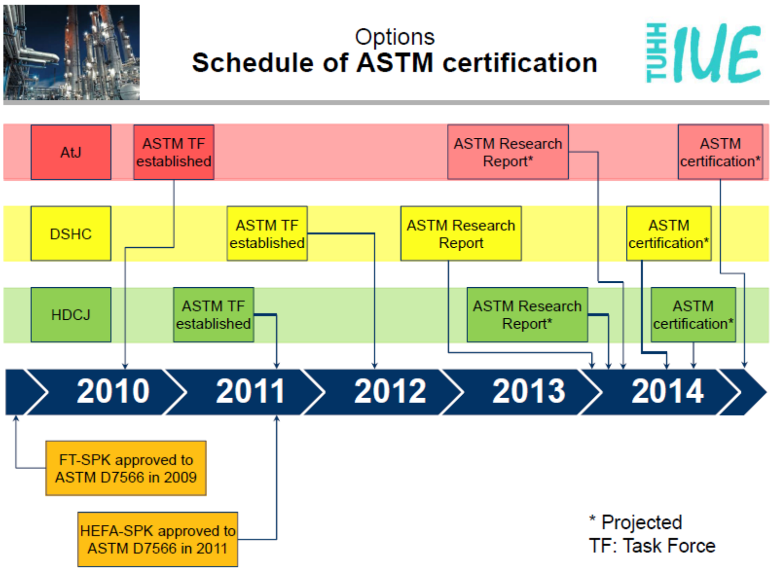


[ASTM D5054]



[Rumizen, May 2016]

Figure 2: ASTM D4054 qualification diagram and steps



[ASTM D02, Dec. 2014]

Figure 3: Example of time schedule for ASTM D4054 qualification for renewable jet fuels

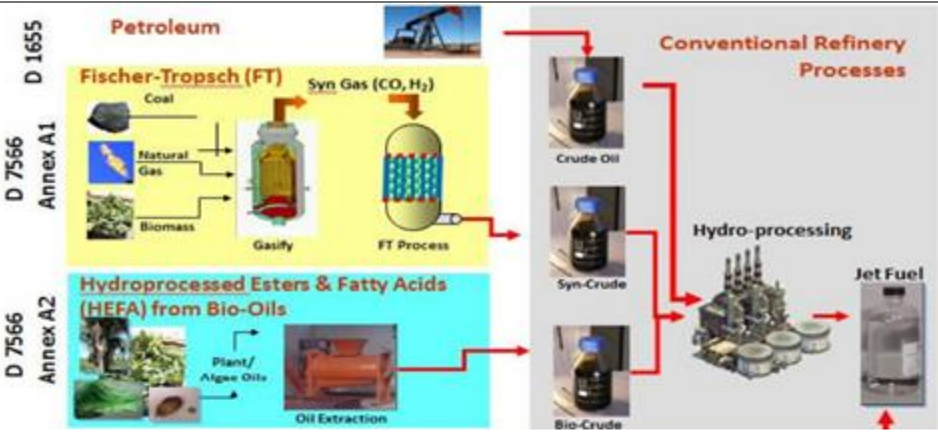
1.2 Certified pathways and pathways under, or close to, ASTM qualification

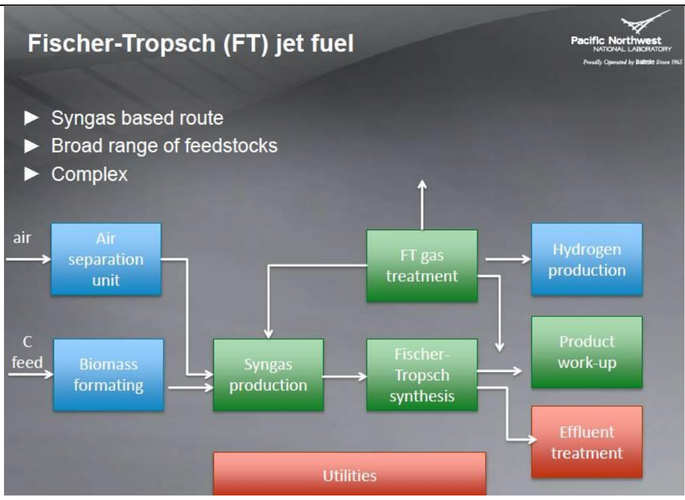
Today five different processes for alternative jet fuels have been already approved by ASTM, providing the technical specifications for these biojet fuels in ASTM D7566-16 Standard Specification for Aviation Turbine Fuel Containing SynthesizedHydrocarbons with 5 annexes A1 to A5.

1.2.1 FT SPK

A first one, **D7566 Annex A1,** initially developed for natural gas and coal, in development by a few R&D centers and licensors for biomasss, based on gasification, followed by **Fischer-Tropsch (FT) Hydroprocessed Synthetized Paraffinic Kerosene** (FT synthesis and hydrotreatement / hydrocracking of the obtained wax), called **FT-SPK and certified in 2009**.

The FT pathway is depicted in Figure 4. Dry grinded biomass or pretreated biomass (i.e. after torrefaction or pyrolysis) is fed to a gasifier with pure oxygen from the Air Separation Unit (ASU) to produce syngas (CO, CO_2, H_2 + impurities and tars). CO/H_2 ratio is adapted to the FT synthesis requirement to enhance the hydrogen content by the so called Water Gas Shift (WGS) reaction ($CO+H_20$ -> CO_2 + H_2) and the final CO/H_2 blend is purified before entering the FT reactor to produce long chain paraffins. A final hydroprocesssing step (wax hydrocraking / hydroisomerization) is required to produce fuels meeting the specifications, especially for the cold flow properties. The final products has a 100% paraffinic structure with a significant content of iso-paraffins (the higher the isoparaffin content the better the cold flow properties) without any impurities (nitrogen, sulfur) nor cyclic hydrocarbons.





[Brown, May 2012], [Holladay, Nov. 5,2014]

Figure 4: FT and HEFA-SPK ASTM certified routes

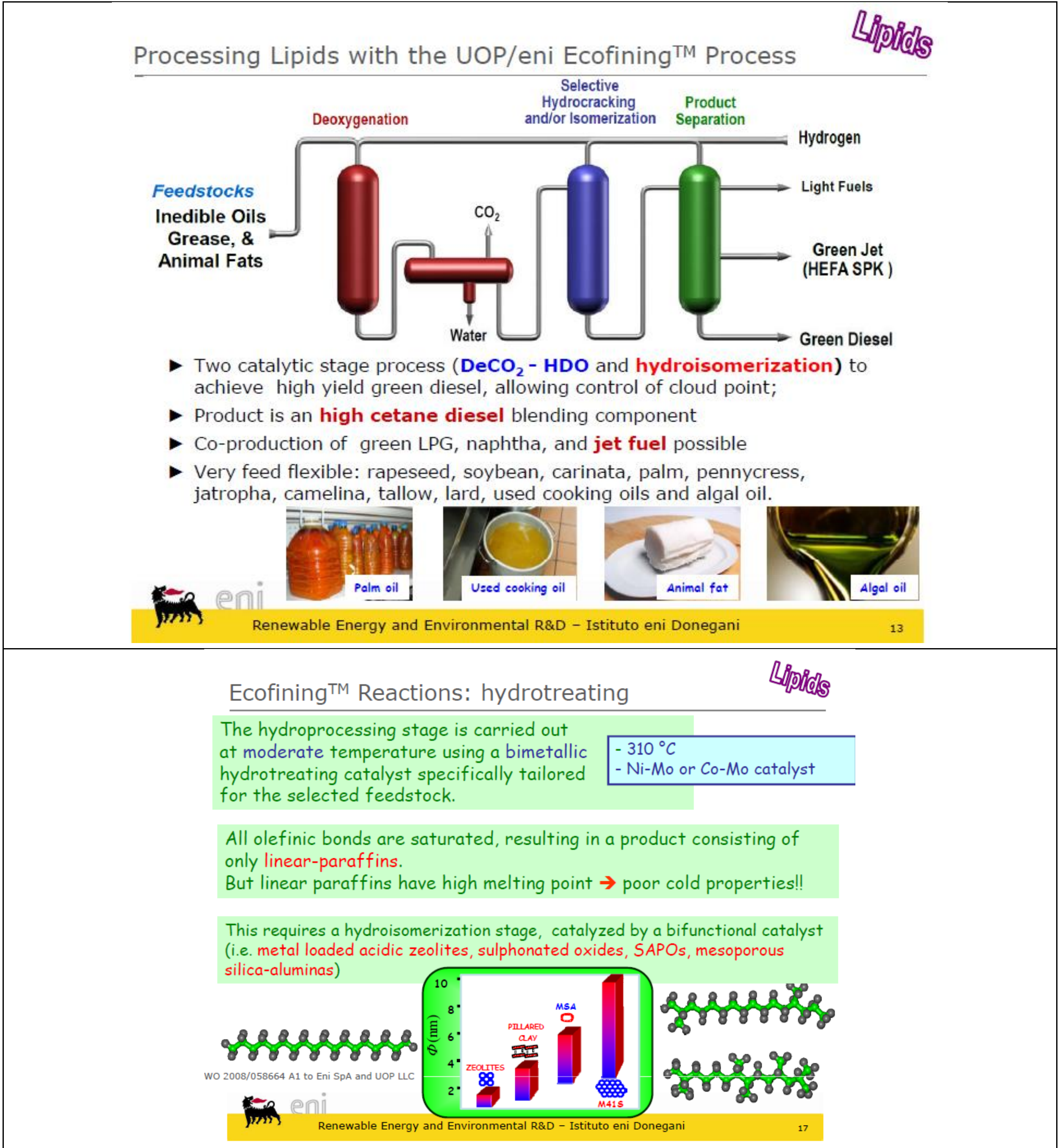
1.2.2 HEFA SPK

A second route, **D7566 Annex A2,** proposed by several licensors (Neste Oil / NExBTL process, UOP-ENI /Ecofining process, Axens / Vegan process ,…), based on oleagineous vegetable oils, animal fats, Used Cooking Oils (UCO) or lipids from microalgae, is called **Hydroprocessed Esters and Fatty Acids / HEFA-SPK, and certified in 2011.**

HEFA is based on the HVO technology developped for biodiesel production, but partially or mainly dedicated to bioful production. The HVO technology may use materials that can be in competition with food such as vegetable oils from rapeseed, soja, palm or sunflower to produce biodiesel to be used for road and of off-road transportation, for marine and river use or for oil heating application. The HEFA technology is similar to the HVO, but the term HEFA is dedicated to HVO application for aircrafts. HEFA will preferably use raw materials that do not compete with food, such oils from camelina, jathropha, halophytes, Used Cooking Oils (UCO), animal fats, or possibly in the future lipids extracted from microalgae.

HEFA pathways is depicted in Figure 5 for the UOP Ecofining process. Other similar processes have also been developped and comercialized, such as the NExtBTL process from Neste or the Vegan process from Axens. The oils or triclycerides (vegetable oils, used cooking oils, animal fats or oil extracted from microalgae) are firstly deoxygenated under hydrogen at a moderate temperature (close to 300°C) and pressure, and then partially hydrocracked/hydroisomerized to meet the final fuel specifications, especially for the cold flow properties. The two hydrotreatment steps may either take place in the same reactor with at least two catalyst beds or in two different reactors. This last configuration is preferred for biojet fuel production to enhance the hydroisomerization catalyst activity and to optimize the cold flow properties such as the freezing point as depicted in more details in Figure 5. The final product chemical structure is quite similar to the FT product.

But SPK fuels lack of aromatic hydrocarbons (aromatic free) which contribute to the swelling of seal o-rings and other elastomeric seals, so blends with conventional fuels that contain them are required for qualification. That is the main reason why **FT-SPK and HEFA-SPK are limited up to 50 % maximum in conventional fossil jet fuel.** This is also the reason why a content higher than 8% aromatics is required in the ASTM D7566 standard (D7566, table 1, part 2).



[Perego, Feb. 2015]

Figure 5: Ecofining (UOP/ENI) HEFA process

1.2.3 Green Diesel/HFP HEFA

Another possibility is the so-called **Green diesel, recently renamed HighFreezing Point (HFP) HEFA.** Green diesel or HFP HEFA is made from materials, such as recycled animal fats, UCO and inedible oils such as camelina or jathropha.Green diesel /HFP HFA (UOP/Boeing) is using HEFA current industrial units producing renewable diesel and using either the light diesel cut or the full diesel cut (it is not yet very clear) as a bio jet fuel, blended with fossil jet fuel, at low concentration.
The intention should be **to directly incorporate a few percent, up to 5% v/v or even less, 2-3% v/v,** HEFA atmospheric distillate in Jet A1 through their direct integration in annexe 1 of ASTM D1655 (Jet A/A1) and not to add another annex to ASTM D7566 as for all the other biojet fuels. A consequence is that it will be treated by ASTM D02.J0.J01 Sub-Committee in place of ASTM D02.J0.J06 Sub-Committee for the other biojet fuels, with the same specification level as for Jet A/JetA1: JFTOT performed at 275°C and triglycerides linitially ower than 5 mg/kg, and today lower than 50 mg/kg after ASTM D1655 recent modification.
he advantage is that it does not require specific investments because it can use existing HEFA production facilities and no new annex is needed to add to ASTM D7566.
The drawback is the possible poor cold flow properties of such a product, especially when HEFA units are producing summer grade diesel and the lack of knowledge of blending rules of such product with fossil jet fuel. It is not sure that even 5% is achievable, especially in summer season when the HEFA units are producing diesel with relatively high cold flow properties. Boeing tested a 15% Green dieel blend with the ecodemonstrator in 2014, but probably with a wintergrade diesel. Cold properties remains an important issue and the lack of knowledge on blending rules for cold flow properties between fossil and synthetic fuels make the prediction of freezing point of the final commercial fuel difficult to make.
In 2016/2017 possible production of HEFA and HFP HEFA could be available from several existing ,or to be in production, units: REG, Neste, Diamond Green, AltAir ENI, UPM Bioverno or in2017 from Total, in Asia, Europe and the USA.
ASTM qualification: from latest ASTM D02 December 2015 meeting news, a research report should be submitted to manufacturers at the end of 2016 and presented to ASTM D02 members in its June 2016 meeting. But there are no news from this last ASTM D02 meeting. **A such, qualification should not be completed before 2017.**

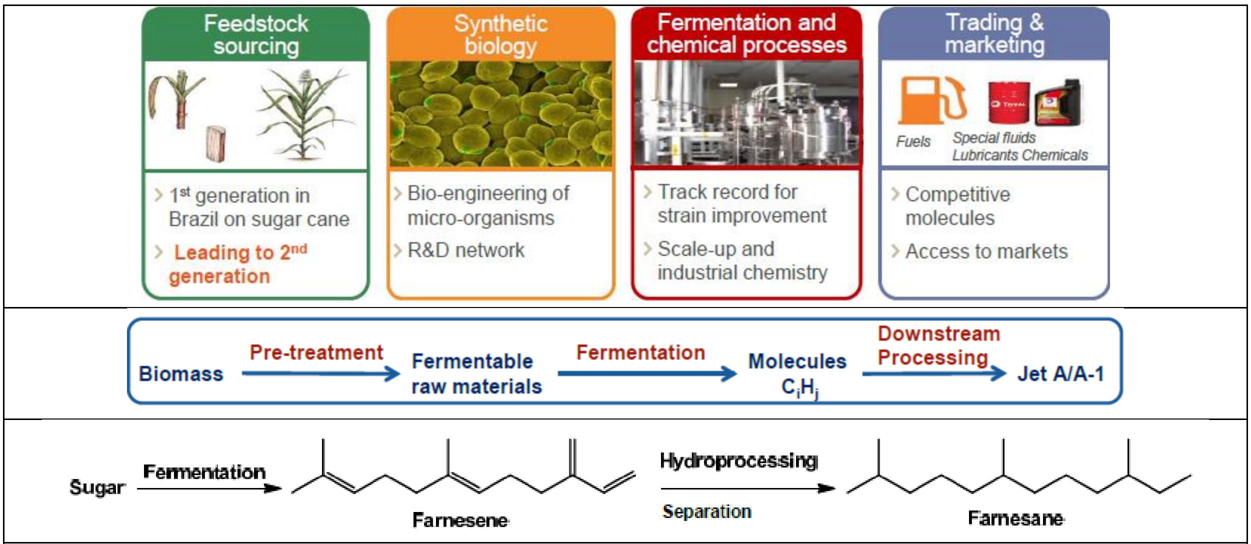
1.2.4 DSHC/SIP

The third route, **D7566 Annex A3,** developped by Total/Amyris called **SIP**, has been recently **approved in june 2014.**. Formerly called **DSHC (Direct-Sugar-to-HydroCarbon**), it was recently renamed **SIP (Synthesized Iso-paraffins from Fermented Hydroprocessed Sugar**). Amyris has a biorefinery in Brazil's São Paulo province that is capable of producing up to 50 000 m^3 of farnesene a year and the company has yet been supplying its renewable diesel product to metropolitan areas in Brazil.

The process is based on fermentation of lignocellulosic sugars process to isoprenoids. Amyris has developed a technology capable of producing a high quality diesel fuel or chemicals from a 15-carbon isoprenoid called farnesene. In the mevalonate pathway Acetyl-CoA is converted into isopentenyl pyrophosphate (IPP), which is further transformed into farnesenyl pyrophosphate (FPP) and into C15 isoprenoids. The process was initially developped from corn and sugar cane. The process is shown on Figure 6. If the feestock consists in sugars, it can be directly treated in the synthetic biologic step with mico-organisms and fermentation reaction, selectively transforming the carbohydrates to β-farnesene, an iso–C15 tetra-olefin (a sesquiterpene molecule 7,11-dimethyl-3-methylene-1,6,10-dodecatriene, chemical formula $C_{15}H_{24}$). Then the olefin is mildly hydrotreated to the corresponding iso-paraffin called farnesane (2,6,10-trimethyldodecane, chemical formula C15H32) that can be directly used as a base jet fuel component. If the feedstock is the full biomass, a pretreatment step is mandatory to separate the cellulose and hemicellulose from the lignin. Then the cellulose (as it is the case for the 2nd generation ethanol plants) is transformed to sugars through hydrolysis, and sugars are converted through fermentation to farnesene.

Farnesene has also a lot of valuable applications for cosmetics, drugs, chemicals and solvents. With a density of 0.77, a kinematic viscosity of 2.325 mm^2/s and a flash point of 110°C for pure farnesane, SIP characteristics are globally corresponding to FT-SPK and HEFA-SPK, but with the main difference that it is an almost pure molecule and not a complex mixture of normal and isoparaffins.

SIP blends are allowed with a limitation up to 10% in conventional jet fuel because it is almost corresponding to a pure chemical compound (98% farnesane) and not to a complex mixture of hydrocabons with a continuous distillation curve, as it is the case for any conventionnal or non conventional fossil jet fuel, or most of the alternative jet fuels.



[Marchand, Oct. 2014]

Figure 6: Amyris/TOTAL SIP ASTM Certified route

Because of the lack of aromatics in the renewable paraffinic type jet fuels from the above processes, there are also other processes that produce synthesized kerosene-containing aromatics, such as Synthesized Kerosene Aromatic or SKA jet fuels or jet fuels obtained from the thermal conversion of biomass with, or without catalyst, and then hydrotreated. Some of these new renewable jet fuels are being evaluated for qualification that may support longer term goals of producing fully synthetic replacement fuels that could be used without blending.

