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Sustainable Aviation Fuel 'Facilitation Initiative'

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Consortium leader: Envisa
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SUMMARY

Aviation is one of the most difficult sectors to decarbonise, as evidenced by the fact that it is one of the few sectors for which annual emissions have increased in the EU since 1990. Whilst aviation only accounted for 3.6% of total EU28 Greenhouse Gas (GHG) emissions in 2016, the figure has more than doubled since 1990. Sustainable Aviation Fuels (SAFs) still play a minor role in the industry (accounting for only 0.004% of total jet fuel used by commercial operators worldwide in 2017), but they are nonetheless seen as one part of the strategy to decarbonising aviation, and one that can reduce emissions from the existing aircraft fleet given its compatibility with existing engines and fuel infrastructure. The International Civil Aviation Organisation's (ICAO) 2050 Vision for Sustainable Aviation Fuels highlights the fact that aviation does not have an alternative to liquid fuels as a source of energy, unlike other sectors such as road transport, and hence calls for a 'significant proportion of conventional aviation fuels to be substituted with sustainable aviation fuels by 2050'.

There are several significant barriers that are limiting the uptake of SAF; these can be broadly split into three categories, namely technical, environmental and commercial. For a SAF to be viable it must meet challenging technical performance and quality criteria i.e. be technically suitable, be truly sustainable in both production of raw materials and processing, and, be available in sufficient quantities at a commercially competitive price, even when accounting for subsidies or other fiscal incentives that may be available. However, one of the most significant barriers to entry for a new SAF is specification approval. Any new aviation fuel must be shown to behave sufficiently similarly to conventional jet fuel to gain approval and be considered suitable for use and further be classed as a "drop-in" product. The process of approval can be an expensive and long one; the cost, volumes of fuel required and time for approval can mean potential sustainable fuel producers will favour using their product in other less challenging and lower risk markets, such as road fuels.

This study examined how a 'Sustainable Aviation Fuels Facilitation Initiative', led by the European Aviation Safety Agency (EASA), could promote increased uptake of SAFs in Europe. The report begins by analysing the status of SAFs in Europe today, including both more established technologies and ones at a lower Technology Readiness Level (TRL), and highlights the fact that SAF penetration in the continent is extremely low today, partly due to the absence of any significant production capacity. However, European production is set to increase significantly in the medium term; it is plausible that SAF production capacity within Europe could reach 500,000 tonnes per year by the mid 2020s.

Due to the limited availability of data on SAF usage today, it is difficult to estimate the CO_2 savings being achieved. EASA's Environmental Portal could in future act as a central repository for such data, which would be collected via reporting mechanisms from various organisations (e.g. EU, ICAO, IATA).

The report reviews one of the major solutions to the obstacle of navigating the SAF approval process, namely the US Clearing House run by the University of Dayton Research Institute and funded by the Federal Aviation Administration (FAA). The issue of sustainability is also examined, via an analysis of the role of Sustainability Certification Schemes (SCS) and how they interact with regulatory sustainability requirements, particularly those in the EU's Renewable Energy Directive (RED II) and ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Through interviews with a wide range of stakeholders, summaries of which are included in the Appendix to this report, the best form of European facilitation initiative has been identified. This study recommends that such an initiative be divided into two separate bodies, the first acting as an EU Clearing House (cooperating closely with the US Clearing House) and the second acting as a stakeholder forum, similar to the Commercial Aviation Alternative Fuels Initiative (CAAFI) in the US. Of the two feasible EU Clearing House models examined, the one more fully integrated with the US Clearing House is recommended as the way forward, at least initially. Activities carried out by an EU Clearing House would include:

- Providing guidance to SAF producers on the prospects of their products to gain approval under ASTM D4054, via 'pre-screening'. This could follow the US model, using the concept of Tier α and Tier Zero testing, which combine laboratory analysis using very low fuel volumes with modelling to 'pre-screen' a fuel before entry into the D4054 process, or attempt to make use of European research on model-based pre-screening (via the JETSCREEN programme for example)
- Bringing together data on fuel composition, physical and performance properties collected via extensive testing as part of research programmes in the EU and the US. This can be used to provide guidance to producers.
- Once producers enter the D4054 process, acting as a link between the producer and OEMs, providing guidance on which tests need to be carried out, carrying out and funding those tests. The funding mechanism for this could follow the US model, in which the Clearing House receives funds from a government research programme then allocates them to producers on a case-by-case basis, based on assessments of the candidate fuel. Potential funding sources include EASA or the EU.
- Working with testing facilities to produce the required research reports following testing, and funding European OEMs to review those reports. The funding mechanism for this could follow the US model, in which funds from a government research programme are channelled to OEMs via the Clearing House, and capped at 50% of total review costs, which can – roughly – reach €100,000 per OEM
- Providing guidance on the various sustainability certification schemes available for SAF producers, and on the sustainability requirements for meeting national and supranational regulations in Europe, including RED II
- Providing guidance on commercialisation options, which could include highlighting research programmes which may be able to provide funding, highlighting any available financial instruments which can be utilised and providing an overview of the status of any mandates which may be in place in certain countries

- Collaborating closely with the US Clearing House and engaging with ASTM to increase European representation in the community

The recommended stakeholder forum could either build on existing arrangements, such as DG ENER's Alternative Renewable Transport Fuel Forum (ARTFF), which already brings together many of the required stakeholders, or be a new initiative run solely or jointly by EASA and more focused on aviation fuels. Some of the stakeholder groups whose involvement would be required are SAF producers, airline operators, member states, EU bodies and aviation Original Equipment Manufacturers (OEMs). The forum's activities would include:

- Supporting the EU Clearing House, specifically by coordinating funding, which could come from EASA or from the European Commission (EC)
- Increasing communication between national governments and European regulatory bodies to deliver a coherent message on SAFs (with the potential aim of introducing EU-wide production targets and/or amending exist regulations such as RED II to further boost SAFs)
- Focusing on increased engagement and coordination of OEMs and other key stakeholders e.g. military groups to accelerate cross-industry approval, for instance to eventually allow the use of shared civil/military infrastructure to transport synthetic fuels including SAFs
- Increasing awareness of the regulatory status of approved SAFs, via EASA's Safety Information Bulletins
- Attempting to help SAF producers overcome commercialisation challenges by providing advice and guidance on commercialisation options and potentially through the establishment of a fund led by the EC and member states

CONTENTS

ABBREVIATIONS

ACRONYM	DESCRIPTION
2BSvs	Biomass Biofuels voluntary scheme
ANCdb	Aircraft Noise Certificates
ANPdb	Aircraft Noise and Performance
APU	Auxiliary Power Unit
ARTFF	Alternative Renewable Transport Fuels Forum
Bio-JET	Bio Jet fuels and Engine Co-opTimization
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAEP	Committee on Aviation Environmental Protection
CB	Certification Body
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DoE	Department of Energy (US)
EASA	European Union Aviation Safety Agency
EC	European Commission
ECNLdb	EASA Certification Noise Levels
EDA	European Defence Agency
EEA	European Economic Area
EIB	European Investment Bank
ETS	Emissions Trading Scheme
EU	European Union (EU28)
FAA	Federal Aviation Administration
FAME	Fatty Acid Methyl Ester
FRED+	Fuel Reporting & Emissions Database
FRL	Fuel Readiness Level
FT	Fisher-Tropsch
GHG	Greenhouse Gas
HEFA	Hydro-processed Esters and Fatty Acids
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ILUC	Induced Land Use Change
ISCC	International Sustainability and Carbon Certification
kt	Kilotonnes
LCA	Life Cycle Analysis
LCFS	Low Carbon Fuel Standard
Mn	Million
MoD	Ministry of Defence (UK)
Mt	Megatonnes
NJFCP	National Jet Fuels Combustion Programme

NPS	NATO Pipeline System
OEM	Original Equipment Manufacturer
RED	Renewable Energy Directive
RFNBO	Renewable Fuels of Non-Biological Origin
ROM	Rough Order of Magnitude
RSB	Roundtable for Sustainable Biomaterials
RSPO	Roundtable on Sustainable Palm Oil
RTFO	Renewable Transport Fuel Obligation
RTRS	Roundtable on Responsible Soy
SAF	Sustainable Aviation Fuel
SAF SIG	Sustainable Aviation Fuel Special Interest Group
SAIB	Special Airworthiness Information Bulletin
SCS	Sustainability Certification Scheme
SIB	Safety Information Bulletin
SQC	Scottish Quality Crops
SSAP	Soybean Sustainability Assurance Scheme (US)
SWAFEA	Sustainable Way for Alternative Fuels and Energy in Aviation
TRL	Technology Readiness Level
UDRI	University of Dayton Research Institute
UK	United Kingdom

1. Introduction

1.1 Background

Aviation is one of the most difficult sectors to decarbonise, as evidenced by the fact that it is one of the few sectors for which annual emissions have increased in the EU since 1990[1]. Whilst aviation only accounted for 3.6% of total EU28 Greenhouse Gas (GHG) emissions in 2016, the figure has more than doubled since 1990[2]. Sustainable Aviation Fuels (SAFs) still play a minor role in the industry (accounting for only 0.004% of total jet fuel used by commercial operators worldwide in 2017[3]), but they are nonetheless seen as one part of the strategy to decarbonising aviation, and one that can reduce emissions from the existing aircraft fleet given its compatibility with existing aircraft, engines and fuel infrastructure.

The International Civil Aviation Organisation's (ICAO) 2050 Vision for Sustainable Aviation Fuels highlights the fact that aviation does not have an alternative to liquid hydrocarbon fuels as a source of energy, unlike other sectors such as road transport, and hence calls for a 'significant proportion of conventional aviation fuels to be substituted with sustainable aviation fuels by 2050'[4]. The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), developed by ICAO, will come into effect from 2021 and aims to ensure that ICAO achieves its goal of carbon-neutral growth from 2020 onwards. CORSIA will help to achieve this by mandating that all emissions from international aviation which exceed a baseline level must be offset by the sector through the purchase of emissions units from the carbon market[5]. The additional cost to using conventional aviation fuel will encourage the increased use of SAFs.

Except for the possible electrification of regional aircraft, aviation has no other energy options in the short and medium term than to use aviation jet fuel (aviation kerosene) that performs within accepted norms for conventional fossil derived fuels. Basically, no other forms of energy storage can compete with aviation kerosene with regard to energy density per unit mass or volume and therefore use of alternative technologies such as battery powered engines would create severe compromises for aviation. It is also worth bearing in mind that current commercial aircraft are designed on the assumption that during landing most of the weight of fuel has been used, whereas with battery power the weight is still on board, increasing stresses and also minimum landing speed. Studies have been carried out looking at liquefied gases such as methane, natural gas and hydrogen but again technical problems and poor energy density bring about severe compromises. Kerosene based fuels are therefore the only option in the near to mid-term, or, until there is a step change in energy storage technology.

There are currently several significant barriers that are limiting the uptake of SAF; these can be broadly split into three categories, namely technical, environmental and commercial. For a SAF to be viable it

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[1] https://www.eea.europa.eu/data-and-maps/daviz/ghg-emissions-by-aggregated-sector-2#tab-dashboard-01
[2] https://www.easa.europa.eu/eaer/topics/overview-aviation-sector/emissions
[3] https://aviationbenefits.org/media/166344/abbb18_full-report_web.pdf
[4] https://www.icao.int/environmental-protection/GFAAF/Pages/ICAO-Vision.aspx
[5] https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx

must meet challenging technical performance and quality criteria i.e. be technically suitable, be truly sustainable in both production of raw materials and processing, and, be available in sufficient quantities at a commercially competitive price, even when accounting for subsidies or other fiscal incentives that may be available. Whilst all these requirements are closely intertwined, commercial feasibility can often remain as the final hurdle, even for a SAF which gains approval and proves sustainability. Nevertheless, one of the most significant barriers to entry for a new SAF is specification approval. Any new aviation fuel must be shown to behave sufficiently similarly to conventional jet fuel to gain approval and be considered suitable for use and further be classed as a "drop-in" product. Such fuels have thus far been based on sustainably produced blend stock blended with conventional fuels at stipulated levels up to 50% in some cases. The process of approval is necessarily rigorous and can therefore be an expensive and long process (discussed in detail later). The cost, volumes of fuel required and time for approval can mean potential sustainable fuel producers may favour using their product in other less challenging markets. At this point it should be noted that many of the sustainable blendstocks in the middle distillate range could much more easily (with less, often energy intensive processing and less testing for approval) be used in other lower performance fuels such as road and/or marine diesel. There is therefore also the effective barrier of competition for these blendstocks to not be used in aviation. The stakeholders consulted for this study (see Appendix Annex B) suggested various options to address this issue, ranging from introducing strict SAF use mandates (as was done for biodiesel in road transport) or new taxes on fossil jet fuel to easing the burden of the approvals process. Clearly, no one solution is ideal and most face barriers to their implementation.