1.2.5 FT-SPK/A

A fourth route, **ASTM D7566 Annex 4, FT-SPK/A,** (FT-SPK with Aromatics) **was added to ASTM D7566 on November 1, 2015**. FT-SPK/A is corresponding to a FT SPK base with the addition of alkylated mono-aromatics with non-petroleum derived light mono-aromatics with FT olefins (Sasol). The maximum allowed amount of FT-SPK/A is identical to FT-SPK and HEFA SPK at 50%vol. If this route is currently only based on fossil ressources such a coal, it could be possible in the future to produce biobased light aromatics (i.e. with the Annelotach process producing mono-aromatics (BTX) from biomasss through a dedicated catalytic pyrolysis or from catalytic pyrolysis (i.e. RTI) or from hydropyrolysis (i.e. GTI IH2 process) with alkylation of mono-aromatics with light olefins from BtL. The composition of this alternative jet fuel is defined in table A.4.2 of ASTM D7566 with a maximum of 15% cycloparaffins (within the range of typical refined jet fuel) and a maximum of 20 wt% aromatics, resulting in a n-paraffin plus iso-paraffin content higher than 65 wt%. **This composition is not very different from a typical petroleum jet fuel**.

1.2.6 ATJ-SPK (from isobutanol)

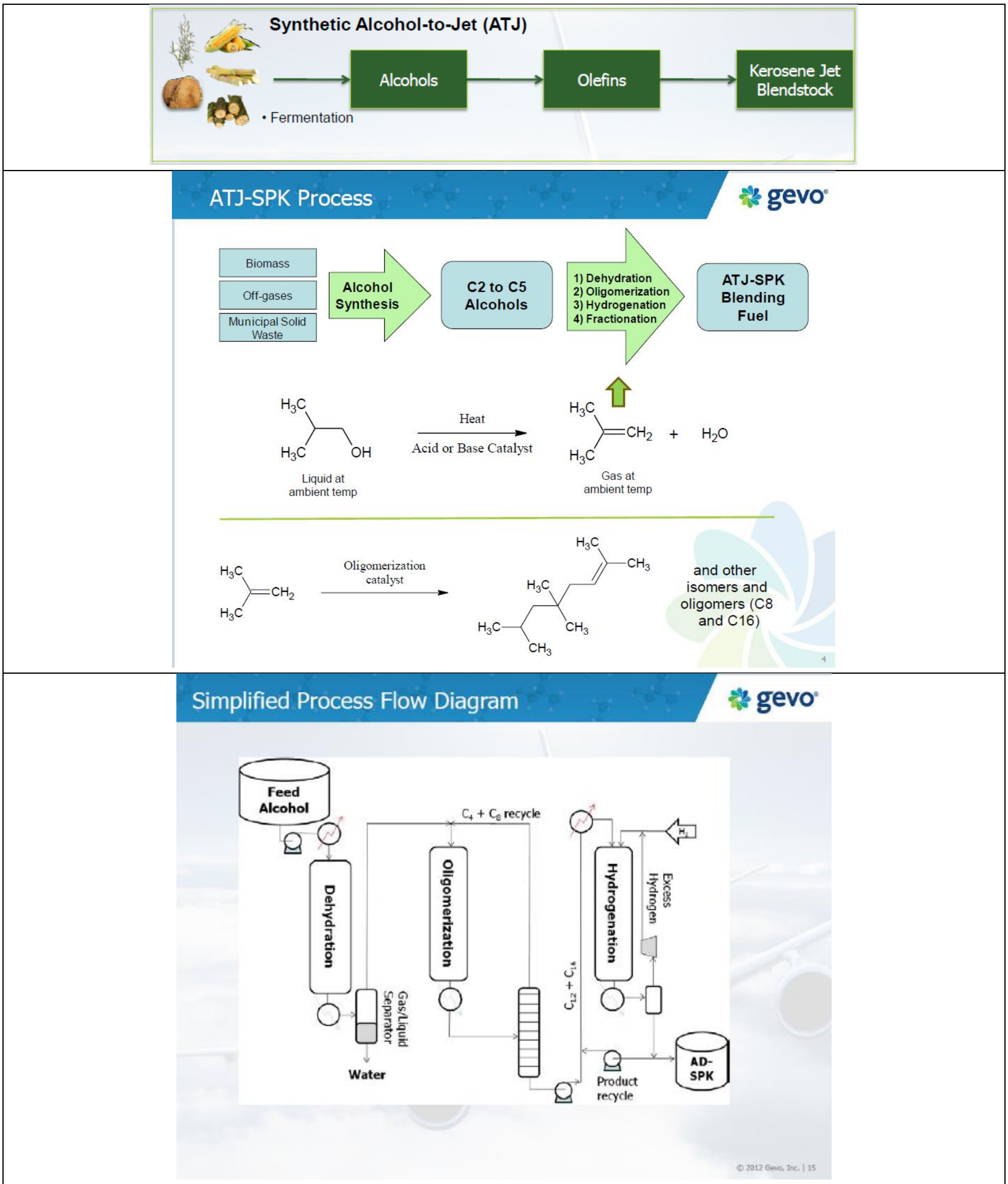
A fifth route, is the **ATJ –SPK** (Alcohol to Jet Synthesized Paraffinic Kerosene) route.
For these pathways, alcohols may be either directly obtained from sugar fermentation or from cellulose / hemicelulose hydrolysis to sugar, followed by sugar fermentation to alcohols or also obtained from industrial gas fermentation (Figure 7). There are then dehydrated to the corresponding olefin and the olefins can be oligomerized into jet fuel. Nevertheless only the isobutanol route is certified.

[Airbus]

Figure 7: Detailed steps of Alcohol-to-Jet pathway

In last year the most advanced route, close to being certified, was the one proposed by Gevo, from fermented isobutanol to iso-C12 and iso-C16 paraffins. In June 2015, the ATJ-SPK data report was completed for specification data, fit for purpose testing, rig testing and engine testing and aircraft testing on isobutanol, with over 100,000 gallons of ATJ-SPK blend produced and a Gevo demo scale facility in Silsbee, Texas, that has been operating in continuous mode for the past 3 years. The process was at ASTM Step 7 level (on 9) for OEM engineering review**. It was completed and very recently approved on April 15th, 2016, and added to ASTM D7566: Annex A5 ASTM D7566**

ATJ-SPK, Gevo pathway is shown in Figure 8. It consists of a primary fermentation step from sugars. On the full biomass a preliminary pretreatment is necessary as for 2nd generation ethanol and the SIP route, separating cellulose/hemicellulose from the lignin and hydrolyzing cellulose or hemicellulose to sugars. **This important step is not yet demonstrated and probaly need further R&D efforts and support.** Then sugars are transformed to alcohols (C2-C5) through fermentation. The alcohol (i.e. isobutanol) is then deshydrated (deshydratation step) under acid catalyst to the corresponding olefin (isobutene) and the olefin is catalytically (acid catalyst) oligomerized (oligomerization step on Figure 8) to longer chain olefin oligomers (dimers, trimers tetramers,…) to produce liquid longer chain iso-olefins and then hydrotreated (dehydrogenation final step on Figure 8) to the corresponding longer chain iso-paraffins to produce biofuels in the jet fuel and/or diesel range (refer to Figure 8). The 1st step dehydratation is known for ethanol and is at industrial level. Butanol can also be dehydrated to butene The 2nd step, light olefin oligomerization + hydrotreatment process is yet well known in the fossil refining industry and is at commercial level with several process licensors.



[Johnston, June 2013], [Johnston, June 2015]

Figure 8: Gevo Isobutanol process

1.2.7 HDCJ/HPO

Another route**, the Hydrotreated Depolimerized Cellulosic Jet, also called HDCJ[3] route (KiOR) was supposed to be approved in 2014,** but the current difficulties and bankrucy of KiOR end of 2014 could make the approval uncertain. It is based on a direct catalytic craking of the biomass to bio-oil, called BFCC (Biomass Fluid Catalytic Cracking), similar to the well known FCC process used in many refineries, but adapted to solid biomass, and followed by hydrotreatment (upgrading) of the bio-oil to road and aviation bio-fuels, as shown on Figure 9. The obtained bioproducts after hydrotreatment are mainly made of aromatics and cycloparaffins, with a low normal and iso-paraffin content without a final hydrocracking step, and looks like SKA products.

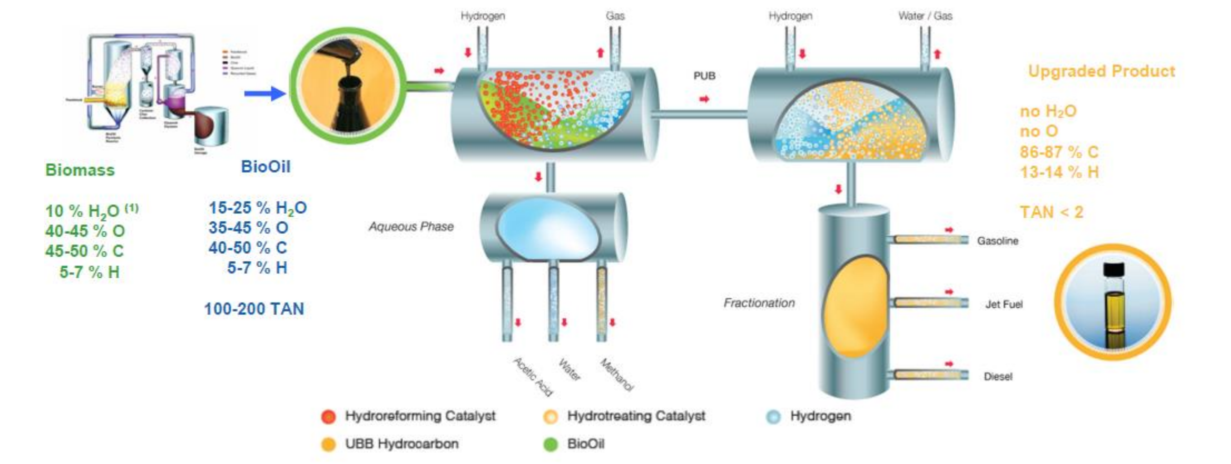
[Loescher, Sept. 2013]

Figure 9: HDCJ/KiOR two-step process

Hydrogenated Pyrolysis Oil (HPO), is a similar route to produce road biofuel and biojet fuel by replacing the BFCC primary liquefaction by fast pyrolyis of lignocellulosic biomass to bio-oil, followed by bio-oil dedicated multistep hydrotreatment / hydrocracking as shown on Figure 10. **HPO**

[3] Hydrotreated Depolymerized Cellulosic Jet though Direct Catalytic Cracking of Biomass and Hydrotreating of the obtained bio-oil

processes may also be considered as an alternate route to KiOR process and another possible source of HDCJ. But since all these processes are still at the R&D level**, an ASTM qualification is not scheduled in the near future.** Products are similar to HDCJ products but the use of an hydrocracking step at the end of the pathway makes possible the production of biofuels with a chemical structure similar to fossil fuels and corresponding to a blend of normal and isoparaffins, mono cycloparaffins and mono-aromatics for the biojet fuel fraction, fully compatible with commercial jet fuel specification ASTM D1655.



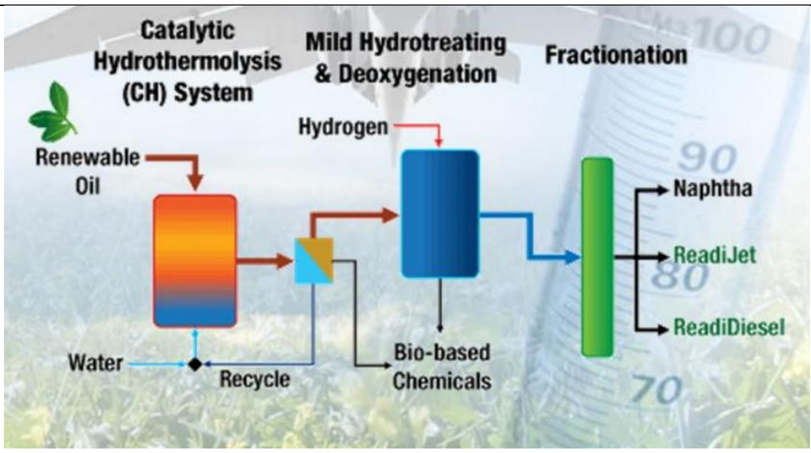
[IFPEN, 2015]

Figure 10: Typical Fast Pyrolysis with 2 steps upgrading of bio-oil to biofuels

1.2.8 CHJ

Another route is also under the ASTM qualification process through an Hydrothermal Conversion, **CH, now called CHJ for Catalytic Hydrothermolysis Jet or Catalytic Hydrothermolysis of lipids** (from plant or vegetable oils or algae) to biokerosene (ARA, paraffins, aromatics and naphthenes). It uses the same feedstocks as for the HEFA processes. This route is developed by ARA (Applied Research Associates) with CLG (Chevron Lummus Global) and the biojet fuel is known under the brand name **ReadiJet**™. The process is depicted in Figure 11. It uses water at high temperature with catalyst and pressure to both crack and cyclise plant/vegetable or algal oils to an intermediate biocrude (catalytic hydrothermolysis). The biocrude is then upgraded and hydroprocessed through CLG's ISOCONVERSION catalysts into on-specification, finished drop-in fuels (naphtha, jet fuel and diesel) that are, as for the previous HPO process, fungible with fossil fuels and nearly chemically identical to petroleum derived fuels.

ARA presented its process to ASTM D02 in last December. The biojetfuel is now called CHJ. The process is called Biofuels IsoConversion or BIC with a Catalytic Hydrothermolysis converion step, followed by an Iso-Conversion (hydrotreatement CLG). The biojet mainly consists of $C_{10}H_{22}$ to C_{14}-H_{30} HC chains, corresponding to a high flash point jet (Otan F-44 type).Studies are now completed and will be submitted to ASTM D02 ballot in order to submit a sixth annex to ASTM D02 with up to 50% in Jet A/A1. **At June 2016 ASTM D02 meeting the process was yet under validation and this pathway will be probably not completed before 2017.**



[Coppola, 2013]

Figure 11: ReadiJet ARA/CLG process

Other hydrothermal processes are at laboratory, or pilot plant level, using a primary conversion of the full ligno-cellulosic biomass though hydrothermal conversion, with or without catalyst, to produce a biocrude with a very low water. The biocude is considered to be easier to be upgraded than fast pyrolysis bio-oil but the process need to be demonstrated at industrial level. These hydrothermal routes from lignocellulosic biomass should produce a biojet fuel fungible and chemically similar to fossil jet fuel too.

1.2.9 ATJ-SPK (from isobutene)

An first alternate route to the yet certified ATJ-SPK (Gevo, Isobutanol) route has been developed by Global BioEnergies (GBE) process, with a quite similar pathway. GBE presented its process at the D02 ASTM meeting in December 2015. It is based on a route quite similar to Gevo, but with a direct fermentation of sugar (glucose or saccharose) in gas phase with a gas purification step to isobutene, in place of isobutanol for Gevo. Isobutene is then oligomerized and hydrogenated (this step should be identical to Gevo'one) to produce a C12 and C16 isoparaffins synthesized jet fuel (refer to Figure 12). The interest of this direct synthesis of the olefins is that it does not require the alcohol deshydratation step with only one purification step.

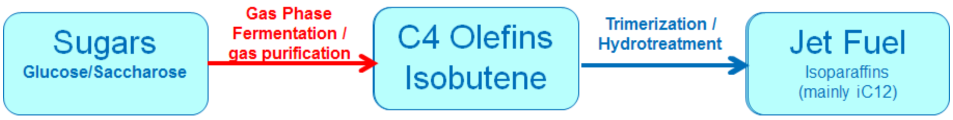


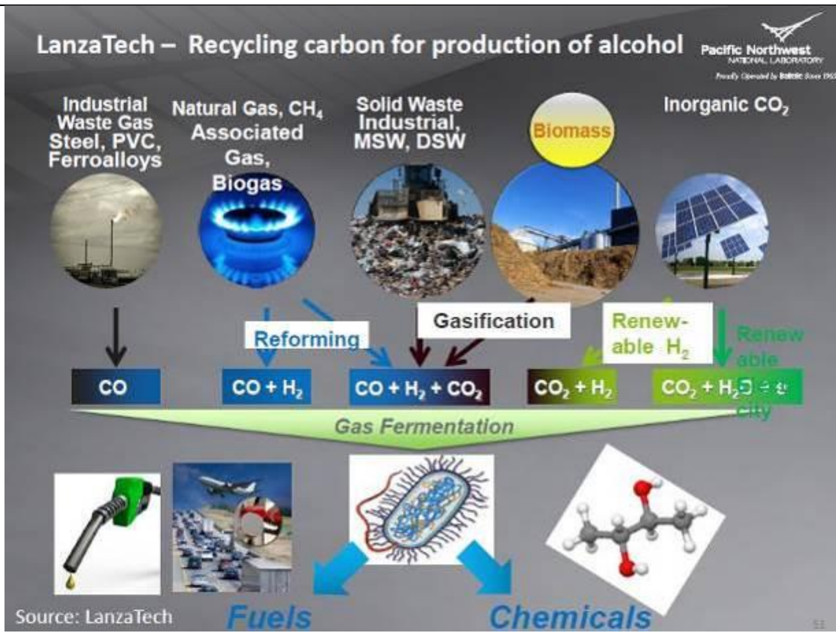
Figure 12: Global Bioenergies route through Isobutene

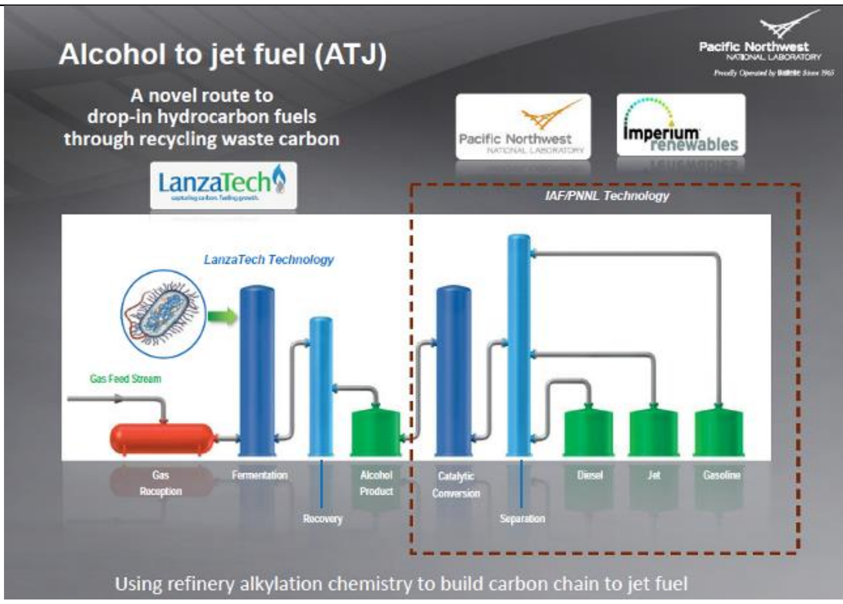
GBE joined the German Aireg initiative in September 2015 to push the jet fuel application of its isobutene process. **GBE wishes to start the ASTM qualification procedure** (annouced in December 2015 ASTM D02 meeting). But the creation of a dedicated working group is probably necessary, even if the experience of the ATJ-SPK, Gevo pathway can be used to save time since both biojet fuels should be quite similar.

1.2.10 ATJ-SKA (from CO rich industrial waste gas)

An second alternate route yet under development / certification is the ATJ-SKA pathway to synthesized kerosene with aromatics, through industrial waste gas, rich in CO, such as from steel, PVC or ferroalloy industry, fermentation to alcohols, followed by catalytic conversion and separation to bio-fuel, develpped by Lanzatech + Swedish biofuels.