Recognising the major obstacle posed by the approval process, the United States set up a D4054 'Clearing House' which provides advice and support on the approval process, carries out and/or coordinates the necessary tests required and funds Original Equipment Manufacturers (OEMs) to review the research report produced based on the tests done (as required by the D4054 standard). This Clearing House is funded by the Federal Aviation Administration (FAA) and has so far proved useful for new fuel producers.

More broadly, the aviation industry recognises the technical challenges of producing SAF that is technically suitable and achieving industry approval. Several ongoing initiatives aiming to ease these challenges are reviewed in this report, including:

- Streamlining the approval process for products which meet specific criteria with regard to similarity to previous products thus far approved i.e. Fast Track Process.
- The aforementioned US Clearing House which serves to financially and technically support potential SAF producers.
- Developing the option for co-processing bio derived and Fischer-Tropsch (FT) synthetic crudes hence allowing the use of sustainable feedstocks in a conventional refinery which may ultimately end up in the jet fuel fraction. Currently there is consideration to create a UK version of the Clearing House[6].
- Work is ongoing to be more intelligent in predicting fuel performance in use based on fuel testing at small scale and thus avoid the need for rig and/or engine scale testing. This work

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[6]UK Aviation Fuel Testing: Analysis of opportunities, May 2019, Element Energy

could provide pre-screening prior to ASTM evaluation to reduce risk and/or reduce the need for higher tier (i.e. larger scale and cost) testing.

- Research into expanding the allowable envelope of fuel composition and hence performance to enable the more efficient and environmental production of SAF blendstock.

1.2 Scope of work

This study aims to determine how best EASA can support the increased penetration of SAFs in the European aviation fuel market, through the formation of a 'Sustainable Aviation Fuels Facilitation Initiative'. Through interviews with various stakeholders, the study aims to outline the form of such an initiative, the stakeholders involved, and the main activities it would carry out. Given the importance of the approvals process, the US Clearing House is used as a model, and the potential of collaboration between it and any European initiative is examined. For ease of reading, the prospective European facilitation initiative is referred to as an 'EU Clearing House' in this report. The exact name of any future initiative is yet to be decided.

The study also reviews the current state of the SAF market and its future outlook. This includes a survey of all major producers and end-users today, an estimate of the volumes currently in circulation and a survey of the most promising early-stage technologies and research projects being carried out today. On the sustainability side, the study includes a brief overview of the various sustainability certification schemes in existence today in addition to an overview of the sustainability requirements of various national and supranational regulations.

This work is in fulfilment of EASA Specific Contract 5, Task 3 (ii). Close collaboration with César Velarde, who is completing Task 3 (i), has been ensured to avoid any duplication of effort, and reference is made to that work where applicable.

The remainder of this report is structured as follows:

- Chapter 2 assesses the status of SAFs in Europe today. It includes a list of currently approved production processes, an overview of the most prominent low Technology Readiness Level (TRL) processes and predictions of future production volumes. The potential of EASA' Environmental Portal to act as a repository for data on SAF use is also discussed.
- Chapter 3 summarises the current SAF approval process, with a focus on ASTM, and lists the main European facilities with the capability to carry out the testing required for approval
- Chapter 4 reviews the main Sustainability Certification Schemes (SCS) in existence today and the sustainability requirements of various national and international regulatory schemes
- Chapter 5 presents recommendations for a European forum or Clearing House which would work to support increasing the penetration of SAFs in Europe, based on the review of the main barriers to SAF development and the initiatives in place in the US
- Chapter 6 concludes the report and proposes next steps

2. Assessment of current and future SAF production volumes across Europe

2.1 Approved products and those going through ASTM D4054 evaluation

Appendix **Error! Reference source not found.** provides a summary of the currently approved products nd those that are currently in the evaluation process (at the time of preparing this report). Note the review in this Appendix only addresses the technical readiness levels and does not pertain to the financial/commercial aspects (funding and company size, ability to commercialise or likely volumes etc.) or environmental (CO_2 and/or other benefits or status of whole life cycle analysis etc.) status which are discussed elsewhere (see section 4.1).

2.2 Summary of current production volumes and main producers

See Sustainable Aviation Fuel 'Monitoring System' report for more information[7]

Worldwide, Sustainable Aviation Fuel (SAF) production and use today are both extremely limited, with total volumes produced equal to less than 1% of total jet fuel demand[8] and total volume used equal to less than 0.005% of total jet fuel use (14 million litres in 2017)[3]. The most recent Energy, transport and environment indicators book from EuroStat[9] does not include any specific indicators for SAF use or the associated Greenhouse Gas (GHG) emissions reductions, making it difficult to estimate the volume of (SAF) in circulation in Europe. However, all 290 member airlines of the International Air Transport Association (IATA) report their fuel use via the Fuel Reporting & Emissions Database (FRED+). Airline operators also submit emission reports to comply with the EU's Emissions Trading System (ETS).

The International Civil Aviation Organization (ICAO) keeps a record of announced offtake agreements of SAFs[10]; this includes as a minimum a record of the producer and the buyer, with additional information on the airports where the product will be used and offtake production per year provided where available. Table 1 summarises published offtake agreements involving European SAF producers and/or airlines.

[7] https://www.easa.europa.eu/document-library/research-reports?search=&research_area%5B%5D=53&research_theme=All&status=All

[8] https://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-alternative-fuels.pdf

[9] https://ec.europa.eu/eurostat/documents/3217494/9433240/KS-DK-18-001-EN-N.pdf/73283db2-a66b-4d34-9818-b61a08883681

[10] https://www.icao.int/environmental-protection/GFAAF/Pages/Facts-Figures.aspx

Table 1 Summary of SAF offtake agreements involving European producers and/or buyers

Producer	Buyer	Airport	Production (mn gallons/y)	Agreement length (years)
Air BP	Avinor	Bergen	Not available	Not available
Air BP	SAS / BRA / Kalmar Municipality	Kalmar	0.026	3
Fulcrum	AirBP	N/A	50	10
Gevo	Lufthansa	Not available	8	5
World Energy (AltAir)	SkyNRG / KLM	Los Angeles International	Not available	3
World Energy (AltAir)	SkyNRG / KLM	Växjö Småland airport	0.032	0.5
World Energy (AltAir)	Swedavia	Stockholm Arlanda, Stockholm Bromma, Göteborg Landvetter, Visby Luleå,	0.148	Not available
World Energy (AltAir) / Neste	KLM / SAS / Lufthansa / AirBP	Oslo	0.33	3
World Energy (AltAir) / Shell	SkyNRG / KLM / SAS / Finnair	San Francisco International	Not available	Not available

Table 1 shows that the number of established SAF producers is very limited, and that practically all of those are based in the US. This is likely to be in part due to increased support provided for SAF producers in the US, for example via the Commercial Aviation Alternative Fuels Initiative (CAAFI) and the US Clearing House (see sections 5.2 and 5.4) and stronger incentives to use SAFs, notably California's Low Carbon Fuel Standard (LCFS). There is no long term continuous SAF supply in Europe today, however SkyNRG recently announced that it will be developing Europe's first SAF plant in the Netherlands, scheduled to open in 2022 with a production capacity of 100,000 tonnes per year. Of that, KLM has committed to purchase 75,000 tonnes per year for 10 years[11].

2.3 Low TRL fuels

As well as the large number of projects related to the large-scale production of Sustainable Aviation Fuels (SAFs) within the EU, many research-focused programmes are funded for development by individual member states, as well as the EU directly. These projects tend to be smaller in scale, from a Technology Readiness Level (TRL) level of 1 – 5, and have a proportionally higher level of uncertainty regarding the potential contribution they finally will make to a future supply of SAFs within Europe. These projects form a key element to the European Commission's (EC) European Strategic Energy Technology (SET) Plan which has the overall objective to accelerate the development and deployment

[11] https://skynrg.com/press-releases/klm-skynrg-and-shv-energy-announce-project-first-european-plant-for-sustainable-aviation-fuel/

of low carbon technologies through collaboration between EU countries, companies, research institutions and the EU itself.

Most of the research and development projects have a focus on particular fuel production technologies and are briefly reviewed below in Table 2 in a non-exhaustive listing. Several projects however are focused on other aspects of fuel use in aviation gas turbines, specifically the impact of the fuels approvals process on the quality of the product and the effort and cost required in the production phase to achieve the quality required.

Many low TRL technologies have initially been developed for producing an intermediate product (such as bio derived butanol) which can then be upgraded to a jet fuel product via more established routes, or alternatively taking technologies developed for the automotive diesel market with a belief that these can be adapted to produce a Jet A-1 product. This step is challenging for many technologies as will be described below and in projects such as SWAFEA[12] and JETSCREEN[13]. There is perhaps a need for the aviation sector to undertake some wider fuel industry engagement activities to educate the fuels production community on the specific, technical requirements of aviation fuels and the approvals process for new fuels as there seems to generally be a lack of appreciation for the technical challenge outside of the sector. SWAFEA recommended a technical network be established in Europe in 2009 for fuel Evaluation; JETSCREEN (2017 – 2020) is the direct successor of that role, but is only of limited funding. The SAF Special Interest Group (SAF SIG) and the NewJET network in the UK offer complementary platforms for discussions, however, no Europe wide group has been further supported at the time of writing.

The principle aim of these projects has been in demonstrating the production of an aviation compatible fuel with a view to approval through the ASTM D4054 process. In most cases the D4054 process is considered as outside the scope of the project. As such, the timescales of the projects as indicated below should not be viewed as a schedule for when these fuels will become available, rather when the uncertainty associated with the particular production technology may be lowered. In almost all cases, the high standard of purity required for fuels to complete the D4054 process has meant that the produced sustainable fuels have a high production cost[14] – between 2 to 8 times that of conventional jet fuel[15] – which is consequently a disincentive to their use whilst conventional refined aviation fuel prices remain low. This can be viewed as one of the principle reasons why the uptake of SAFs has been below initial expectations. This may in some part be rectified by the advent of compulsory CO_2 trading or taxation schemes such as the ICAO CORSIA scheme in 2021. In any event, the current low cost of conventionally refined aviation fuel limits the potential for any alternative fuel production route. This reinforces the status quo that fuel is a commodity that is bought in and burnt, driving the cost down as low as possible, even below that of diesel and gasoline.

Although less common, several projects (SWAFEA (2009–2011) AlfaBird (2008-2012), and Boeing Green Diesel (currently in the D4054 process) have proposed an alternative approach by assessing the cost and benefit of broadening the allowed blendstocks in jet fuel to permit fuel with a lower

[12] https://www.icao.int/Meetings/EnvironmentalWorkshops/Documents/2011-SUSTAF/18_Novelli.pdf
[13] Rauch, B.; 'JetScreen'. Available at https://www.jetscreen-h2020.eu/
[14] https://www.iea.org/newsroom/news/2019/march/are-aviation-biofuels-ready-for-take-off.html
[15] https://www.ft.com/content/bee21390-9297-11e9-b7ea-60e35ef678d2

production cost (both financially and environmentally) from a wider range of feedstocks and production pathways. This is challenging as the cost of raw materials can be a constraint. In some cases, the raw material is more expensive than the final jet product, even before processing. It is also possible that such fuels may offer performance advantages in flight compared to conventional fuels, and could be viewed as an enabler of new technologies rather than simply just a commodity product. This approach has the potential to permit lower cost materials to be produced for flight, although there may be a need to limit the flights which can use this fuel. This could include:

- lowering the aromatic content requirement of fuels or relaxing the freeze point limitations of the specification. The former of these will also considerably reduce the non-CO_2 related emissions from flight, such as particulate matter impact on contrails and cirrus cloud formation, as well as having a positive impact on local air quality

Lowing the sulphur content of fuels, reducing soot and SOx emissions

The technical and safety challenge associated with having a number of fuel grades at an airport is yet to be assessed; the recently awarded EPSRC NewJET project will attempt to make this assessment, and it may be a necessary component of the forthcoming H2020 SmartAirports call.