ATJ-SKA (Figure 13), corresponding to the process route developped by Lanzatech and Swedish biofuels, the pathway is quite similar in its principle, also based on a preliminary fermentation. But it uses industrial waste gas as feedstocks in place of biomass, such as CO, $CO+H_2$ or $CO+CO_2+H_2$, also including methane and H_2S, such as gases from hydrothermal vent on which is based the LanzaTech's proprietary technology with a naturally-occurring micro-organism in the family of acetogens, or gas-fermenting organisms.
Since 2012 a precommercial unit is operational in Shangaï (Baosteel) with a $400m^3$/year ethanol capacity. Very recently Lanzatech and ArcelorMittal in Belgium "*announced a letter of intent to construct Europe's first-ever commercial scale production facility to create bioethanol from waste gases produced during the steelmaking process. Construction of the $96M million flagship pilot project, which will be located at ArcelorMittal's steel plant in Ghent, Belgium, is anticipated to commence later this year, with bioethanol production expected to start mid-2017. Construction will be in two phases, with phase one providing an initial capacity of 16,000 tons of ethanol per annum by mid-2017 and phase two, which will be completed in 2018, bringing the total capacity to 47,000 tons of ethanol per annum*."
But at this time only the ethanol production from industrial steel gas rich in CO is demonstrated, but not the final conversion to biojet fuel and **the date of the ATJ-SKA qualification is not known, without news from qualification process in December 2015 as well as from June 2016 ATSM D02 meeting**.





[Holladay, Nov.14, 2014]

Figure 13: Lanzatech / Swedisch biofuels process from industrial gases process

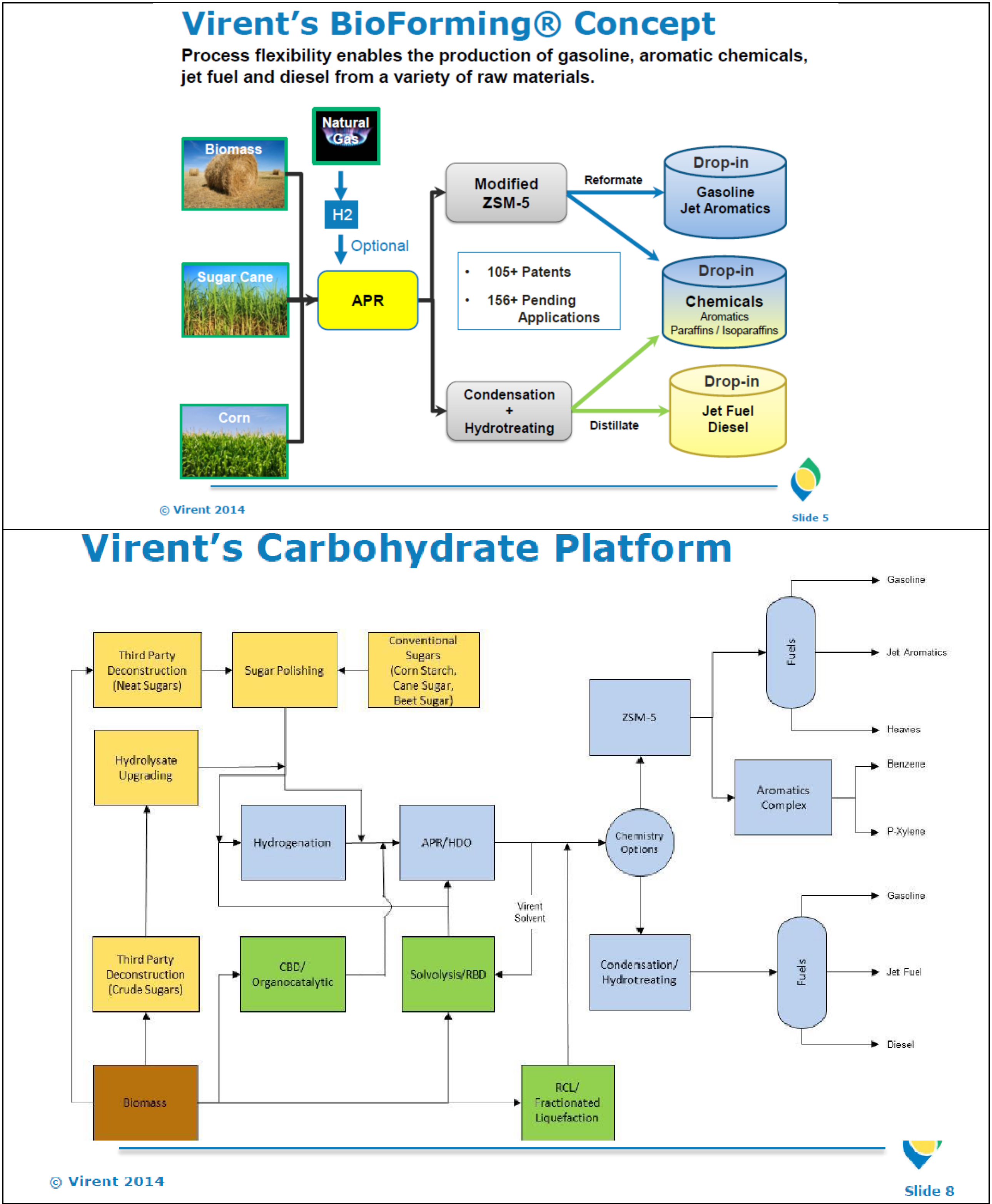
1.2.11 HDO-SAK and HDO-SK/CPK

Virent and Shell, with other partners, are also developing a biofuel process with their Bioforming® process, through the Aqueous Phase Reforming, or APR (refer to Figure 14), of cellulosic biomass or sugars, either followed by:

- Aromatics processing: a cracking process on a modified ZSM5 zeolite to produce an aromatic rich reformate stream, called Bio-Formate suitable for producing biogasoline (BioForm™ Gasoline) and biojet (BioForm™ Jet Fuel), called **Hydro-DeOxygenated Aromatic Synthetized Kerosene** or **HDO-SAK that could be blended up to 25% with fossil jet fuel,** as well as several chemical products: refer to upper part of each scheme of Figure 14 or,

- Distillates processing: a condensation + hydrotreating process to produce jet fuel (BioForm™ Jet Fuel) and diesel (BioForm™ Diesel) (refer to downer part of each schemes of Figure 14). The **Hydro-DeOxygenated Synthetized Kerosene, initially** called **HDO SK, was recently renamed CPK (Cyclo-Paraffinic Kerosene),** because of its high cycloparaffin content. It is at ASTM steps 4/1 and **could be approved by ASTM in the near /medium future and probably blended with fossil fuel up to 50%.** HDO-SK/CPK has about the same type of hydrocarbons that are present in fossil jet fuels with a broad carbon number range, but with a quite different chemical family ratio: it has a lower paraffin content, a much higher cyclo-paraffin and a much lower aromatic content. Typical composition (wt%) is : 8% n-paraffins, 11% iso-paraffins, 63% mono-cycloparaffins, 18% di-cycloparaffins and less than 1% aromatics and naptheno-aromatics. Carbon number is in the 8 to 17 range, corresponding about 160- to 260°C distillation range. **This makes CPK a very specific product** with a chemical composition (about 80% of cycloparaffins centered on monocycles) far away from most of the other routes.

Virent has built and operates two small demonstration units at its headquarters in Madison, Wisconsin. The first was commissioned in 2010 and is capable of producing up to 10,000 gallons per year (25 tons per year of Bio-Formate capacity) of an aromatic rich reformate stream suitable for biogasoline, biojet (HDO-SAK) and several chemical products, with thousands of hours of operating experience. The second was commissioned in 2013 and is capable of producing up to 5,000 gallons per year (15 tons per year) of distillate product stream suitable for biodiesel, biojet (HDO-SK/CPK) and additional chemical markets. Virent is producing its in-house proprietary catalysts.



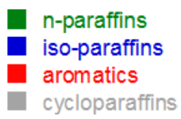
[Holladay, Nov. 5, 2014], [Cortright, July 2014]

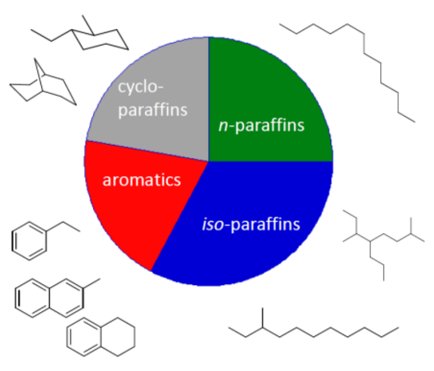
Figure 14: Virent/Shell Bioforming® based process

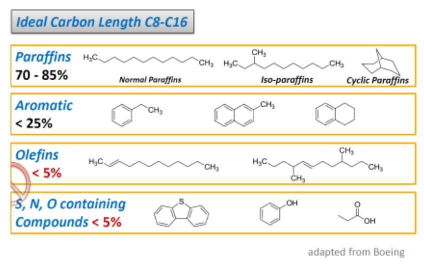
1.3 Highlights on alternative aviation fuel certification

1.3.1 Certified, or close to be certified, biojet fuels

Typically fossil jet fuels consist mainly in C8-C16 (Carbon n°) saturates (80-90%) and aromatics (10-20%), with an olefins content in the 1 to 2% range and napthalene content in the 0-2.5% range. Sulfur content is in the 0 to 3000 ppm range with an average value close to 500-700 ppm. Jet fuel chemical composition is related to its specifications: light aromatics have excellent cold flow properties but a very bad combustion behaviour. Nevertheless a minimum content of aromatic is needed to counterbalance the negative impact of paraffins on ring (especially synthetic rubber) compatibility and to enssure that seals may swell (this is the reason why a minimum of 8% aromatics is required in ASTM D7566 in jet fuel and alternative jet fuel blends). On the contrary normal-paraffin exhibit excellent combustion properties with very bad cold flow properties. Iso-paraffins exhibit both excellent combustion and cold flow properties properties. Naphthenes (cycloparaffins) have intermediate properties. An illustratrion of jet fuel composition is given in Figure 15 and illustrate an typical jet fuel composition.







Legend	Typical petroleum Jet A or JP-8	Jet A or JP-8 composition
[Holladay, June 2015]		

Figure 15: Jet Fuel required characteristics

Unfortunately the chemical composition, as well as the boiling temperature distribution, of the bio-jet fuels are not always close to this typical composition (Figure 16). Beyond the swelling trouble with jet fuel only based on paraffins/iso-paraffins, this is the reason why, bio-jet fuel cannot be incorporated up to 100% in the commercial jet fuel pool, at least for current ASTM D4054 qualified routes.

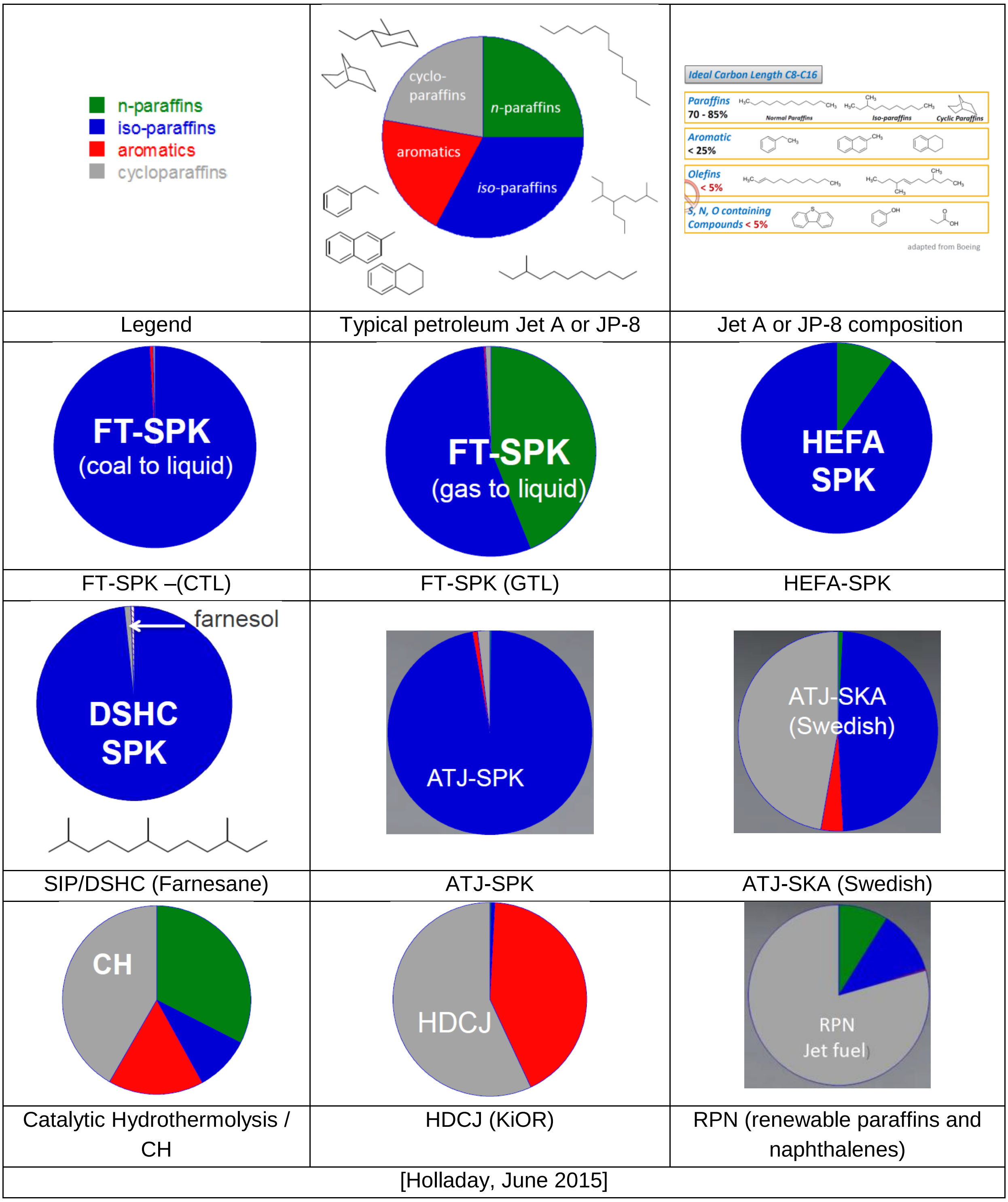


Figure 16: Renewable Jet fuel characteristics and pathways

Today **5 ASTM certified routes are summarized** in Table 1: **FT-SPK, HEFA-SPK, SIP from hydroprocessed fermented sugar, FT-SPK/A and ATJ-SPK through the isobutanol intermediate** production and a few more should/could be certified in the short term before the end of 2017.

Table 1: ASTM D4054: qualified routes in April 2016

Approach	Max blend vol. %	Type of molecules	Annex D7566	Date of approval	Main players and feedstock
Gasification & FT (FT-SPK)	50	iP	A1	2009	Fulcrum, RedRock, Axens (BioTfuel Demo. In France),.. from lignocellulosic biomass or waste
Hydroprocessed lipids (HEFA-SPK)	50	iP	A2	2011	Neste, UOP-ENI, Axens,… from vegetable oil mainly to produce biodiesel, very limited production of biojet fuel (only AltAir in California) from non edible oil, UCO or animal fats
Biochem sugars (HFS-SIP SPK)	10	Iso C15	A3	June 2014	Amyris/Total from sugar currently
FT-SPK/A	*50*	*iP with alkyl benzenes*	*A4*	*Nov. 2015*	*Sasol, but currently from natural gas or coal, not from biomass*
Isobutanol conversion (ATJ-SPK)	30	IC12 and iC16	A5	April 2016	Gevo from sugar currently

All these yet certified pathways are based on isoparaffin kerosene with the exception of the fourth one based on isoparaffin kerosene plus the addition of alkylated benzene.The composition of this alternative jet fuel is defined in ASTM D7566 with a maximum of 15% cycloparaffin (within the range of typical refined jet fuel), a maximum of 20 wt% aromatics resulting in a paraffin content higher than 65 wt%, with mainly iso-paraffins, and a very low n paraffin content, typically not more than a few %. This composition is not very different from a typical petroleum jet fuel and it show a continouos distillation curve as for petroleum based jet fuels. It can be added up to 50% by volume in the final jet fuel product.

The first two certified routes, FT-SPK and HEFA-SPK, have a very similar chemical structure and are basically made of a continuous repartition of isoparaffins, within the jet fuel typical boiling range, resulting in a continuous distillation curve. These alternative jet fuels can be mixed up to 50% by volume. The 3rd and the 5th routes are only based on isoparaffins, but are not corresponding to a statistical distribution of molecules, as for the 3 other routes. SIP is mainly based on one iso C16 molecule called farnesane with a t least 97 wt%, almost corresponding to a pure molecule. That is the reason why it can be blend up to 10% by volume. ATJ-SPK is corresponding to a mixture of iso C12 and iso C16 with a non continuous distillation curve too. That is probably the reason why it can be blend up to 30% by volume, and not up to 50% as initially proposed by Gevo. Currently these two routes are based on fermented sugar, but not industrually developped on cellulosic biomass (biomass pre-treatment to separate sugars from lignin). **This important step is not yet demonstrated and probaly need further R&D efforts and support.**

From these routes **none are at industrial production level, with the exception of HEFA**.

These other routes closed to the final ASTM qualification are gatherd in Table 2.

Green diesel, recently renamed HighFreezing Point (HFP) HEFA. The intention should be to directly incorporate a few percent (v/v) HEFA distillate in Jet A1 through their direct integration in annexe 1 of ASTM D1655 (Jet A/A1) and not to add another annex to ASTM D7566 as for all the other biojet fuels. Qualification: from latest ASTM D02 December 2015 meeting news, a research report should be submitted to manufacturers at the end of 2016. This report should be presented to ASTM D02 members in its next June 2016 meeting. Qualification should not be completed before end of 2016, or beginning of 2017.

Another route is also close to the finalization of the ASTM qualification process through an **Hydrothermal Conversion: CH, now called CHJ for Catalytic Hydrothermolysis Jet or Catalytic Hydrothermolysis of lipids** (from plant or vegetable oils or algae) to biokerosene (ARA, paraffins, aromatics and naphthenes). The biojet mainly consists in $C_{10}H_{22}$ to C_{14}-H_{30} HC chains and the chemical structure should be similar to petroleum derived jet fuel. Studies are now completed and will be submitted to ASTM D02 ballot in order to submit a sixth annex to ASTM D02 with up to 50% in Jet A/A1 (could be in late 2016 or more probably in2017).

Other pathways are still under the ASTM qualification process at a less advanced stage. We can cite:

- Hydrotreated Depolimerized Cellulosic Jet, also called **HDCJ** route (KiOR) was supposed to be approved in 2014, but the current difficulties and bankrucy of KiOR end of 2014 could make the approval uncertain. HPO processes may also be considered as an alternate route to KiOR process and another possible source of HDCJ. But since all these processes are still at the R&D level, an ASTM qualification is not scheduled in the near future.
- For **ATJ-SKA** corresponding to the process route developped by Lanzatech and Swedish biofuels, the pathway is based on a preliminary fermentation as for ATJ-SPK, but it uses industrial waste gas rich in CO (CO, CO+H_2 or CO+CO_2+H_2), such as from steel, PVC or ferroalloy industry, as a feedstock in place of biomass. Then gas is fermented to alcohols, followed by catalytic conversion and separation, to produce bio-fuel (Lanzatech + Swedish biofuels, paraffins+aromatics). At this time **only the ethanol production from industrial steel gas rich in CO is demonstrated**, **but not the final conversion to biojet fuel** and the date of the ATJ-SKA ASTM qualification is not known.
- Virent and Shell, with other partners, are also developing a biofuel process with their Bioforming® process, through the Aqueous Phase Reforming, or APR of cellulosic biomass or sugars, either followed by a cracking process to produce an aromatic rich reformate stream suitable for producing biojet called **Hydro-DeOxygenated Aromatic Synthetized Kerosene or HDO-SAK**, or a condensation plus hydrotreating process to produce jet fuel or an **Hydro-DeOxygenated Synthetized Kerosene** called **HDO SK**, recently **renamed CPK (CycloParaffinic kerosene)**, because of its high cycloparaffin content These route could be approved by ASTM in the near future, but without known date. The CPK is a very specific product with a chemical composition (about 80% of cycloparaffins centered on monocycles) far away from most of the other routes.