Of a similar approach are the projects proposing an advanced fuel, beyond the specification, to a higher grade well beyond the energy content per unit mass and volume of conventional fuel, resulting in a more energy dense fuel, such as the US FAA funded Advanced Fuels Programme (ending in 2019) and the US Department of Energy (DOE) high performance jet fuels (Bio-JET) programme. The DOE is also funding the Bio-Jet fuels and Engine co-optimization (CO-OPTIMA) programme which is focused on the parallel optimisation of IC engines and fuel, involves developing lower cost novel production pathways for advanced fuels and quantifying the added value of those fuels. This idea has previously been developed by fuel companies such as Shell and their Shelldyne product produced in the 60s – 70s. In all cases of advanced fuels and several performance enhancing additives, the cost of such products has been a disincentive to their use and production has been limited or has ceased completely.

The approach of optimising the fuel specification and hardware combination is a complementary potential means of reducing overall aviation emissions to the current efforts where the fuel specification is “fixed”. Changing the industry in this way is disruptive and is therefore seen as a longer-term solution but efforts should be run in parallel to the current approach of making existing fuels more environmentally friendly.

Within the CO-OPTIMA programme, eight representative blendstocks from chemical families are currently undergoing detailed investigation: alcohols (ethanol, iso-propanol, n-propanol, and iso-butanol); ketones (cyclopentanone); furans (a 40:60 mixture by weight of methylfuran:2,4-dimethylfuran); alkenes (di-isobutylene); and high-aromatics mixtures. The fuel production technologies developed for other transport sectors are of interest to the aviation community. As with conventional, fossil feedstocks, the most economic production process for SAF fuels may be as a one of a slate of sustainable products and synergies between the final products must be considered.

A number of projects are developing purely synthetic products for the road market, such as synthetic diesels which, unlike biodiesel (FAME) products and biobutanol, do not require blending to be compliant with European production standards. These projects have been included in the table below as they are proposing using the same feedstocks and pathways as the SAF market.

Projects such as 2synfuel and the aviation specific flexJET offer an alternative approach to reduce the cost of the HEFA product by producing the hydrogen required for the hydrotreatment step from waste materials such as sewage sludge, or other low-grade waste materials such as food and market wastes. Such integration of processes may also offer a route to also lower the environmental impact of fuel production, through heat recovery between processes as demonstrated by H2020 programmes such as Heat-to-Fuel.

Finally, projects such as BioMates have taken an alternative approach to support the production of a synthetic oil component for co-processing with conventionally refined crude oil. Although only one feedstock for such components is currently approved, several other routes are applying for approval and this may offer a low cost for sustainable fuel production in comparison with the high energy cost associated with the D4054 routes. This is currently an emerging trend, with the approval of co-processing of fatty acid ester feedstocks and the presentation of FT-waxes as a potential product to go through similar approvals process.

The problem of producing a SAF product for the open market is not based solely on the technology for production. A number of European projects are also developing supply chain networks for the provision of bio sourced feedstocks either in regions of the EU, or across the whole of Europe (SecureCHain and uP_running). As these activities are close to the commercial demonstration stage, they are not included in this section of the report.

The research community has recognised the need to streamline the fuels approvals process, in order to permit early identification of feedstocks and pathways with high levels of promise and to provide guidance and feedback to potential fuel producers throughout the process of developing an aviation specific product. To these ends, several research programmes including JETSCREEN, the NJFCP in the US (and outside of aviation, ADVANCEFUEL) have sought to produce modelling tools to predict fuel performance from detailed knowledge of the fuel chemistry alone. These tools are collectively being known as Tier Alpha and Tier Zero steps to the formal D4054 approvals process (see section 3.1). These modelling tools have the additional advantage of replicating large scale testing in-silico and reducing the cost and fuel volume required from smaller fuel producers (see section 5.1.2).

Table 2 Overview of low TRL (Research Project) fuel pathways (with established production pathways added for context)

Feedstock	Source	Production Pathway	Research Project	FRL[16]	Approved (Y/N/Not jet fuel)	Volume	Comments
Crude oil	Mining	Refining		10	Y		Large scale production
Coal	Mining	Fischer Tropsch + processes to provide heavier molecules		10	Y		As a 100% replacement product or blendstock.
Natural gas	Mining	Fischer Tropsch		10	Y		As blend component
Oils and Fats	Diverse	HEFA	Bio4A flexJET burnFAIR	9	Y	>5kt 1.2kt 1.6kt	As blend component
		Syn gas to FT		7	Y		As blend component
		Bio crude		8	Y		Coprocessed material
Lignocellulosic materials	Waste / Agriculture	Lignin to Jet		4	N		
		Hydrothermal Liquefaction	HyFlexFuel	4	N		Produces fertiliser as byproduct
		Depolymerized sugars (SIP – DSHC)		6	Y		As blend component
		Syn gas to FT	ComSym	6	Y		As blend component
		Bio crude	flexJET	6	N		
		Alcohols / Olefins to Jet	REWOFUEL Swedish Biofuels	6	Y		As blend component
			Torero		Automotive		
Sugars and Starch	Waste / Agriculture	Depolymerized sugars (SIP – DSHC)		6	Y		As blend component
		Alcohols / Olefins to Jet	REWOFUEL	6	Y		Isobutene as a vector

[16]Fuel Readiness Level, a technology readiness scale developed by CAAFI specifically for alternative aviation fuels http://www.caafi.org/information/pdf/FRL_CAAFI_Jan_2010_V16.pdf