Other routes are also under ASTM qualification, but with no recent news (Table 2).

Table 2: ASTM D4054 - routes in progress for qualification in April 2016

Approach	Feedstock	Approval ?
CHJ /ARA-CLG	Lipids	Studies completed, will be submitted to ASTM D02 ballot in order to submit a sixth annex to ASTM D02 with up to 50% in Jet A/A1. Qualification probably not before 2017.
Green Diesel/HFP HEFA	Lipids	Qualification probably not before 2017.
ATJ SKA /Lanzatech	Industrial waste gas, rich in CO	only the ethanol production from industrial steel gas rich in CO is demonstrated, not the final conversion to biojet fuel. Date of ASTM qualification not known.
HDO SAK / HDO SK, recently renamed CPK	Sugars	Virent: ASTM D4054 Steps 4/1 To be approved in 2017 ?
HDCJ (pyrolysis)	Cellulose – biocrude	ASTM qualification not scheduled in the near

		future.
ATJ-SKA	Sugars – alcohols	Byogy, LT, SwB, Vertimass, Poet Qualification ??
ATJ-SPK	expansion Sugars – ethanol / xOH	GranBio, UOP, LT, SwB: Qualification ??
Co-processing	*Biocrude*	*Chevron, BP, Phillips66*
HEFA expansion	*Lipids, renewable diesel*	*In development*

There are even more routes in the pipe, but with a lot of uncertainties to be able to give an idea of the possible range of dates of qualification (Figure 17).

ASTM D7566 qualification activity

	Approach	Feedstock	Notes
In- Process	FT-SPK/A (annex A4)	Cellulose – syngas & alkylation	approved 4Q'15
	ATJ-SPK (annex A5)	Sugars – isobutanol	approved 2Q'16
	CH	Lipids	ARA: Step 3
	HEFA Expansion	Lipids – renewable diesel	R.R. in devel.
	SK/SAK (CCS-APR)	Sugars	Virent: Steps 4/1
	HDCJ (pyrolysis)	Cellulose – biocrude	LanzaTech, UOP
	Co-processing	Biocrude	Chevron, BP, Phillips66
	CATJ-SKA	Sugars – alcohols	Byogy, LT, SwB
			Vertimass, Poet ?
	ATJ-SPK expansion	Sugars – ethanol / xOH	GranBio, UOP, LT, SwB

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ASTM D7566 pipeline

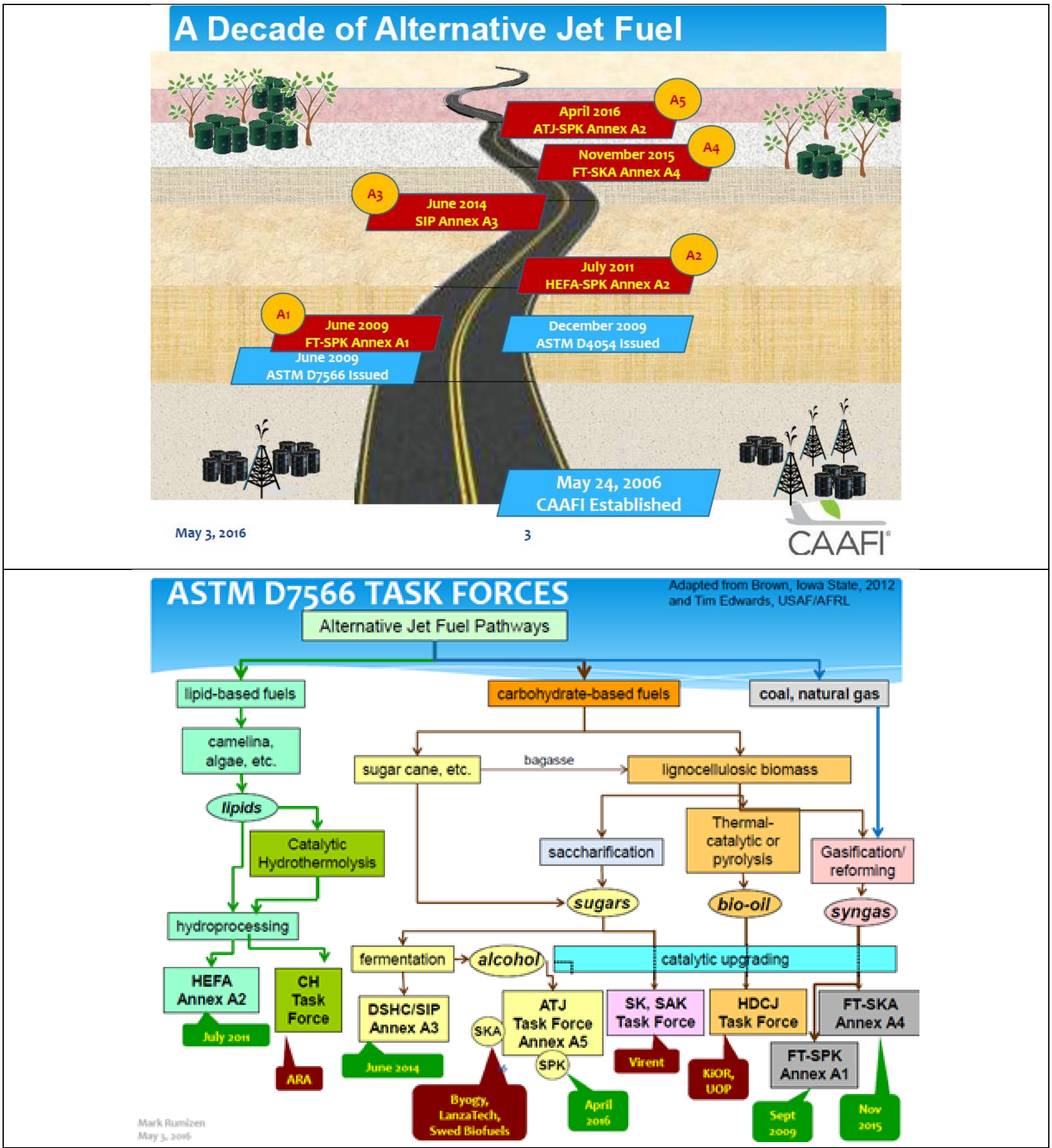
	Approach	Feedstock	Notes
Pre-Pipeline	1) CHyP (syngas, non-FT)	Cellulose	Proton Power
	2) Microbial conversion	Sugars - isobutene	Global Bioenergies
	3) HTL	Cellulose	Algenol, Genifuel, Sapphire
	4) Catalytic HTL	Cellulose	Licella, Muradel, QUT
	5) SBI CGC PICFTR	Lipids - biodiesel	SBI Bioenergy
	6) CCL	Lipids	Tyton
	7) Hydrogenotrophic Conv.	CO2 / Producer Gas	Kiverdi
	8) Cyanobacterial Prod.	CO2	Joule
	9) STG+ GTL	c1-c4 Gas / Syngas	Primus
	10) Acid Deconstruction	Cellulose	Mercurius
	11) Thermal Catalytic Conv.	Cellulose	Shell/CRI/IH2
	12) Thermal Deoxyg.	Lipids	Forge Hydrocarbons
	13) Ionic Liquid Decon.	Cellulose	JBEI, tbd
	14) Metal Catalytic Conversion	Cellulose	Purdue research
	15) Enzymatic Conversion	Lignin	GLBRC & JBEI

6 May 2016 29 CAAFI

[Csonka, April 2016]

Figure 17: Other possible routes in the pipe towards ASTM qualification

For a comprehensive view, all these pathways yet or under ASTM qualification are also reminded in Figure 18.



[Rumizen, May 2016]

Figure 18: ASTM D4054 qualification pathway in 2016

1.3.2 A few examples of potential innovative routes for the future

For the long term there are also very innovative routes such as the Power to Liquid (PtL) and Sun to Liquid (StL) pathways.

This route is addressed in Deliverable 4.4 "Report on compilation, mapping and evaluation of R&D activities in the field of conversion technologies of biogenic feedstock and biomass independent pathways (final report).

Lignin to jet is also another innovative route to produce alternative jet fuels. There is an European FP7 project called Biorefly[4] with the objective to produce biojet from the lignin fraction of the second generation ETOH plant (hydrolysis and fermentation route using the Biochemtex-PROSEA® technology in Italy). Currently this lignin-rich fraction is burned for the process internal need, but it could also be valorized to higher value products, such as aromatics, BTX or biofuels. A first objective of Biorefly is a feasibility study in order to validate and to scale-up data generated from a pilot plant facility in US Chemtex International Sharon center in Ohio (2.5 kg/h lignin capacity) to a demonstration scale, using a novel competitive technology (MOGHI technology[5]) based on the catalytic thermochemical depolymerization with hydrogen of this lignin-rich fraction to a phenolic oil followed by an hydrodeoxygenation/hydrotreatment step and final separation to biofuels and bio-aviation fuel. The main goal is to design and to construct in Italy a demonstration lignin-based biorefinery producing 2000 ton/y alternative jet fuel meeting the Jet A/A1 requirements from the lignin-cake from the 2 G ethanol Beta Renewables plant (Italy). Another objective is also to conduct an environmental assessement of the full route and to study socio-economic impacts, as well as to test the biojet fuel in turbines and engines, including demo flights. The quality of the biojet fuel is not known, but based on the chemical knowledge of lthe structure of lignins, and taking into account the phenolic structure of the intermediate biooil, it should probably consist in a blend of paraffins, naphthenes and aromatics, with a chemical structure probably not to far from HDCJ/HPO route or from Virent HDO SAK jet fuel, as well as also not to far from jet A/A1. ASTM qualification is not foreseen into the project lifetime.

There are a lot of pathways and it is not easy to get a comprehensive view, as well as to try to choose between all these routes for the future.

1.4 Demonstration and commercial flights using biojet fuels and early deployment of commercial biojet fuels

Looking at the complicated production pathways towards renewable fuels issued from a lot of different feedstock and a lot of primary conversion/refining processes in a fast moving world, poses a lot of challenges, with many scientific, technical, environmental and economic issues. All these issues have to be addressed carefully under the statement that future large-scale deployment of alternative aviation fuels shall be realized in a sustainable and economically viable way. To date, the only industrially developed value chain yielding renewable jet fuels depends on biogenic oils (triglycerides), used cooking oils and animal fats as feedstock, through the Hydroprocessed (HEFA) route. **We are still only at the very early commercial stage with a lot of one shot test on commercial or military aircrafts and only a few demo flights on the long term** (from several weeks to one year) since 2011:

- the **burnFAIR project** with the first 6 months A321 flight trial corresponding to 1187 flights using 1560t biojet –fuel by Lufthansa on the Hamburg-Frankfurt-Hamburg route, four times daily, and using a 50/50 blend SPK-HEFA produced by Neste from jatropha and animal fats with fossil jet fuel or,

[4] http://www.biorefly.eu/

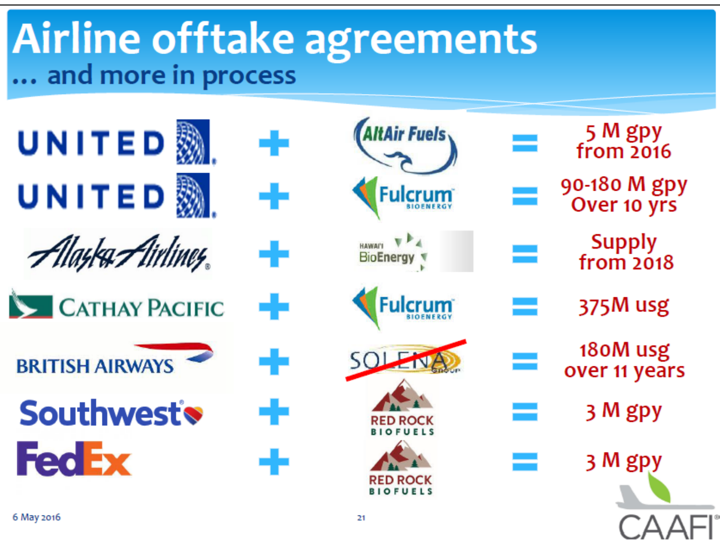
[5] http://www.biochemtex.com/sustainable-chemistry/moghi
The MOGHI project aims at complementing Biochemtex research on conversion of lignocellulosic feedstock, by investigating the possible routes to transform lignin co-product produced at the Crescentino plant, into higher value molecules and/or products: bio-naphtha and relative aromatic derivatives.

- in 2013 KLM used a biojet fuel for their weekly flights from New York to Amsterdam derived from UCO and produced by REG (Renewable Energy Group), formerly Dynamic Fuels), in the United States (Biofining™ process by Syntroleum),
- the **lab'line** demonstration with a flight operated once a week on Friday afternoon from Toulouse Blagnac to Paris Orly by AirFrance on an A321 aircraft using a 10% SIP blend produced by Total / Amyris with 90% and operated from September 2014 to January 2016,
- very recently under the European Union's **Itaka project** at Oslo airport with 80 biofuel KLM flights over five to six weeks using a Cityhopper Embraer E190 operating from Oslo to Amsterdam and also using a 50/50 blend SPK-HEFA (also produced by Neste mainly from camelina) / fossil jet fuel.

All the flights using biojet fuels are gathered in a data base, publicly available on the web, called Biojet Map (refer to chapter 1.5).

In order to decrease commercial risks and to secure biojet fuel production, some of the most advanced US producers, such as AltAir fuels (HEFA), RedRock Biofuels or Fulcrum Energy (FT-SPK) yet signed with airlines rather long term agreement to provide a few million to a few hundred million gallons biojet fuel (Figure 19).

There was a UK Greensky project leaded by Solena , whose objective was to produce fuels from Municipal Waste (MSW) to jet fuel process with London city waste for British Airways. It was stopped because in November 2015, Solena's project has been dropped due to the company's failure to raise the necessary investment to build the plant in light of low oil prices, the company needing $70 per barrel oil prices to be competitive at the scheduled 16 million gallon facility.



[Csonka, April 2016]

Figure 19: Agreement between producers and airlines

We are today in the very early beginning of true commercial flights for the long term. In March 2016 United launched multiple daily Boeing 737 flights from LAX (Los Angeles international airport) a 30% blend of HEFA biofuel produced by AltAir and conventional jet fuel. AltAir Fuels is the first dedicated US production facility for HEFA-SPK fuels in Paramount, CA, starting with a 40 Mgpy initial phase. Synthetic Aternative Jet Fuel (SAJF) is delivered to the LAX fuel farm and F76 military jet fuel is delivered to Navy via 77M gal within the Defense Logistic Agency (DLA) purchase in current fiscal year.

US DPA Program

The Defense Protection Act (DPA) was established in 1950 for the purpose of providing investments in anything America needs, but doesn't have at scale, for national security.
In 2012, the US President and Secretary of the US Navy determined that alternative fuels met this criteria.
The Navy entered into an MOU (Memorandum of Undertstanding) with US DOE and USDA to fund the commercialization of 3 fuel production facilities (RedRock Biofuels, Fulcrum Bioenergy and Emerald Biofuel) with a combined production level of 104M gpy. The agencies jointly funded the program at ~$510M over 3 years, and such funding has been approved by Congress (Figure 20).

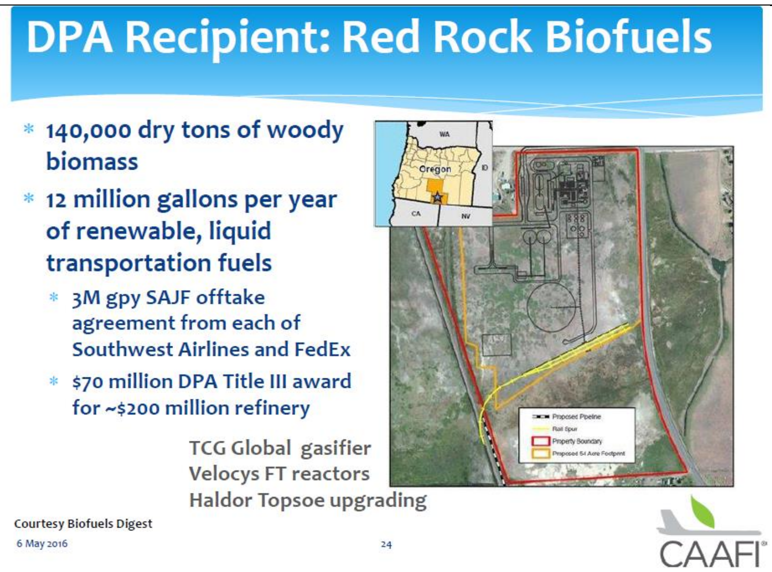
DPA Recipient: RedRock Biofuels (Oregon) with 140,000 dry tons of woody biomass
- Converted into 12 million gallons per year of renewable, liquid transportation fuels
- 3 million gallons per year SAJF offtake agreement from each **of Southwest Airlines and FedEx**
- $70 million DPA Title III award for ~$200 million refinery
    - TCG Global gasifier / TCG Global LLC technology[6] (http://www.tcgenergy.com/)
    - Velocys FT reactors
    - Haldor Topsoe upgrading

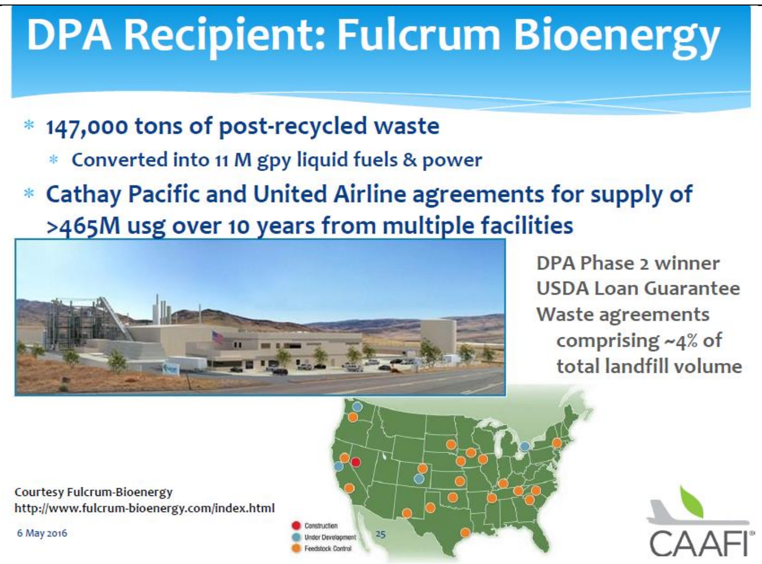
DPA Recipient: Fulcrum Bioenergy (http://www.fulcrum-bioenergy.com/index.html) with 147,000 tons of post-recycled waste
- Converted into 11 million gallons per year liquid fuels & power
- **Cathay Pacific and United Airline agreements** for supply of >465 million gallons over 10 years from multiple facilities
    - DPA Phase 2 winner
    - USDA Loan Guarantee
    - Waste agreements comprising ~4% of total landfill volume

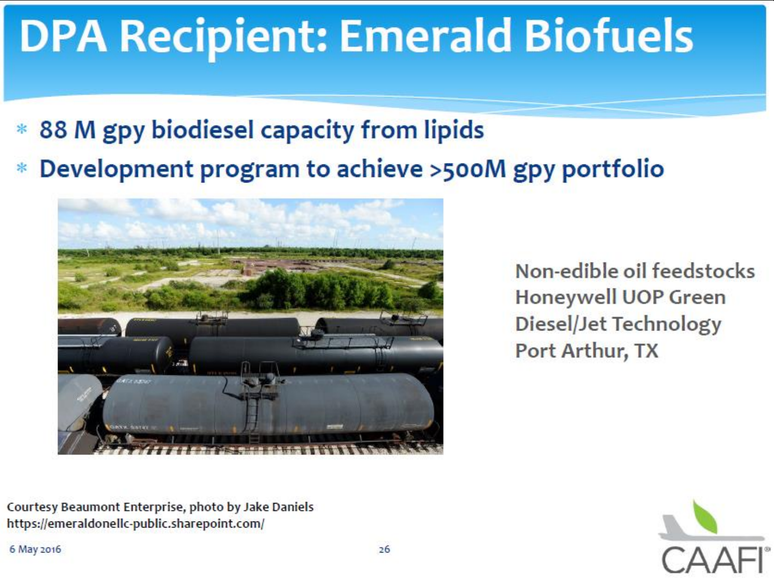
DPA Recipient: Emerald Biofuels (https://emeraldonellc-public.sharepoint.com/) with 88 M gpy biodiesel capacity from lipids
- Development program to achieve >500 million gallons per year portfolio
    - Non-edible oil feedstocks
    - Honeywell UOP Green Diesel/Jet Technology
    - Port Arthur, TX

In the USA (Figure 20) several other entities are engaged in commercial development of existing and soon-to-be qualified pathways and other commercial-scale technology demos to occur in next 12 months.