			Waste2Fuel		Automotive		
Carbon Dioxide	Industrial waste gases	Syn gas to FT	KEROGREEN Sun2Liquid	3	N		Uses plasma to disassociate CO2 Requires renewable electricity / heat
		Alcohols	Photofuel				
	Air	Power to liquid		4	N		Requires renewable electricity / heat
Carbon Monoxide	Industrial waste gases	Alcohols / Olefins to Jet	Bac-to-fuel	6	Y Automotive		As blend component
Green Electricity			Balance eForFuel	4			

2.3.1 Principal technologies

Research into several core technologies supports the projects mentioned above at a lower TRL level, principally:

- Catalyst development for FT, HEFA and syngas conversion to hydrocarbons
- Synthetic biology for the production of intermediate alcohols or olefins

Production of liquid hydrocarbons from low and high concentration CO and CO_2 sources using renewable electricity

Catalyst approaches are challenged by the high yields of n-paraffins which result in high freezing point materials unsuitable for use in aviation without an additional isomerisation step. They are also poisoned by water and the presence of other materials.

Biological routes through the genetic modification of microbes produce intermediate alcohols (which are often branched), but then require detoxification and oligomerisation. The REWOFUEL project seeks to avoid this by producing olefins as an intermediate (Isobutene). Synthetic biology also permits the production of diverse hydrocarbon structures well outside those typically seen in conventional fuels and is the principle driver for the Advanced Fuels Programme in the US[17]. The molecules investigated in such studies will behave very differently to conventional fuels; the trade of cycloalkanes for alkanes to increase the energy density may have a detrimental effect on the thermal stability of the fuels, whilst being prohibitively expensive at the present scale of production.

The production of liquid hydrocarbons from waste gas and air source carbon sources, such as the KEROGREEN and Sun2Liquid projects are attractive as the need to transport feedstock to a production plant is removed, and the energy cost associated with the fuel production is solely based on the conversion technologies. The consideration of required energy input for the fuel production step may appear high compared to other technologies, however as there are no associated feedstock transport costs, care must be taken in establishing a level playing field for Life Cycle Analysis (LCA) calculations.

Additionally, the purity of the hydrocarbon products produced from a waste gas / air source process is likely to be high, compared to the use of more varied biological raw materials and mix waste streams.

[17] https://www.energy.gov/sites/prod/files/2019/04/f61/Analysis%20for%20Engine%20Optimized%20Sustainable%20Drop-In%20JET%20High%20Performance%20Fuels%20%28HPF%29_NL0033867.pdf

2.4 Projection of future production volumes

See sections 6.4 and 6.5 of Sustainable Aviation Fuel 'Monitoring System' report for more information[7]

Table 3 lists the companies that have announced plans to produce SAFs in Europe, with estimates of production volumes and production start dates where those are available.

➡ **Table 3** List of companies with plans for SAF production in Europe

Company	Country	Production start year	Production volume (tonnes/year)
Repsol	Spain	Mid 2020s	250,000*
Swedish Biofuels	Sweden	Not available	5,000[18]
LanzaTech	UK	Not available	Not available
Quantafuel	Norway	Not available	5,600 – 7,200
Total	France	2019	5,000**
Preem	Finland	2022	1,000,000*
Altalto	UK	Mid 2020s	60,000*
SkyNRG	Netherlands	2022	100,000[11]
Neste	Finland	2022	400,000***

*total renewable fuel capacity; SAF fraction unknown
**one-off target as part of Bio4A project[19]
***production spread between Europe and US

Whilst Table 3 lists the most prominent SAF production announcements, it is not an exhaustive list. Furthermore, not all the projects listed are guaranteed to reach production stage. Nevertheless, it is possible that SAF production capacity within Europe could reach 500,000 tonnes per year by the mid 2020s.

2.5 Role of the Environmental Portal for monitoring fuel volumes and properties

See César Velarde's report on Task 3 (i) for more information[7]

EASA's Environmental Portal is a web database that collects and publishes environmental data on aviation for use by stakeholders. It was created as a response to the 598/2014 EU regulation (entered into force in 2016) requiring the collection and publication of data on aircraft noise emissions[20]. Currently, there are 3 databases in Environmental Portal's scope:

- Aircraft Noise Certificates (ANCdb)
- EASA Certification Noise Levels (ECNLdb)
- Aircraft Noise and Performance (ANPdb)

The stakeholders involved in the Environmental Portal include EASA, the EC, aircraft operators, airports and national aviation authorities, and one of its main goals is increasing the efficiency of the process of exchanging noise data between the various stakeholders. In its current form, the Environmental Portal is exclusively

[18] https://cordis.europa.eu/project/rcn/197830/factsheet/en
[19] https://www.bio4a.eu/industrial-production-of-sustainable-aviation-fuels/
[20] https://publications.europa.eu/en/publication-detail/-/publication/b6947ca7-f1f6-11e3-8cd4-01aa75ed71a1/language-en

focused on noise emissions data, however there are plans to expand the scope to include aircraft and engine emissions data.

Collection of aircraft fuel use data, including SAFs, is already done today via several platforms, some of which also record the emissions reductions achieved via the use of SAFs. These include:

- IATA's FRED+ was developed to help airlines comply with CORSIA's emissions reporting requirements. The main focus of the platform is CO_2 emissions reporting for CORSIA compliance.
- EuroStat collect data on production, consumption, imports and exports of bio-jet kerosene, but no data on emissions reductions associated with consumption. No data is available as of the time of writing of this report.
- The EU's Renewable Energy Directive (RED II), which reports the use of bio-jet kerosene in EU transport every year (split between domestic and international aviation) via the Renewable Energy Progress Report[21]. Consumption data does not include associated emissions reductions.
- The EU's ETS, which requires all airlines operating in Europe to report their emissions for flights within the European Economic Area (EEA) and any SAF use in those flights. The data is compiled by the EU into the Report on the Functioning of the European Carbon Market[22]. The emissions factor for the use of SAFs which are compliant with RED II sustainability criteria is zero under ETS rules, hence exact emissions reductions associated with any SAF use are not recorded.

Therefore, expanding the Environmental Portal to require stakeholders – whether airline operators, airports or member states – to report SAF use and emissions will likely be inefficient and counterproductive. However, the Environmental Portal may be able to act as a useful central repository for such data from the various sources listed above, thereby making such data easily available in one place to all stakeholders.

[21]https://ec.europa.eu/commission/sites/beta-political/files/report-progress-renewable-energy-april2019_en.pdf
[22]https://ec.europa.eu/clima/sites/clima/files/ets/docs/com_2018_842_final_en.pdf

3. Overview of fuel testing requirements and European testing and certification capabilities

3.1 Overview of aviation fuel approval process

3.1.1 Background

Since the early 1990s the aviation industry has recognised the need to produce fuels from sources other than conventional fossil-based crude oil or the like (condensates, tar sands, syncrudes, etc.). This was for security of supply and, somewhat later (mid-2000s), to allow the use of renewable (sustainable) fuels and fuel blends to meet environmental obligations. No other forms of energy storage can complete with aviation kerosene with regard to energy density per unit mass or volume and therefore use of alternative technologies such as battery powered or cryogenic fuels (liquefied natural gas, hydrogen etc.) creates severe compromises for aviation use. Kerosene-based fuels are therefore the only option in the near to mid-term or until there is a step change in other energy storage technologies. Further, aircraft service lives are typically 20-30 years or more and so compatibility with the legacy fleet and forward compatibility with aircraft now going into service has to be preserved. As a worldwide commodity there is also the restriction or inertia that prevents localised changes to fuel specifications, in contrast to what could be done with automotive fuels for example.

Fuels and fuel blends from non-conventional (aka alternative, renewable, sustainable) sources must therefore be specification compliant to internationally agreed standards, behaving within established norms under all conditions within the aircraft. Further, such fuels must have no deleterious effect on aircraft and engine performance, safety, operability or cost of ownership. As such these fuels must be fit-for-purpose and drop-in, requiring no special handling or use requirements from point of manufacture to aircraft. This is essential not only for the aircraft as the final user but also the distribution systems around the world that are designed on the basis of essentially one fuel type/grade.

The following paragraphs provide a review of the full ASTM D4054 process. Following that the report reviews technical developments including the new Fast Track process now in place that builds on the experience base of products evaluated and approved thus far, and finally for the longer term, R&D efforts to develop a pre-screening process. These technical efforts complement organisational improvements brought about by the Clearing House concept, which is described later.

3.1.2 ASTM approval process – full evaluation

ASTM D7566, the specification controlling alternative fuel blends, has evolved to meet the challenge of introducing new raw materials, processing and blends[23] that are wholly compatible with distribution and aircraft hardware. Each Annex in ASTM D7566 is linked to a specific raw material, process and eventual blendstock. This division and specificity is to mitigate the risks of new products causing problems. ASTM D7566 also defines specific requirements for the final blend which requires a defined maximum of Annex blendstock

[23] ASTM D7566-19, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, ASTM International, West Conshohocken, PA, 2019, www.astm.org

and the balance being conventional jet fuel. Importantly, once produced and blended in compliance with ASTM D7566 fuel is then designated as ASTM D1655 Jet A or Jet A-1 and handled as per conventional fuel. This is on the basis that these new blends have been shown to be technically equivalent to conventional fuels. Note also that jet distribution systems and aircraft hardware only allow Jet A/A-1 as approved.

ASTM D4054[24] (management of change process) defines the process by which a new blendstock, defined by raw material, transformation process and finishing requirements, must be evaluated before approval and inclusion within ASTM D7566, as a new Annex Extensive testing on the blendstock and final blends is required to ensure the fuel is fit for purpose and performs within expected norms. Once approved, the new blendstock is codified within ASTM D7566 and the specification up-issued to incorporate the new material.

In summary D4054 is a tiered process that requires testing with increasing complexity, scale and therefore cost:

- **Tier 1** - Basic standard specification testing.
- **Tier 2** - Fit for Purpose testing which includes mainly laboratory scale testing of a wider range of properties, compositional analysis (bulk and trace), material compatibility and performance properties, etc.
- **Tier 3** – Rig scale testing to assess behaviour under simulated airframe and/or engine conditions to cover such parameters as thermal stability, cold flow, combustion under adverse conditions (operability), etc.
- **Tier 4** – full engine testing to assess impact on performance, durability, emissions, etc.

Figure 1 and Figure 2 below provide an overview of the whole process and details of testing requirements within each tier. Tier 1 refers to specification properties testing, Tier 2 to fit-for-purpose properties testing, Tier 3 to component/rig testing and Tier 4 to engine testing (see Figure 5).

[24]ASTM D4054-19, Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives, ASTM International, West Conshohocken, PA, 2019, www.astm.org