[6] : TCG designs, builds, sells, owns, and operates gasification plants capable of converting any carbon-containing feedstock such as biomass, coal, petroleum coke, or municipal solid waste into synthesis gas (Syngas







[Csonka, April 2016]

Figure 20: DPA Recipients to RedRock Biofuels, Fulcrum Energy & Emerald Biofuels

In summary (from CAAFI – CORE-JetFuel Cooperation Workshop, Alexandria, Virginia, April,28, 2016) for the US initiative for the use of synthetic alternative biojet fuels, CAAFI considers aviation as a first mover and dedicated long-term offtaker with:

- A fuel production at petroleum pricing parity (policy as needed)
- FAA (US Federal Aviation Administrative): Aspirational 1 billion gallons per year by 2018
- 20 million gallons per year facility in each of 50 states (AltAir is 40 million gallons per year jet and diesel)
- Translated to F2F2[7] goal of standing-up feedstocks to enable 1Bgpy
- DLA (US Defense Logistic Agency) as a regular offtaker:
- Navy: 50 percent of total Navy energy consumption afloat by 2020
- US AirForce: 50 percent of total non-contingency consumption by 2025
- First real test is CNG2020: => as low as 282 million gallons per year in US
- Project engagement from each:
    - State, Airline, OEM, key Business aviation player
- Significantly reduced technology & execution risk to unlock capital

1.5 BioJetMap database

A database called BioJetMap gathers all the information published on the web, but also completed from industrial parties, by questionning biojet fuel producers, aircraft and engine manufacturers as well as airlines. BioJetMap is a graphic interactive database gathering the numerous demo flights run with alternative fuels worldwide. The work was performed in the High Biofuel Blends in Aviation / HBBA study[8] (Lufthansa) in accordance with a tender by the European Commission as ENER/C2/2012/ 420-1 "High Biofuel Blends in Aviation". The database is now public and can be used on the web: http://www.biojetmap.eu/#31080.

BioJetMap was initially presented at the FORUM-AE workshop on Alternative Fuels, Madrid 20-22 October 2014 in Madrid in October 2014 with a lot of interest in the potential of the application. More recently a workshop presenting the BioJetMap was held in Brussels in February 2015 with a twofold purpose: firstly to present the BioJetMap as a tool which could be used for dissemination, policy, monitoring and reference; secondly to facilitate a level of understanding that will enable the user to contribute directly to the ongoing population of the map itself. Hands-on sessions demonstrated both how to use the BioJetMap and how to use the Add a Flight Tool. This was followed by an informed discussion on issues raised in the mapping, for example the issue of the extent to which supply chains can be mapped.

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[7] Farm to Fly 2.0; USDA, Airlines for America , Boeing, FAA, DOE initiative to enable commercially viable, sustainable biojet-fuel supply chains in the U.S., that are able to support the goal of one billion gallons of bio-Jet Fuel production capacity and use for the Aviation Enterprise by 2018.

[8] To learn more about the HBBA study, it is possible to view the relevant presentations delivered at the HBBA Study and Biojet Map Workshop in Brussels on 11. February 2015:

1. Background and Fuels used [Download]
2. Properties of Bio Kerosene Blends [Download]
3. Material Compatibility [Download]
4. Effects on emissions [Download]
5. Conclusions [Download]

http://www.hbba.eu/study/HBBA_Study_Report_6.2.2015.pdf

The description of BioJetMap database is taken from its web-site.

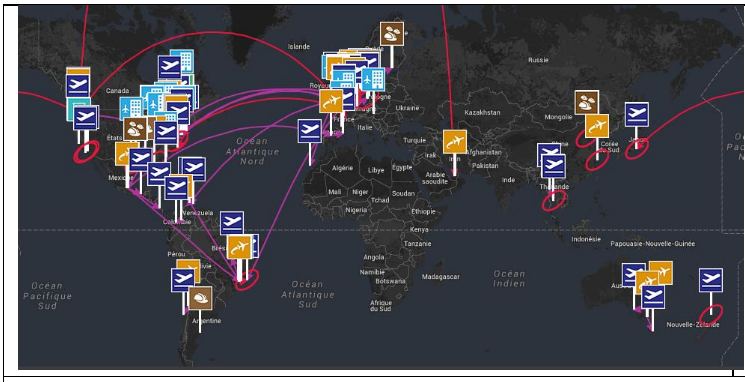
"The BioJetMap is a Biokerosene flight database and web application initiated in 2012, and further developed under the HBBA study project. The scope is global and historical. Its time-enabling traces the evolution of the aviation biofuels sector through successive demonstration, test and commercial flights. Its sortable tabular indexes enable exploration by feedstock, biofuel, and airline.
The most recent development has taken place in two parts: firstly the compilation of a Flights Map, and secondly the aggregation of components of the value chains, including cultivation, certification, production, logistics and supply.

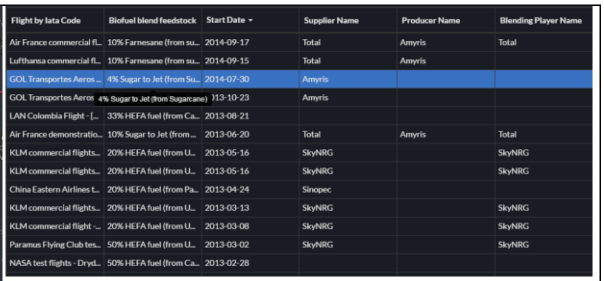
Data for the Flights map is sourced from data provided directly by airlines and operators, and data is also linked directly from news articles and press releases. The scope is global and historical. Its time-enabling traces the evolution of the aviation biofuels sector through successive demonstration, test and commercial flights. Its sortable tabular indexes enable exploration by feedstock, biofuel, airline, etc.

Data for the whole value chain components is sourced directly from players involved in cultivation, production, blending, logistics and supply, where available. In particular for EC and Industry funded projects, detailed supply chains are mapped. Where detailed information is not available, publicly available upstream information from news articles, press releases, and sustainability certification is aggregated and presented in flow diagrams."

The public version of the BioJetMap contains the Flights Map, with limited supply chain information.

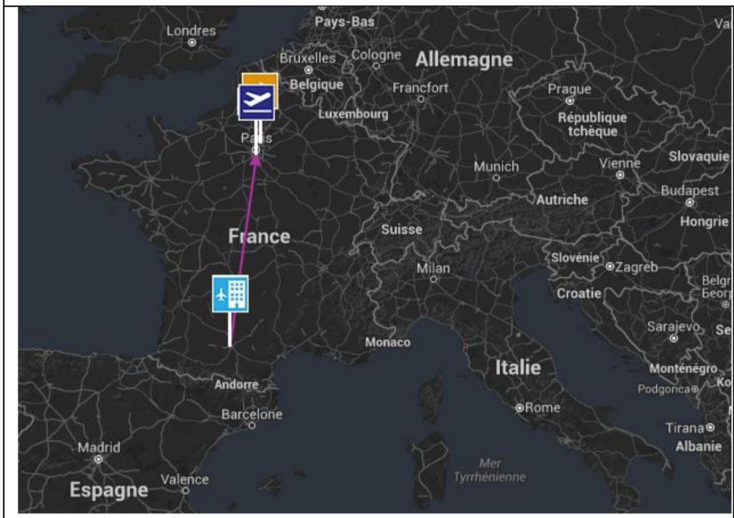
Illustration of BioJetMap screens and data are given in Figure 21.



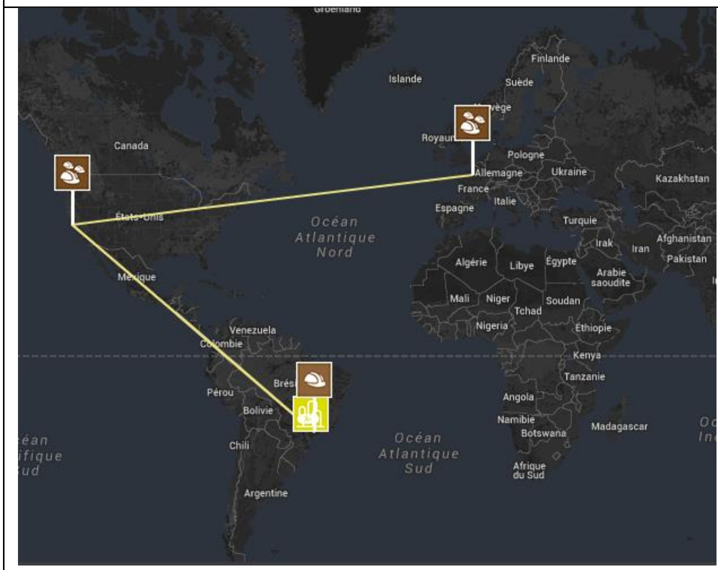


Flight by Iata Code	Biofuel blend feedstock	Start Date	Supplier Name	Producer Name	Blending Player Name
Air France commercial fl...	10% Farnesane (from su...	2014-09-17	Total	Amyris	Total
Lufthansa commercial fl...	10% Farnesane (from su...	2014-09-15	Total	Amyris	
GOL Transportes Aeros ...	4% Sugar to Jet (from Su...	2014-07-30	Amyris		
GOL Transportes Aeros	4% Sugar to Jet (from Sugarcane)	[illegible]013-10-23	Amyris		
LAN Colombia Flight - [...	33% HEFA fuel (from Ca...	2013-08-21			
Air France demonstratio...	10% Sugar to Jet (from ...	2013-06-20	Total	Amyris	Total
KLM commercial flights...	20% HEFA fuel (from U...	2013-05-16	SkyNRG		SkyNRG
KLM commercial flights...	20% HEFA fuel (from U...	2013-05-16	SkyNRG		SkyNRG
China Eastern Airlines t...	20% HEFA fuel (from Pa...	2013-04-24	Sinopec		
KLM commercial flights...	20% HEFA fuel (from U...	2013-03-13	SkyNRG		SkyNRG
KLM commercial flight -...	20% HEFA fuel (from U...	2013-03-08	SkyNRG		SkyNRG
Paramus Flying Club tes...	50% HEFA fuel (from U...	2013-03-02	SkyNRG		SkyNRG
NASA test flights - Dryd...	50% HEFA fuel (from Ca...	2013-02-28			

BioJetMap overall flight screen and table



Example of Lab'line: demo flight



Example of Lab'line: fuel supplying

[BiojetMap]

Figure 21: BioJetMap database

1.6 Highlights on current and on going pathways

There are a lot of possible routes to make renewable jet fuels today, a few ones at, or near to, industrial level suitable for a short term production, other processes (most of them) being for the mid or long term. Range of feedstock that are suitable for each technology can differ a lot, as well as product slates that can also dramatically differ.

Today 5 routes are ASTM certified: FT-SPK, HEFA-SPK, SIP from hydroprocessed fermented sugar, FT-SPK/A and ATJ-SPK through the isobutanol intermediate production. For the 5 certified routes, all are based on isoparaffin kerosene with the exception of the fourth one based on isoparaffin kerosene plus the addition of alkylated aromatics.

A few more should/could be certified in the short term before the end of 2017, such as Green Diesel or HFP (High Freezing Point) HEFA, the CHJ/ARA-CLG process from lipids or the HDO SK (Virent), recently renamed CPK (Cyclo Parrafinic Kerosene).

Another route is proposed by Virent, Hydro-DeOxygenated Aromatic Synthetized Kerosene or HDO-SAK that could be blended up to 25%, but the final qualification date is not yet well known. ATJ SKA route (Lanzatech) from industrial waste gas, rich in CO is under ASTM qualification, but with no recent news and no known date for qualificationand the process is currently only demonstrated for the ethanol production from industrial steel, but not the final conversion to biojet fuel.

For the remaining routes under ASTM qualification, HDCJ/HPO (pyrolysis), CATJ-SKA ¨ Byogy, LT, SwB, Vertimass, Poet, ATJ-SPK / GranBio, UOP, LT, SwB, we have no news related to the possible qualification date. Other routes could also be qualified by ASTM in the medium/long term.

All these routes still have unique challenges, are region and/or feedstock dependent / specific, and have a higher, or a much higher cost, than current fossil jet fuel in 2015/2016.
There is no unique solution and the right or best solution depends on many factors: the regional one, feedstock sourcing, availability and price, tax structure, product slate, value of co-products, environmental impact (LCA including or not including LUC and iLUC) and the like.

Figure 22 shows a road map for biofuels incorparation in the IFPEN vision. Y axis is related to the possible biofuel percentage (gasoline, jet fuel and diesel) in the final commercial transport fuel pool. There is no scale because, today, the production is quite impossible to forecast, even with a rough estimation, for G2 and G3 biofuels. The doted line means that biofuel production from algae is quite uncertain, even in the medium/long term. The branching points illustrate the fact that it is a continuous long term development, with the startup of G1 biofuels production, the complement to be brought by G2 biofuels since a couple of years with the 1st G2 EtOH industrial size plants in the US, Brazil, China and inEurope and foreseen in the future, and, may be, in the long term by G3 biofuels.
Even if not necessarily shared by all the stakeholders, it visualizes the aspect of current and potential future biofuel process development and possible biofuel industrial production over the next two or three decades, in IFPEN current expectation.

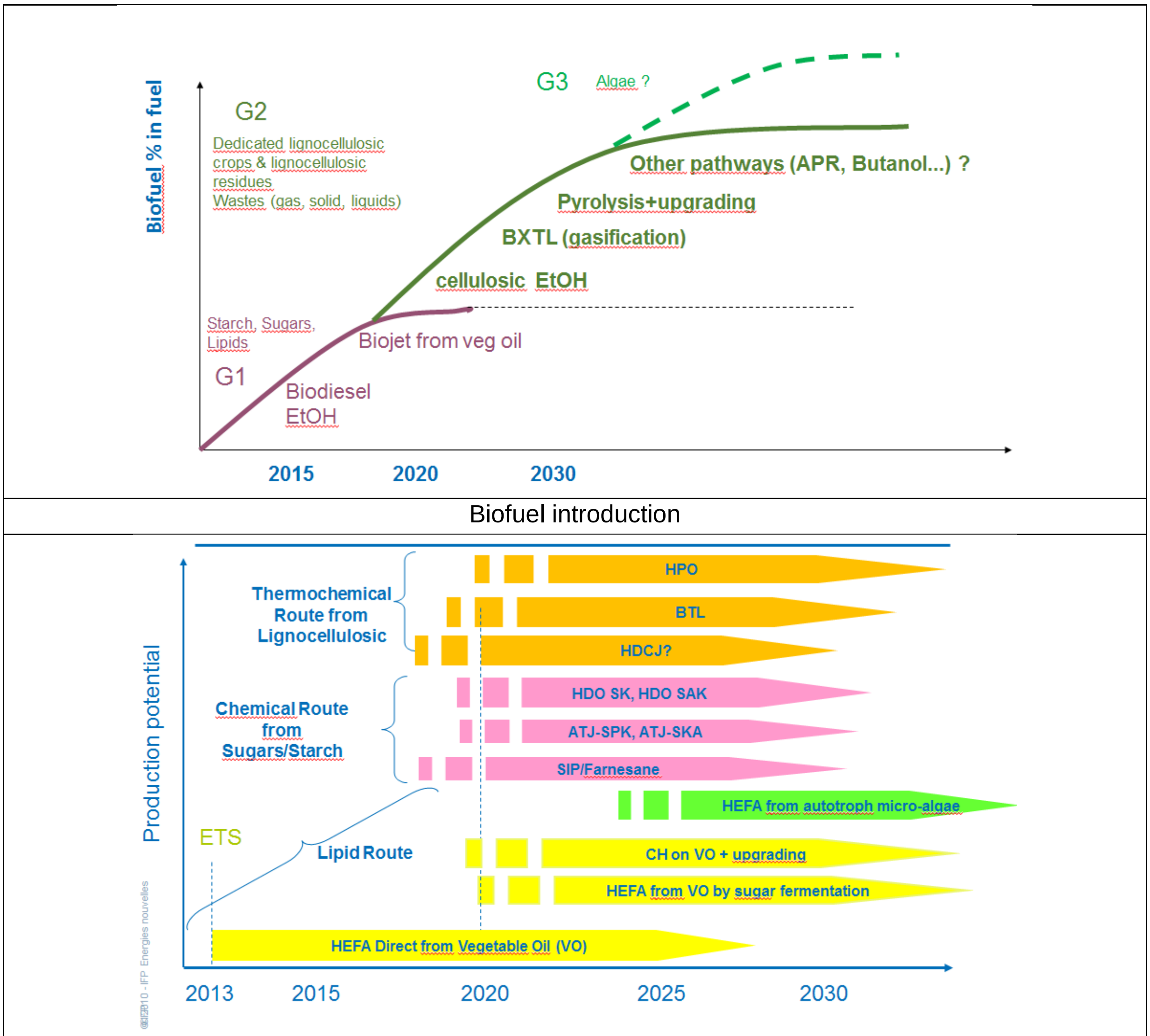
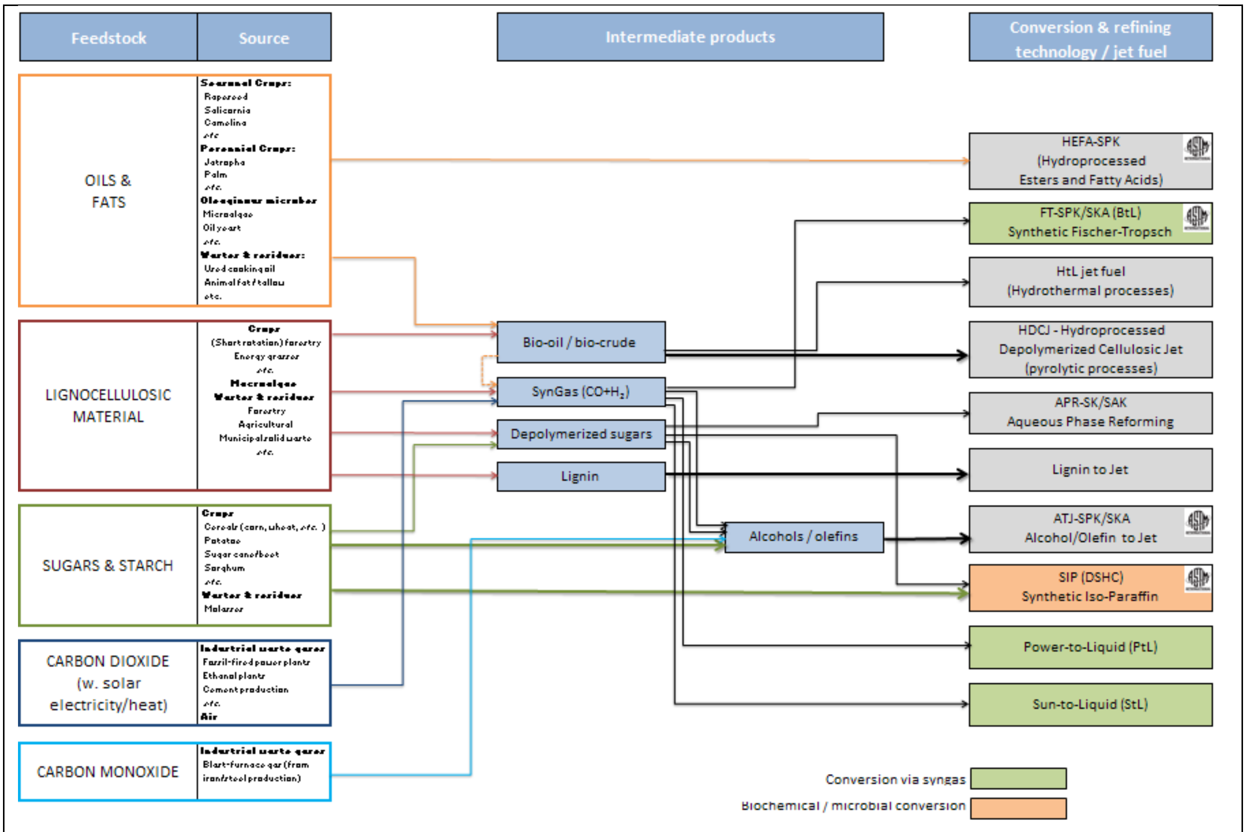


Figure 22: IFPEN Vision

In the CORE-JetFuel project, the team classified the main pathways (Figure 23), with:

- 5 types of feedstocks:
  - Oils & Fats, including 4 subtypes: seasonal crops, perennial crops, oleaginous microbes, waste and residues,
  - Lignocellulosic, including 2 subtypes: crops and macroalgae, waste and residues,
  - Sugars and Starch, including 2 subtypes: crops, waste and residues,
  - Carbon Dioxyde including industrial waste gases and air,
  - Carbon Monoxyde including industrial waste gases only.
- 5 types of intermediate products:
  - Bio-oils, Bio-crudes
  - Syngas ($CO+H_2$)
  - Depolymerized sugars
  - Lignin
  - Alcohols/Olefins
- 3 types of processes correponding to the main pathways:
  - Thermocatalytic conversion, including CH, HEFA, HtL, HDCJ, HPO, APR-SK, APR-SAK, Lignin to Jet (refer to end of chapter 1.3),
  - Biological / microbial conversion (orange) DSHC/SIP,

- Through syngas production (green) plus conversion to fuels, including BtL with FT synthesis and Solar and Power to liquid.

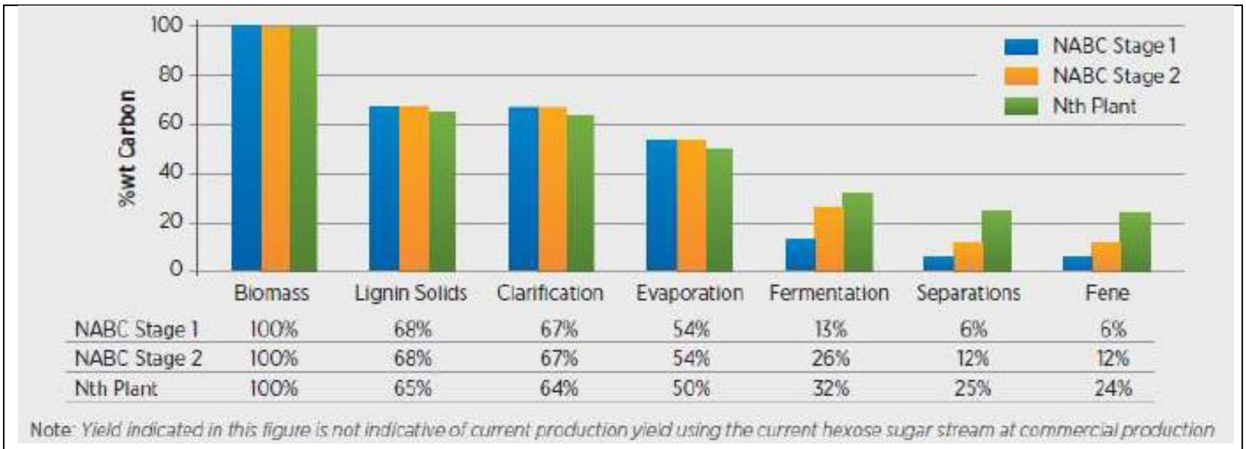


[Michel, April 2016]

Figure 23: Feedstock and Biojet fuels pathways according to CORE-JetFuel classification

Economic viability: a pending main issue

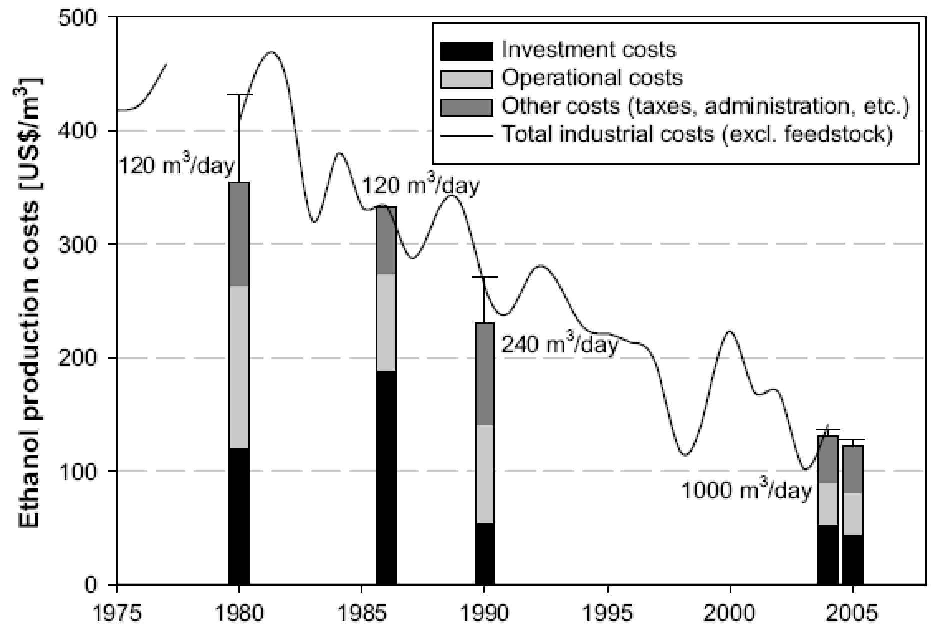
Apart the price of the biomass, another key factor to reduce the price of biofuels and biojet fuels is the increase of the final product yield versus biomass. An example based on the fermentation of biomass to farnesane (Amyris) is given for the SIP process. The yield gain from lignocellulosic biomass is only indicative for this type of process, but the tendancies and phylosophy are still valid for any biofuel process based on fermentation to alcohols or to hydrocarbons (refer to Figure 24). Within the National Advanced Biofuels Consortium (NABC) the Fermentation of Lignocellulosic Sugars (FLS) team focused on tracking the carbon losses in the different steps of the SIP process. The largest percentage of carbon lost during the process is related to the pretreatment step with the removal of lignin plus clarification and evaporation: 50-54% carbon lost. The next largest carbon loss is during the fermentation step itself, including fermentable sugars lost to yeast biomass, CO_2 production during yeast metabolism, with 20 to 35-40% carbon lost. But the downtsream steps, such as separations, are also important steps than can loss carbon, with about 10%. At the end, the carbon lost on farnesane production v/s the initial biomass is in the range from 94% to 76%. It also demonstrates that, by optimizing the technology and the process steps (refer to NABC stage 1 v/s stage 2 on Figure 24), it is possible to two fold increase the yield from 6 to 12%, with a main effect on the final cost of the product. And by optimizing the carbon loss on a yet industrialised process (refer to NABC stage 1 v/s Nth plant on Figure 24), it is usually possible to even decrease more the carbon loss.



[Holladay, Nov.5, 2014]

Figure 24: Example of yield gain on the SIP process

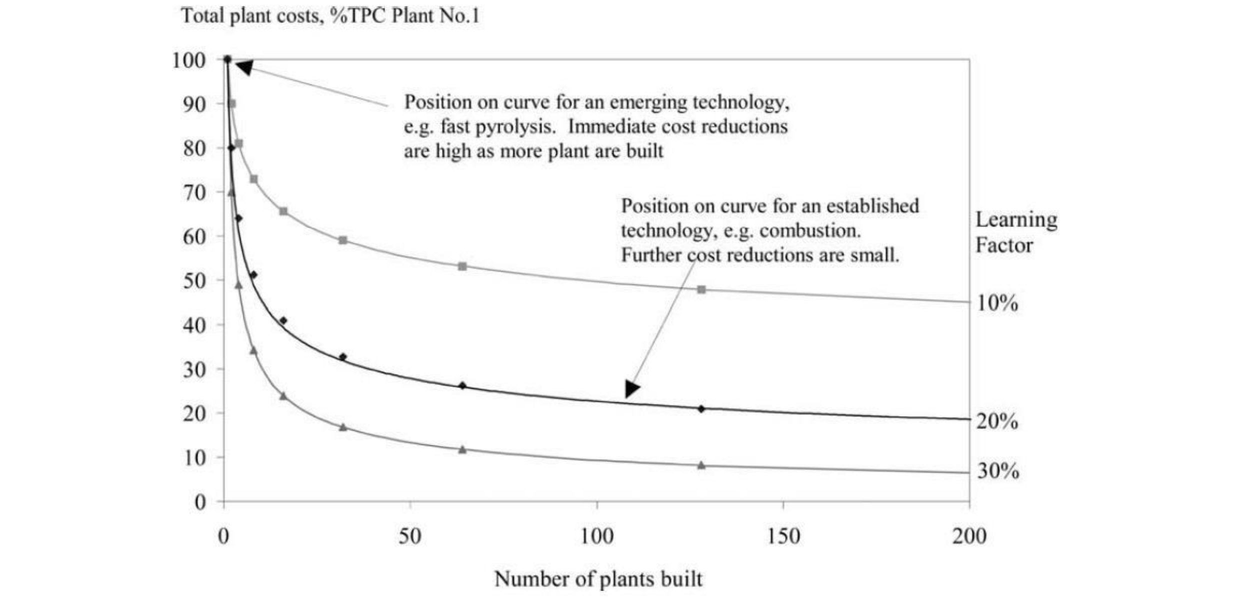
An other key factor is related to the scale factor, the production cost of a big unit being always lower than a smaller one (Figure 25), the limitation being related to the biomass availability and to the learning factor. The cost of an industrial plant is always necessarily quite high for the1st industrial unit and is decreasing quite sharply after several units or a few tenth of units in operation, then it decreases much more slowly (Figure 26).



[Van den Wall, 2009]

Figure 25**:** Impact of production capacity on ethanol costs (excluding sugar feedstock costs) in US$ per m^3, total and per component

(notes: the average size of new ethanol distilleries in m^3 capacity per day is also shown)



[Bridgewater, 2004]

Figure 26: Industrial plant cost and learning factor v/s number of plant built

Production of alternative fuels for aviation is still very limited. It is produced by a small number of companies, primarily in Europe and the US, most of the time produced batchwise, or continouly from medium size demo units. The HEFA jet fuel production route is currently the most popular, and called HVO (Hydrotreated Vegetable Oils) when producing mid-distillate for road transportation. HVO is industrially used to produce bio-diesel using a variety of vegetable oil feedstocks: mainly rapeseed oil, soja oil, palm oil, animal fats and UCO. About 10 industrial units are built or to be built in the near future. With the exception of AltAir in California starting with biojet fuel (plus biogasoline and biodiesel) production in March 2016, all the units are only producing biodiesel and a very limted quantity of biogasoline, but a biojet fuel production is possible, for example adding a second step to the first HDT (HyDroTreatment) reactor with a dedicated deep Hydroisomerization to meet the very low cold flow specification suitable for aviation fuels Another possibility could be to introduce small amount (a few %) of Green Diesel / HFP HEFA, when the route wil be qualified by ASTM.

Whatever the considered bio jet fuel process, the main challenges remain to reduce the production price, to develop the industry and to deploy the existing or near coming technological processes. For the mid and long term, advanced conversion technologies, still at small pilot or bigger pilot plant or at demo unit level, will be necessary for further development at commercial level for a large-scale use by the airlines. More over the relatively low weight yields of biomass conversion to biofuels (range from 15 to 25 wt% on dried biomass), with even a lower yield if we focus on biojet fuel (range from 10 to 15 wt% on dry biomass), may also be a constraint related to the biomass availability with the future demand into biofuels and competition with terrestrial biofuels (road and rail). Currently the competition with sea and water transportation using biofuels to replace marine fossils fuels (marine gasoil and diesel, heavy distillate, light and heavy fuel oils, LNG,..) is not foreseen to be at a significant level in the next 10 years, excepted may be from HEFA plants.

Finally, it is important to remind that ASTM qualification is a long and costly process. It is a mandatory step before setting new jet fuel specifcations and before the commercialization of the fuel. It requires a large quantity of jet fuel, from about 38 to 380 m^3, several years, e.g. 2 to 3 years or more, with a cost that can overpass US$10 millions.

2 Recommendations to the European Commission

Keep monitoring deployment / implementation initiatives with a critical expert analysis

The review of state of the art of deployment / implementation initiatives is a mandatory step to be aware of the numerous pathways that are currently used or could be used to produce bio-jet fuels in the near, medium or long term. This review is strongly linked to the assessment of conversion technologies in Deliverable 4.4. "Report on compilation, mapping and evaluation of R&D activities in the field of conversion technologies of biogenic feedstock and biomass independent pathways (final report).

An overwiew of current and short term biojet fuel productions is also very important to have an accurate picture of the technologies that are and will be capable to produce biojet fuels in the near future at an acceptable cost (refer to Database / Short term production chapter). An overview of deployment initiatives, about their viability and the participating stakeholders, including success stories is also important, as well as global overview of industry-driven projects and initiatives for the medium/long term.

Develop initiatives connecting the stakeholders engaged in alternative aviation fuels

It is very important to develop initiatives gathering the stakeholders related to a dedicated biojet fuel pathway, such as the European ITAKA project[9] (HEFA from camelina) or the Lab'line for the future initiative[10] (SIP), to demonstrate the technical viability as well as assessing all the logistic issues, such as how to fill the tank of an aircraft in an airport, using the current Jet A1 airport hydrant system, or the social acceptance by passengers of using biofuels. Such initiatives could be pushed forward by the EC in the future for new pathways.

Decrease the industrial risk to scale-up production

It is also very important to decrease the industrial risk of producing biojet fuel within a highly moving world of fossil crude and fuel prices by securing the production through long term contracts with airlines or national defense/civil administration, such as done in the US (refer to 1.4 Demonstration and commercial flights using biojet fuels and early deployment of commercial biojet fuels).

Improve production costs and biojet fuel implementation / deployment

Because the initial cost of biojet fuels from the 1st industrial units is always quite much higher than when the process is fully optimized after the start-up and production of a few industrial units, it is also mandatory to get the help of National State Members and /or the EC to introduce new biojet fuels, as made for transportation biofuels, without the possibility of incentives through tax discounts due to the absence of tax on jet fuel.

Because of its chemical structure, biomass composition is far away from the suitable chemical composition required for drop-in jet fuels, mainly based on an isoparaffinic structure with a limited amount of monoaromatics and mononapthenes. It results in very low weight yield or biomass to biojet fuel, typically within the 5-15 wt% range (corresponding to 10-25 wt% total biofuel –naphtha, jet fuel, diesel yield). This is the main driver explaining the higher or much higher cost of biojet fuel v/s fossil fuel. It is the reason why any R&D study to reduce the carbon losses and to improve the final yield to

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

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

biofuels is very important. It is true for all the steps of the pathway: biomass production, biomass pretreatment, primary conversion process, secondary refining process, optimization of recyling flows, optimization of energy use and balance, gains in separation systems and energy consumption,….. These studies are of main importance to decrease the production cost as well as to invrease the carbon and energy balances and to decrease the GHG fingerprint. This type of study could be supported by EC.

Improve the understanding of the properties of biojet fuels

A lot of R&D efforts are still needed and compulsory to understand the properties of alternative jet fuel blends based on detailed chemical analysis, at qualitative level first (molecule identification) and finally at quantitative level. The analysis of chemical properties has qualitative aspects with respect to the identification of specific molecules as well as quantitative aspects aiming at a reasonably precise prediction of properties. It should be the aim of such analysis of the alternative jet fuel to identify the most critical aspects of the certification process (i.e. red/green light for specific parameters).
Furthermore, some properties (cold flow such as freezing point and viscosity, as well as thermal and oxidation stability) of blended fuels are "non-additional" and may not be easily calculated from the ratio and properties of the blending components. The efforts have to be focused on such properties and also on combustion properties.

Optimize and improve the use of ASTM D4054 process [11]

ASTM qualification of alternative fuels is sufficient to guarantee safety of operations. **It is a robust process to guarantee than the new fuel will comply with all requirements related to compatibility, quality and safety.**
Fuel analysis is a good means to SUPPORT the qualification process, but shall NOT REPLACE the qualification process. Such support may serve to reduce costs and time needed for the qualification process, as well as to reduce the time for the overall development of a new pathway and to be able to judge in advance at a relatively low TRL how the new synthetic fuel may comply with final fuel requirements for aircraft.
Certification of chemical properties instead of pathways is not considered easier and **it is agreed** (refer to stakeholder telephone conference April 4th, 2016) **that including a new Annex for each certified pathway in ASTM D4054 qualification remains mandatory**, especially for safety issues.
Detailed fuel analysis is a good means to support the qualification process, but shall not replace this one. It will serve to reduce costs and time needed for the qualification process, as well as to reduce the time for the overall development of a new pathway and to be able to judge in advance, at a relatively low TRL, how the new synthetic fuel may comply with final fuel requirements for aircraft use.

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

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

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

It is stated that certification costs are not regarded as “show-stopper” for the development of alternative aviation fuels.

Pay attention to logistic and quality insurance

The logistics of alternative fuels may have a negative impact on the quality assurance of blended fuels. The current ASTM qualification process does not cover potential problems originating from logistics aspects and the presence of new players, and the ASTM certification process may need to be adjusted.

An other key element is contaminants with a lack of understanding of their effects and there is a need for research in this area. This is not a question of qualification but a question of quality insurance and to be able to check that the production is performed in a good way.

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

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

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

3 Database / Short term production

3.1 Database construction

An identification and information gathering the most promising deployment initiatives and industrial value-chains under development worldwide were performed.

Since it is a very important and time consuming work, with a similar approach performed within the ICAO/AFTF group, the AFTF (Alternative Fuels Task Force) and the CORE-Jet-Fuel databases were finally merged in order to get a comprehensive worldwide shared base. The database was built as an Excel file. The inventory of alternative fuel production announcements included in the file is the result of the merging of three different files:

- an inventory initially made at ICAO Secretariat,
- an inventory initially made by the European project CORE-Jet Fuel,
- an inventory initially built by the JRC and provided by the European Commission.

The ICAO/AFTF assessment was perfomed in the AFTF WP2 Fuel Process Assessment (FPA). The main objective was to gather all the available and changing public annoucements (even if currently, with the low oil price, there are much less new press releases, news and public information than till 2014 or early 2015) related to biojet fuel processes at laboratory, pilot plant, demonstration or industrial level, that are yet implemented, or to be implemented in the near future (2020) or in the long term (2035-2050).

The focus is on “advanced alternative fuels” that could have an application in aviation. The production step of ethanol itself, as an intermediate product feedstock for alcohol-to-jet, is not included, but ATJ routes are considered. The file currently mainly includes announcements by industry or processes at large scale pilot plant or demo level.

A group of ICAO/AFTF experts[12] is providing updates / announcements by setting a number of criteria. The group, under the leader ship and secretariat from Volpe, with support of US FAA, can then update the file and keep it updated on the AFTF website. Calls and face–to-face meetings within the group are performed all over the year in order to discuss and to quote, on a consensus basis between experts, the news, press releases and publications related to the evolution of existing projects, as well as new projects or project cancelation. This organization makes it possible to update the database in real time. Today the database is only available for ICAO members.

The database is organized into two main Excel sheets. A first sheet called “Announcements” provides all the data collected. This sheet is finalized but is regularly updated with new coming announcements.

A second sheet called ”Short term projections” is dedicated to the building of projections for a number of scenarios. The objective is to build the projection in a second step after converging on the credibility assessment from the assessment sheet. This sheet is also finalized and regularly updated with new coming announcements too.

A third sheet called “Post-Submission_Updates” is a working sheet with the last update and changes that are then incorporated in the “Announcements” and “Short term projections sheets.

[12] N. Brown (US FAA), R. Boyd (IATA), N. Jeuland (Safran), K. Lewis (Volpe, US DOT), L. Lonza (EC/JRC), R. Malina (MIT), A. Quignard (IFPEN), M. Starples (MIT), C. Velarde (Ministry of Transport of Indonesia)

A fourth sheet called "Explanations" explains how the announcements and the short term projection are classified by the FPA expert group.

A fifth sheet called "Analyses & Figures" is used for projections.

3.2 Database presentation

The first sheet "Announcements" provides all the data collected from public announcements. The "Announcements" sheet collects all the announcements or production information related to advanced biofuel pathways than can have some application in aviation. Announced production capabilities are listed together with information about the company and publically available references

Announcements are classified per line/ per company.

A color code (Figure 27) is used in the file to distinguish between companies for which jet fuel production is identified (green) or only included in companies' target (blue), or companies whose process could be applied for aviation fuel (purple). Companies colored in grey are no longer on the market. They are included only for completeness, to indicate that the company was actually identified.

ICAO - Advanced fuel producers database

Legend

	Jet fuel production or project identified
	Company's target includes jet fuel
	No clear mention of jet fuel production but the process could be applied
	Cellulosic ethanol/butanol production - Included with a view to the development of alcohol-to-jet pathway
	No longer on the market
	Not applicable to aviation
2013	Effective starting in 2013

Figure 27: ICAO Advanced fuel producers database Legend (sheet "Announcements)"

In the "Announcements" table, columns are gathering public information such as described in Figure 29 and Figure 30 and in Figure 32 (explanations).
On the left side of the table, columns have been added on the right to collect the assessments from the ICAO/AFTF group experts on credibility of the announcements, with an Estimated Credibility and a Comments Column for each of the 5 expert (Figure 31).
This last part is used to finalize the 2nd sheet "Short term projections".

The second sheet "Short term projections" is dedicated to the building of projections for a number of scenarios. The color legend is the same as for the "Announcements" sheet (Figure 27).

Jet-fuel ratio range is estimated by the expert group (Figure 28).

Jet fuel ratio

Process	Low range	High range	Uncertainty	Jet fuel ratio updated with IFPEN value on 15/05/2015
HEFA	30%	70%	Low	
BIC (ARA)	30%	55%	High	
Pyrolysis + upgrading	15%	50%	Medium	
Gasification + FT	30%	50%	Low	

Figure 28: Jet-fuel ratio range

The "Short term projection" sheet (Figure 33 and Figure 34) contains the projection for short term production derived from the companies' announcements for different scenarios corresponding to more or less optimistic assumptions. For this sheet, the columns are organized in the same way as for the first sheet (Figure 35).

In the "Announcements" sheet, there is also no systematic rule to go from the company's announcements to the projection. It was agreed by the expert group to adopt a three credibility levels (low, medium and high), with an associated description, which would work as thresholds when applying different treatments to build the projection from the announcements, based on the "Short term projection" sheet (Table 3).

Table 3: Credibility level and Criteria from the "Short term projection" sheet

Credibility level	**Criteria**		**Guidelines**
High		Company is already producing	
	or	Company has a plant under construction (physical construction has started) + company has already run a demo or pilot + Credibility of the partnership (e.g. financial backing)	Demo or pilot depends on the technology (e.g. for HEFA a new comer can build a plant) A demo should have been done by one of the partner
	and	Fuel is already certified or being in the process of being approved	
Medium		The company has not yet started to produce but has financial partners, off-take agreement or some government support for technology scale up to commercial demo	
	and	The fuel readiness level (FRL) is greater or equal to 6	FRL >=6 is equivalent to say that the fuel is under consideration for approval
	and	Company has made some kind communication over the last 12/18 months or some information could be found in the media on on-going activities	
Low		All other situations	

Although the "expert judgment" role was acknowledged in assessing credibility and projecting fuel production in the "Short term projection" sheet. In the table the credibility assessment is based on a shared position by the expert group, remaining an expert qualitative and empiric vision. Nevertheless, with the high level of uncertainty resulting from the public assessments, it is probably a pretty good view of reality, even if it could be considered as too arbitrary. Using a more rigorous and a more delineated approach to try to classify the assessment is not straightforward and not necessary very pertinent, because a classification based on data obtained with a very high level of uncertainty should probably be not so significant, neither so discriminant.

Common assumptions and notes for all scenarios are:

- pilot plant production is not included in the projection,
- it is also assumed that the use of green diesel or High Freezing Point HEFA from hydroprocessing (HEFA) will be approved for aviation between 2016 and 2020, making all hydroprocessed oil volume accessible to aviation (which does not mean that it will go to aviation). In accordance with the information obtained on the on-going work within ASTM, the whole diesel cut is considered for inclusion in the jet fuel. No distillation is envisaged to retain only the kerosene cut. The maximum blending ratio is likely to be limited to 5% or less (10% has been done but with artic diesel),
- the approval of green diesel is currently limited to hydroprocessed oils and fats,
- Fischer-Tropsch diesel could also be considered but would need a separate approval. In addition, the FT process is likely to produce longer carbon chain lengths than hydroprocessing (for which the maximum length is defined by the feedstock). The assumption that all the diesel cut is retained could thus not be valid for FT fuels, for which a distillation may be required. However due to the long carbon chain lengths, the FT process produces waxes that need to go through hydrocracking in order to obtain diesel. As hydrocracking is not highly selective, some kerosene cut is obtained that can be either blended with diesel or be directed toward aviation fuel.

A five level scenario and assumption table was built within the expert group in order to classify the pathway (Table 4).

Table 4: 5 level scenarios

Scenarios	Assumptions
Low 1:	> Projection limited to the announced production of plants currently under construction for companies with a high credibility quotation. > Jet fuel production ratio in the low range if jet fuel production is mentioned by the company. If not, jet fuel ratio = 0 > For green diesel, no displacement from the diesel market to the aviation market > No inclusion of the jet fuel fraction of the production of FT diesel.
Low 2:	Same as Low 1, but: > all the green diesel produced through oils and fats hydroprocessing is considered available for aviation (max potential jet fuel availability); > the fraction of jet fuel produced when producing FT diesel is included (5% or 10% tbc). A blend wall will be put on green diesel to account for the limit under consideration under ASTM. It will be applied as a sanity check with a look at regional situation for blend wall issues.
Med 1:	> Projection including half of the production of projected plants for companies with a high credibility quotation. > Only first announced plant for companies with a medium crebility quotation. > Jet fuel production ratio in the low range if jet fuel production is mentioned by the company. If not, jet fuel ratio = 0 > For green diesel, no displacement from the diesel to the aviation market > No inclusion of jet fuel fraction of the production of FT diesel.
Med 2:	Same as Med 1, but: > all the green diesel produced through oils and fats hydroprocessing is considered available for aviation (max potential jet fuel availability); > the fraction of jet fuel produced when producing FT diesel is included (5% or 10% tbc). A blend wall will be put on green diesel to account for the limit under consideration under ASTM. It will be applied as a sanity check with a look at regional situation for blend wall issues.
High:	Same as medium 2 but: > Projection including 100% of the production of projected plants for companies with a high credibility quotation. > High jet fuel production ratio if jet fuel production is mentionned by the company, in the low range if not

The case of the green diesel was discussed because it was not yet very clear whether, in the final ASTM approval process, the plan is to use the full diesel production slate or also the diesel cut after distillation into a light diesel. This has impacts on the production ratio that will be accessible to aviation. In any case, a limitation to 5% (or even less) of the blending ratio of green diesel in jet fuel is not seen as raising a blending wall for green diesel by 2020.
In accordance with the information obtained on the on-going work within ASTM, the whole diesel cut is considered for inclusion in the jet fuel. No distillation is envisaged to retain only the kerosene cut. This assumption can change a little bit if new units, totally or partially dedicated to biojet fuel production (including a Hydroisomerizarion step), are built in the near future (refer to AltAir in California)..

Companies may have projects in different regions of the world, which raises the question of the need for a regional assessment taking into account regional policies that will have a strong impact on whether jet fuel is produced or not. Therefore, assessing the credibility of the different regional announcements for each company is an option to consider.

Production capacity (kt/y):
- Jet fuel Capacity (kt/y) if in bold character
- Total fuel production when normal character;
- Estimates when in italic (now clear announcement found)

	Updated	Company	Country	Activity	Process	Fuel	Feedstock	Facility	Facility type	Expected Entry into service	Actual Entry into Service	In Service?	Investment	Expected capacity	Jet Fuel production	2013	2014	2015	2016	2020
1	01/12/2014	Algenol	USA	Technology	"Direct to ethanol®"	Ethanol	Algae	Pilot-scale integrated biorefinery Fort Myers (Florida),USA	Pilot	2013				0.04 kt/y		0	0	0	0	0
					Hydrothermal liquefaction	Gasoline diesel Jet fuel	Algae biomass	Process under development, to be integrated with ethanol production		2017					0,002	0	0	0	0	
2	02/12/2014	Aliphajet	USA	Technology	Decarboxylation (Catalytic de-oxygenation	Jet fuel, drop-in diesel and gasoline	"crude fats"	Demo-plant (project)	Demo	2014			4-5 M$	0.23 - 1.5 kt/y (0.3 - 1.89 Ml)		0				
								Houston - Pilot plant (UOP or AltAir?)	Pilot	2009		Yes		3 kt/y	?					
3	04/06/2013	AltAir	USA	Fuel production	HVO 5UOP/ENI Ecofining)	Diesel and jet fuel	Vegetable oils and animal fats	Paramount, CA	Commercial	2014	2016	Yes		90 kt/y	ratio ?		15	45	90	
								Anacortes (Washington State)	Commercial	2014 ?				350 kt/y	?					

Figure 29: Database / Announcements Excel sheet (1)

	V	W	X	Y	Z	AA	AB	AC
12								
13	Comments	Références	Site web	Process documentation	Input	Output	Max theoritical biofuel prod. Kt/y	Max theoritical jet fuel prod. Kt/y
14	From the company website, Algenol technology allows to produce about 30,000 l of liquid fuels per year per acre of algae, 25700 l being ethanol through the DIRECT TO ETHANOL® technology. *Note: in Feb 2014, on ocean.unblo.fr, Algenol CEO claimed that the process enables the production of ethanol for around $1.00 per gallon using sunlight, carbon dioxide and saltwater at production levels above 9,000 gallons (34,000l) of ethanol per acre per year.* Algenol has received 185 M$ of private investments plus 35 M$ of grants. In Jan. 2015, BiofuelsDigest reports the deployment of demo algae production (400 photobioreactors) at the Reliance Jamnagar Refinery in India (the algae were wildtype host species, not the algae used by Algeniol to produce fuel). In Fort Myers, Algenol has deployed 4000 PBR	http://ocean.unblog.fr/2014/02/10/algenol-boasts-10350-gallons-of-biofuel-per-acre/ http://www.biofuelsdigest.com/bdigest/2015/01/26/worlds-largest-oil-refinery-adds-algae-demonstration-project/	http://www.algenolbiofuels.com/about-algenol	DIRECT TO ETHANOL® technology uses enhanced blue-green algae (or cyanobacteria) and photosynthesis to convert CO2 and seawater into "sugar" (pyruvate) and then into ethanol and biomass. Algae are cultivated in salt water in plastic film photobioreactors. Proprietary Vapor Compression Steam Stripping (VCSS) technology further purifies the ethanol for downstream processing using standard distillation	1 tons CO2	472 l ethanol 660 l fresh water		
15	ethanol production, using the remaining algae biomass processed through thermal liquefaction. This would produce about 1890l of diesel, 1440 l of gasoline and 1190 l of jet fuel. *Note: in Feb 2014, in ocean.unblo.fr, Algenol CEO was announcing 1350 gallons (34000 l) per acre per year of diesel fuel, jet fuel, and gasoline on top of the 9,000 gallons of ethanol per acre per year from the Direct to Ethanol® proces.*	http://ocean.unblog.fr/2014/02/10/algenol-boasts-10350-gallons-of-biofuel-per-acre/	http://www.algenolbiofuels.com/about-algenol	The biomass is dewatered before being fed into a hydrothermal liquefaction (HTL) unit. The primary output from the HTL unit is a green crude oil. The HTL crude oil is upgraded in a hydrotreater unit to a hydrocarbon product that essentially contains a mixture of liquid hydrocarbons in the range of diesel, jet and gasoline fuels. The upgraded product contains none of the oxygen, nitrogen or sulfur present in the biocrude from HTL and can be distilled into diesel, jet fuel and gasoline		30 l diesel 27 l diesel 19 l jet fuel		
16	AliphaJet claims that its BoxCar™ catalytic de-oxygenation process would require less hydrogen than hydroprocessing to remove the oxygen from the feedstocks (the technology was licensed from the Conn Center for Renewable Energy from the the Univesity of Louisville, where it was patended by Paul Ratnasamy). No recent news are available regarding Aliphajet's project and company website has not been updated. No confirmation that the demo plant was built.	http://www.reuters.com/article/2012/07/09/idUS123869+09-Jul-2012+BW20120709 http://www.ricardo-aea.com/cms/assets/Documents-for-Insight-pages/Transport/05.-R-AEA-Biofuels-v2.pdf	http://www.aliphajet.com	http://www.aliphajet.com/technology.html			0,23	0,18
17	Headquartered in Seattle, Washington, AltAir Fuels develops and operates projects for the production of low carbon fuels and chemicals derived from sustainable feedstocks. Its first project, a 30 million gallon per year facility is located near Los Angeles in southern California and will produce renewable jet and diesel fuel as well as other green intermediate chemicals. Jesta Group is the lead investor in AltAir.	\\icaonet\fileroot\UsersFiles$\PNovelli\My Documents\Archives\Carburants\Bourget 1011\Présentations\AltAir Fuels Company Presentation.pdf						
18	United Airlines press release on 4/6/2013 announced the purchase by UA of 5 Mgal/y from this retrofited refinery (in a prvious presentation AltAir, initial production of the facility was 45 kt/y)	http://ir.unitedcontinentalholdings.com/phoenix.zhtml?c=83680&p=irol-newsArticle&ID=1826859&highlight=	http://www.altairfuels.com/				90	70,12
19	Officially designated as Award No. F10-92101-020, Altair Fuels, a Seattle-based producer of aviation fuel made from renewable biomass, received a grant of $2 million from the Department of Energy to help convert the existing Tesoro refinery in Anacortes (Washington State, near Seatle)into a biofuels plant. (TheOlympiaReport.com - August 2012)						350	272,67

Figure 30: Database / Announcements Excel sheet (2)

	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
12	Ph. Novelli		Alain Quignard		K. Lewis		N. Jeuland		R. Malina		Final assessment	
13	Estimated credibility	Comments	Estimated credibility	Comments	Estimated credibility	Comments	Estimated credibility	Comments	Estimated credibility	Comments	Credibility	Comments
14	N.A	No reason to specifically consider this source of ethanol compared to other source of ethanol production (ATJ should rather be assessed based on ATJ facility announcements)	Low	Price at 1$/gal looks very optimistic and not reasonable	Low	Have pilot facilities in India, have significant investment backing, ATJ fuels are under consideration for ASTM approval but only for butanol at this time, so pt as low	Low	AtJ certification for ethanol is still far.	low		N.A.	
15	Low	Process under development	Low	Upgrading HTL biocrude need to be demonstrated even if probably easier than from Fast pyrolysis biooil	Low	Process under development	Low	upgrading ?			Low	
16	Low	Most recent news is from 2012	Low	No info on the process Catalytic Deoxygenation. Catalytic Pyrolysis + HDO ?	Low	Company inactive, no demo plant or significant funding evident	Low				Low	
17		N.A.										
18	High	Opening of the plant in May from information at CAAFI meeting	High	O based on UOP/ENI Ecofining process : no news from AltAir Fuels nor from UOP: refer to recent CAAFI meeting (March 2015) news	High	Received $4M in Sept 2014 to expand production to 40 M gal and expand feedstocks (http://www.greencarcongress.com/2014/09/20140911-cec.html)	High	quite consistent business model (use existing refinery processes). Some question about financial viability (very low cost of biojet fuel)	High	production expected to start in 2015 as confirmed by United in early 2015	High	
19		Low No recent update found on this second plant						see above		production expected to start in 2015 as confirmed by United in early 2015		

Figure 31: Database / Announcements Excel sheet (3)

Description of the columns: Columns are gathering public information such as:
○ Updated date of the information, Company, Country, Activity of the Company ○ Process (type), Fuel (biofuel type), Feedstock (type) ○ Facility, Facility type (type: lab scale, pilot, demo, industrial), Entry into service, Investment, Expected capacity, ○ Jet fuel production, Projected production capacity (kt/y in 2013, 2014, 1015, 2016, 2020) ○ Comments ○ References (from the web seminar, presentations,..), web site ○ Process documentation ○ Input (feedstock), Output (biofuels), Max. theoretical biofuel production (Kt/y), Max. theoretical biojet fuel production (Kt/y)

Figure 32: Database / Announcements Excel sheet (column description)

	Company	Country	Activity	Process	Fuel	Feedstock	Facility	Facility type	Expected Entry into servic	Actual Entry Into Servic	In Service?	Expected capacit	Jet Fuel productic
								Announcement (kt/y)					
1	Algenol	USA	Technology	Hydrothermal liquefaction	Gasoline diesel Jet fuel	Algae biomass	Process under development, to be integrated with ethanol production	Pilot	2017				0,002
2	Aliphajet	USA	Technology	Decarboxylation (Catalytic de-oxygenation	Jet fuel, drop-in diesel and gasoline	"crude fats"	Demo-plant (project)	Demo	2014			0.23 - 1.5	
3	AltAir	USA	Fuel production	Hydroprocessing	Diesel and jet fuel	Vegetable oils and animal fats	Houston - Pilot plant (UOP or AltAir?)	Pilot	2009	2009	Yes	3	?
							Paramount (Calif, near Los Angeles)	Commercial	2014	2016	Yes	14	4.2-14
							Anacortes (Washington State)	Commercial	2014 ?			350	?
4	Alternative Fuels America	U.S.A.	Fuel production	?	Diesel Jet fuel mentionned	Oleaginous (jatropha, coyol, castor, algae)							
5	Altranex	Canada	Technology	Electrochemical deoxygenation	Lubricants Diesel Jet fuel		Prototype stage						
6	American Clean Coal Fuels	USA	Fuel production	Fischer-Tropsch	Green diesel, jet fuel	Coal and biomass (switchgrass, municipal refuse)	Oakland	Commercial	2013			1210	?
7	Amyris	Brazil	Technology / Fuel production	Sugar to alkane	diesel, jet fuel (farnesene)	Sugar	Pilot - Emerville (California)	Pilot				0,032	
							Brotas (Brazil)	Commercial	2013	2013	Yes	40	ratio ?
							Sao Martinho 1 (Sao Paulo State)	Commercial	2017			80	
							Sao Martinho 2 (Sao Paulo State)	Commercial	2019			80	
8	ARA / Blue Sun Energy	USA/Canada	Technology	Catalytic hydrothermolyse + hydroprocessing (Biofuels ISOCONVERSION - BIC)	Diesel, Jet fuel	Vegetable oils	Pilot	Pilot	2010	2010	Yes	0,14	33%
							Demo plant (with Blue Sun Energy)	Demo	2014	2014	Yes	4,6	

Figure 33: Database / Short term projections Excel sheet (1)

	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
16		Projected production														
17	Estimated credibility	Hyp.	2020	Comment	Input	Output	Max theoritical biofuel prod. Kt	Max theoritical jet fuel prod. Kt	High with no green diesel	Hydroprocessing	FT	Sugar-Alkane	ATJ	Depolymer.	Others	Unknown
18	Low	Low1	0			30 l diesel										
19		Low2	0			27 l diesel										
20		Med1	0			19 l jet fuel										
21		Med2	0													
22		High	0													
23	Low	Low1	0													
24		Low2	0													
25		Med1	0				0,23	0,18								
26		Med2	0													
27		High	0													
28	High	Low1	4,2	Low range of HEFA jet fuel						4,2						
29		Low2	14	Inclusion of diesel						14						
30		Med1	56,7	Low range of HEFA jet fuel			90	70,12		56,7						
31		Med2	189	Inclusion of diesel						189						
32		High	364	HEFA jet fuel + diesel			350	272,67	254,8	364						
33	Low	Low1	0													
34		Low2	0													
35		Med1	0													
36		Med2	0													
37		High	0													
38	Low	Low1	0													
39		Low2	0													
40		Med1	0													
41		Med2	0													
42		High	0													
43	Low	Low1	0													
44		Low2	0													
45		Med1	0													
46		Med2	0													
47		High	0													
48	High	Low1	20	With SIP, all the production can be available for aviation. 50% of the production only is considered to account for competition with diesel								20				
49		Low2	40	Full capacity available			40	40				40				
50		Med1	60	With SIP, all the production can be available for aviation. 50% of the production only is considered to account for competition with diesel			80	80				60				
51		Med2	120									120				
52		High	200				80	80	200			200				
53	Medium	Low1	0											0		
54		Low2	0											0		
55		Med1	1,38											1,38		
56		Med2	1,38	Diesel not accounted because no approval considered yet										1,38		
57		High	2,53						2,53					2,53		

Figure 34: Database / Short term projections Excel sheet (2)

Description of the columns: Columns are gathering public information such as: ○ Company ○ Country of the facility ○ Announcements (classified per Facility type, Entry into service, Expected capacity, Jet fuel production, Estimated credibility, Projected production capacity (kt/y in 2013, 2014, 1015, 2016, 2020) ○ Comments ○ Input (feedstock), Output (biofuels), Max. theoretical biofuel production (Kt/y), Max. theoretical biojet fuel production (Kt/y).

Figure 35: Database / Short term projections Excel sheet (column description)

The objective of the database is to have a tool to try to estimate, using the "Short term projection" sheet, the expected biofuel and the biojet fuel production volume, currently and for the short term, on a yearly basis: 2013 to 2020.
Since these estimates are only used for internal ICAO/AFTF prediction, this part in not included in this CORE-JetFuel report.

3.3 Database maintenance

ONERA, within the ICAO/AFTF organization, was in charge of the construction and maintenance of the database till mid-2015. In end of 2015 the FAA has offered to support Volpe to keep this database up to date regularly. Since the beginning of 2016 a 1st call conference with AFTF experts[13] working on this database was launched by Kristin Lewis to restart the activity. As in the past, database experts will continue to provide updates / announcements as they see them and the group, under the leader ship and secretariat from Kristin Lewis, can then update the file and keep it on the AFTF website." A face to face meeting was also performed on April 27th, 2016 in Alexandria taking the opportunity of the common CAAFI/CORE-Jet Fuel workshop, in order to update the database. The maintenance of the database will be based on this organization, mainly through e-mail communication and exchange, plus a few conference calls and, on request, face-to-face meetings, taking the opportunity of international alternative fuels seminars, workshops or conferences. These calls and face-to-face meetings are performed all over the year in order to discuss and to quote, on a consensus basis, the news, press releases and publications related to the evolution of existing projects, as well as new projects or project cancelation. This organization makes possible the update of the database in real time.

3.4 Data analysis at 1st level

This analysis could be performed in the future:

- by pilot/demo size and by project and capacity (TPD or TPY),
- by technology based on family pathways and taking into account the ASTM qualification level,
- by main feedstock pathways,
- by integrated processes or technology bricks.

3.5 Data analysis at macro level

This analysis could be performed in the future, and depending on data availability:

- by main zone (geography),
- by pathway maturity,
- by LCA/ GHG emission level if results are available (can be gathered in class such as 50-60%, 60-80% or >80% GHG decreasing),
- including co-products valorization and impact (if available) on LCA.

3.6 Database Table

Due to the size of the excel sheets, the database table is not printed in the report: a first idea is given on Figure 29 to Figure 35.

[13] N. Brown (US FAA), R. Boyd (IATA), N. Jeuland (Safran), K. Lewis (Volpe, US DOT), L. Lonza (EC/JRC), R. Malina (MIT), A. Quignard (IFPEN), M. Starples (MIT), C. Velarde (Ministry of Transport of Indonesia)

4 Conclusion

Biojet fuel qualification process under ASTM

ASTM qualification is a long and costly process, which is mandatory, before setting new jet fuel specifications and before the commercialization of the fuel can be pursued. It requires a large quantity of jet fuel, from about 38 to 380 m3, several years, e.g. 2 to more than 5 years, with a cost that can overpass US$10 millions. Nevertheless this cost is relatively marginal, when comparing to the mandatory step for the development of new biofuel process: the construction, and operation for a few years, of a big size pilot plant or demo plant, to demonstrate the proces and to be able to scale-up it with costs typically in the range of US$ 100 to a few hundred millions.

There are a lot of possible routes to make renewable jet fuels today, a few ones at, or near to, industrial level suitable for a short term production, other processes (most of them) being for the mid or long term. Range of feedstock that are suitable for each technology can differ a lot, as well as product slates that can also dramatically differ.

Today 5 routes are ASTM qualified: FT-SPK (Fisher Tropsch Synthesized Paraffinic Kerosene), HEFA-SPK (Hydroprocessed Esters and Farry Acids Synthesized ParaffinicKerosene), SIP (Synthesized Iso-Paraffins / Farenesane) from hydroprocessed fermented sugar, FT-SPK/A (Fisher Tropsch Synthesized Paraffinic Kerosene with alylated mono-Aromatics) and ATJ-SPK (Alcohol To Jet Synthesized Paraffinic Kerosene) through the isobutanol intermediate production. For the 5 qualified routes, all are based on isoparaffin kerosene with the exception of the fourth one based on isoparaffin kerosene plus the addition of alkylated aromatics.

A few more routes should/could be certified in the short term before the end of 2017, such as:

- Green Diesel or HFP (High Freezing Point) HEFA: it consists to directly incorporate HVO biodiesel in the jet A/A1 pool,
- the CHJ from ARA-CLG (Catalytic Hydrothermolysis Jet from Applied Research Associates and Chevron Lummus Global) process, from lipids through a catalytic hydrothermal conversion (hydrothermolysis) followed by an isoconversion to produce a synthetic jet fuel (called ReadiJet^{TM}) with a chemical composition similar to fossil jet fuel. Studies are completed and will be submitted to ASTM D02 ballot in order to submit a new annex to ASTM D02 with up to 50% in Jet A/A1,.

- HDO SK (Hydro-DeOxygenated Synthesized Kerosene) from Virent, recently renamed CPK (Cyclo Parrafinic Kerosene) is at ASTM steps 4/1 and could be approved in 2017, and blended up to 50% with jet A/A1.

Another route is proposed by Virent, HDO-SAK (Hydro-DeOxygenated Aromatic Synthetized Kerosene) that could be blended up to 25%, but the final qualification date is not yet well known.
There is also another ATJ route under ASTM qualification, but with no recent news and no known date for qualification: ATJ SKA (Alcohol To Jet Synthesized Kersone with Aromatics) from Lanzatech from industrial waste gas, rich in CO: currently only the ethanol production from industrial steel gas rich in CO is demonstrated, but not the final conversion to biojet fuel.

Apart these routes, these are also other pathways based on different biomass conversion technologies.

- Direct thermal conversion of biomass or fatty materials:

  - the Hydrotreated Depolimerized Cellulosic Jet also, called HDCJ route (KiOR) was supposed to be approved in 2014, but is currently in stand-by because of KiOR bankrupcy. Another route, called Hydrogenated Pyrolysis Oil (HPO) is very similar but still at the R&D level. So ASTM qualification of the Hydrogenated Pyrolysis Oil / Depolimerized Cellulosic Jet should not be completed before a couple of years, if completed.

- Alcohols to Jet or ATJ pathways, with one route already adressed and certified (ATJ-SPK/Gevo through isobutanol production and conversion to isoparaffins) and a second route under ASTM qualification:
  - ATJ-SKA through industrial waste gas, rich in CO, fermentation to alcohols and alcohols conversion to bio-fuel (Lanzatech, Swedish biofuels).

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

All these routes still have unique challenges, are region and/or feedstock dependent / specific, and have a higher, or a much higher cost, than current fossil jet fuel in 2015/2016.

Whatever is the considered biojet fuel process, the main challenges remain to reduce the feedstock cost and the production price, to develop the industry and to deploy the existing or near coming technological processes. For the mid and long term, advanced new conversion technologies, still at small pilot or big pilot plant or at demo unit level, will be necessary for further development at commercial scale for a large-scale deployment by airlines. More over the relatively low yields of biomass conversion to biofuels (range from 15 to 25 wt% on dried biomass), with even a lower yield if we focus on biojet fuel (range fro 10 to 15 wt% on a dry biomass basis), may also be a constraint related to the biomass availability with the future demand of biofuels and in light of the competition with terrestrial biofuels (road and rail). Currently the competition with sea and water transportation using biofuels to replace marine fossils fuels (marine gasoil and diesel, heavy distillate, light and heavy fuel oils, LNG,..) is not foreseen to be at a significant level in the next 10 years.

There is no unique solution and the right or best solution depends on many factors: the regional one, feedstock sourcing, availability and price, tax structure, product slate, value of co-products, envirommental impact (LCA including or not including LUC and iLUC) and the like.

Production of alternative fuels for aviation is still very limited today. It is produced by a small number of companies, primarily in Europe and the US, most of the time produced batchwise from HVO units, or continouly from medium size demonstration units, with the exception of AltAir retrofitted facility in Parammount, California, now producing biofuels and biojet fuels at industrial scale since March 2016, with a rather long term contract with United Airlines. The HEFA jet fuel production route is currently the most popular one, mainly using oils not in competition with food such as jathropha or camelina oil, animal fats and UCO. About 10 HVO industrial units are built or to be built in the near future. With the exception of AltAir in California, all are only producing biodiesel, but a biojet fuel production is possible adding or adjusting the second hydroisomerization step to meet the cold flow specification suitable for aviation fuels with a significant yield into jet fuel. Today, and for the near future, the main, and almost unique, industrial solution to produce significant quantities of biojet fuel at a price not too far from the current fossil jet cost is based on the HVO/HEFA technology. As done by AltAir, it is necessary to both secure the feedstock availability and price, as well as the jet fuel sales, by medium /long term contracts with feedstock purchasers and product users.

From a general point of view, a crude oil price not too far or above $/bbl 100 ((which is about twice the current price), should push forward the above technologies, close to, or yet at, industrial scale, in the medium term, with probably a biojet fuel production cost close to jet A/A1, and should justify decision to invest for the production of alternative jet fuels.

Multiple demonstration and commercial flights have taken place demonstrating the technical viability of alternative drop-in fuels. A publicly available database, called BiojetMap, has been performed within the High Biofuel Blends in Aviation (HBBA) European project with a graphic interactive database of the flights run with alternative fuels worldwide, established from published data and completed by information from industrial parties.

Recommendations to the European Commission

Recommendations to the European Commission, issued from the CORE-JetFuel members, as well as from a dedicated phone meeting with the stakeholders and from the final project workshop held in Brussels in mid-June 2016, are detailed in a specific chapter of this report and briefly reminded below:

- Keep monitoring deployment / implementation initiatives with a critical expert analysis
- Develop initiatives connecting the stakeholders engaged in alternative aviation fuels
- Decrease the industrial risk to scale-up production
- Improve production costs and biojet fuel implementation / deployment
- Improve the understanding of the properties of biojet fuels
- Optimize and improve the use of ASTM D4054 process, through a better understanding between the chemical structure and the properties of the fuels and taking into account the feedback of the approved routes
- Pay attention to logistic and quality insurance.

Database

In that highly moving world, especially in the field of biofuels and biojet fuels, new processes and new initiatives are announced quite often, even if the rate of annoucements declined since about one year, some projects may also disappear, firms may face bankrupcy or may be purchased by other firms and it is compulsory to get a comprehensive and updated view on the state of maturity of each announcement (lab- scale, pilot unit, demo unit, industrial production).

This is why an important task in the CORE-JetFuel project is the collection, mapping and evaluation of information related with the most promising research and innovation activities addressing technical compatibility, certification of new technical pathways and value-chain deployment projects and initiatives, with the construction of a database.

An identification and information gathering the most promising deployment initiatives and industrial value-chains under development worldwide were performed.
Since it is a very important work 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 worldwide shared base.
The focus is on “advanced alternative fuels” that could have an application in aviation. The production step of ethanol itself as an intermediate product feedstock for alcohol-to-jet is not included, but ATJ

routes are considered. The file currently mainly includes announcements by industry or processes at large scale pilot plant or demo level.
The database is organized into two Excel sheets. A first sheet called "Announcements" provides all the data collected. A second sheet called "short term projections" is dedicated to the building of projections for a number of scenarios. The final objective is to have the right shared/controlled data to be able to build the alternative biojet fuel projection.

A group of ICAO/AFTF experts[14] is providing updates / announcements by setting a number of criteria. The group, under the leader ship and secretariat from Volpe, with support of US FAA, can then update the file and keep it updated on the AFTF website. Call and face to face meetings within the group are performed all over the year in order to discuss and to quote, on a consensus basis between experts, the news, press releases and publications related to the evolution of existing projects, as well as new projects or project cancelation. This organization makes it possible to update the database in real time. Today the database is only available for ICAO members.

The data base is useful to easily find any data on biojet fuel pathways and current or predicted possible alternative jet fuel production, to quickly know about the status of deployment initiatives and to make projection for the future of biojet fuel production, based on shared data that have been reviewed and classified/"criticized" by the panel of experts.

[14] N. Brown (US FAA), R. Boyd (IATA), N. Jeuland (Safran), K. Lewis (Volpe, US DOT), L. Lonza (EC/JRC), R. Malina (MIT), A. Quignard (IFPEN), M. Starples (MIT), C. Velarde (Ministry of Transport of Indonesia)

5 Bibliography

Airbus: internal communication

ASTM D02 meeting, December 2014, internal communication

ASTM D4054-14 Standard: Guideline for the Qualification and Approval of New Turbine Fuels and Fuel Additives

ASTM D7566-16: Standard Specification for Aviation Turbine Fuel Containing SynthesizedHydrocarbons

Biojet Map public web site, Available http://www.biojetmap.eu/#31080 (last visit 09/08/2016)

Bridgwater et al, 2004

Brown N., (US FAA), May 18, 2012, *Sustainable Alternative jet Fuel, Update on ASTM Approval*, Available https://www1.eere.energy.gov/bioenergy/pdfs/10_brown_roundtable.pdf (last visit 09/08/2016)

Csonka S. (CAAFI), April 28, 2016, *CAAFI – CORE-JetFuel Cooperation Workshop*, Alexandria, Virginia, Available http://www.caafi.org/information/pdf/2_Intro_Csonka_CAAFI_04282016.pdf (last visit 09/08/2016)

Coppola EN. et al, (ARA), Nov. 2013, *Production of Unblended, "Drop-in," Renewable Jet Fuel*, Paper ID#325066, AIChE annual meeting,, Available http://www3.aiche.org/proceedings/content/Annual-2013/extended-abstracts/P325066.pdf (last visit 09/08/2016)

Cortright R. D. (Virent), July 30, 2014 ,*Virent is Replacing Crude Oil*, Biomass 2014, Available http://energy.gov/sites/prod/files/2014/11/f19/cortright_biomass_2014.pdf (last visit 09/08/2016)

Holladay J., Albrecht K., Hallen R. (PNNL), November 5, 2014, *Innovative concepts for carbon neutral growth,* Japan Aviation Environmental Workshop, Available http://aviation.u-tokyo.ac.jp/eventcopy/ws2014/20141105_07DOE%EF%BC%BFHolladay.pdf (last visit 09/08/2016)

Holladay J. (PNNL), November 14, 2014, *Refinery Integration of Renewable Feedstocks*, CAAFI R&D SOAP-Jet webinar series, Available http://www.caafi.org/information/pdf/Refinery_Integration_of_Renewable_Feedstocks_Nov142014.pdf (last visit 09/08/2016)

Holladay J. (PNNL), June 9, 2015, *Jet fuel advances in bio-oil and alcohol upgrading*, CORE-JetFuel Sustainable alternative aviation fuels Workshop Vienna, Available http://www.core-jetfuel.eu/Shared%20Documents/6-CORE-JetFuel-Workshop_Aviation%20Fuels_Vienna_PNNL_Holladay.pdf (last visit 09/08/2016)

IFPEN and Dynamotive, 2015, internal communication

Johnston G. (Gevo), June 2013, *Alcohol to Jet (ATJ)*, Gevo Airshow 2013, Available http://www.alternativefuelsworldwide.com/presentations/Gevo%20Paris%20Airshow%202013.pdf (last visit 09/08/2016)

Johnston G.(Gevo), June 24th, 2015, *presentation at Alcohol-to-Jet Synthetic Paraffinic Kerosene Task Force*, ASTM D02 Committee week-FT Lauderdale, no web link found

Loescher M. (KiOR), September 2013, *The Path to Commercialization of Drop-in Cellulosic Transportation Fuels*, tcbiomass Conference, Chicago, Available to participants to tcbiomass 2013 http://www.gastechnology.org/news/Pages/tcbiomass2013-Announces-Call-for-Papers.aspx

Marchand P. (Total New Energy), 20-22 October 2014, *Amyris-Total Biojet Fuel, Breakthrough Solution for Aviation*, Sustainable Aviation Forum, Madrid, Available http://www.core-jetfuel.eu/Shared%20Documents/Philippe_Marchand_AMYRIS_TOTAL%20Biojet_Fuel.pdf (last visit 09/08/2016)

Michel J., (FNR), April 28, 2016, CAAFI – CORE-JetFuel Cooperation Workshop, Alexandria, Virginia, Available http://www.caafi.org/information/pdf/4_Intro_Michel_FNR_04282016.pdf (last visit 09/08/2016)

Perego C. (eni s.p.a., Centre for Renewable Energy and Environmental Research), February 16-17, 2015, *From biomass to advanced biofuel: the greendiesel case*, Sinchem Winter School, Bologna, Available http://www.sinchem.eu/wp-content/uploads/2015/01/15-Perego-ENI.pdf (last visit 09/08/2016)

Rumizen M. (US FAA), May 3, 2016, Aviation Technical Committee Meetings of CRC, Alternative Jet Fuel Update, Alexandria, VA, Available to participants to the CRC May 2016 meeting http://www.crcao.com/workshops/2016_CRC_Aviation_Meetings/index.html last visit 09/08/2016)

Van den Wall Bake, J. D., Junginger, M., Faaij, A., Poot, T. & Walter, A., 2009*, Explaining the experience curve: Cost reductions of Brazilian ethanol from sugarcane,* Biomass and Bioenergy, 33(4), 644-658.