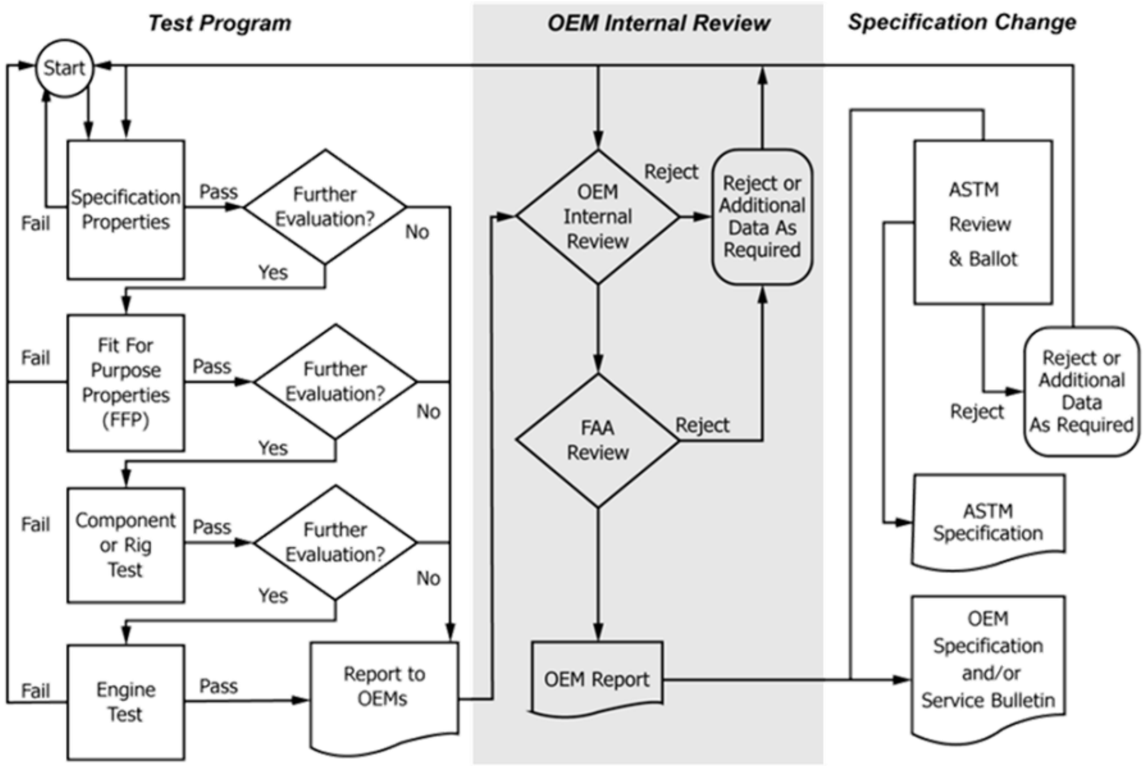

Figure 1 Overview of ASTM D4054 evaluation and approval process

ASTM D4054 programmes have to be run with key industry stakeholder engagement as an integral part of the process, not least the Original Equipment Manufacturers (OEMs i.e. the engine and airframe manufacturers) as the most critical final users. Figure 3 shows the key stakeholders and key relationships.

Note that the process as defined is not a list of tests that must be done, as some believe, but rather is a list of tests that should be considered within a rational test programme design. Thus, testing requirements may be reduced for products similar to those already approved, or occasionally, more extended and/or bespoke testing may be required for products that are outside experience. Indeed, the Fast Track process (see below) is a natural development of this rational approach to approve products with very limited testing based on read across form existing products.

Lastly, one key barrier to new entrants is the requirement to make significant (industry scale) volumes of fuel either for testing per se but also to demonstrate the production process at scale and show that it has a high enough technology readiness level.

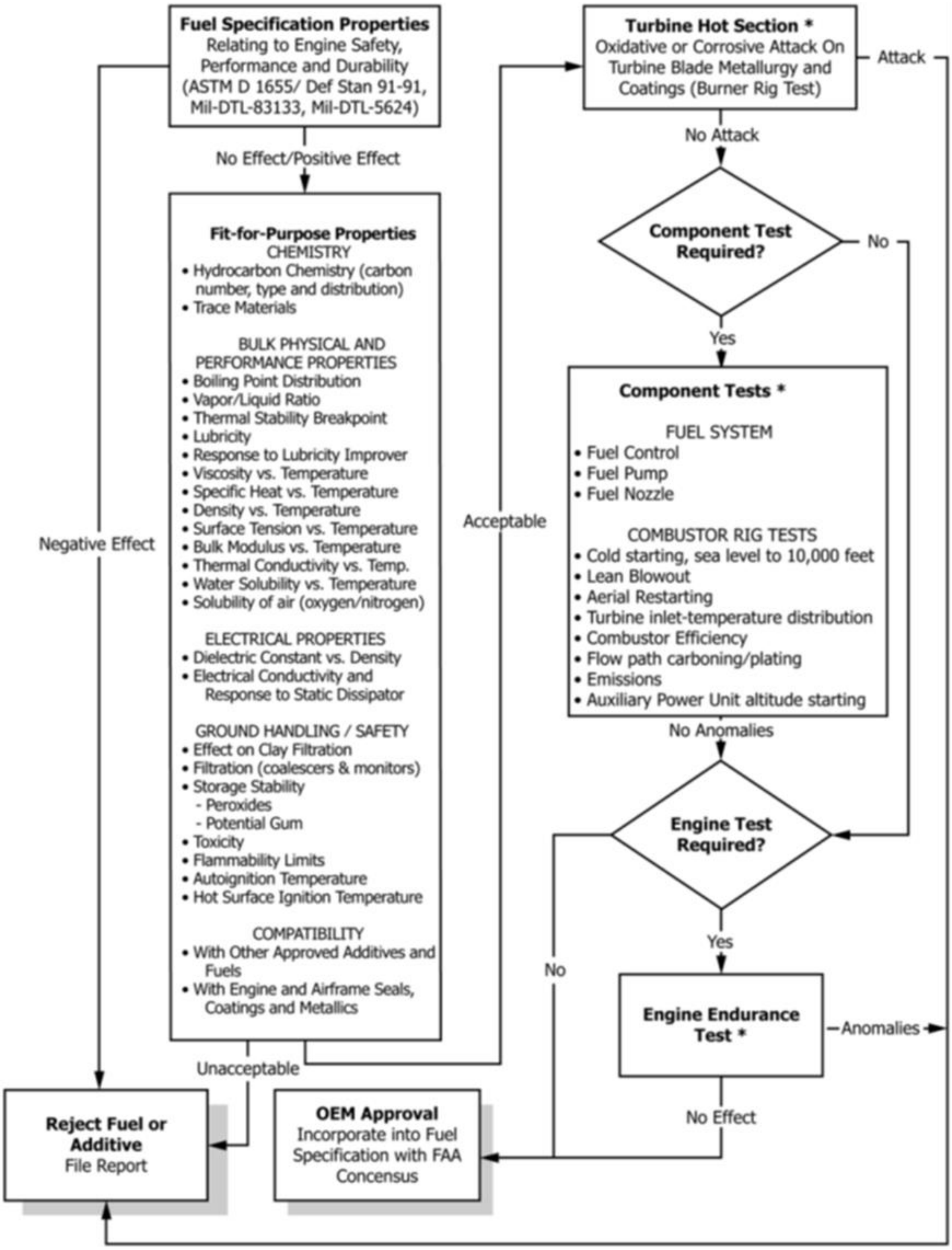

Figure 2 ASTM D4054 evaluation and approval process detail of Tiers

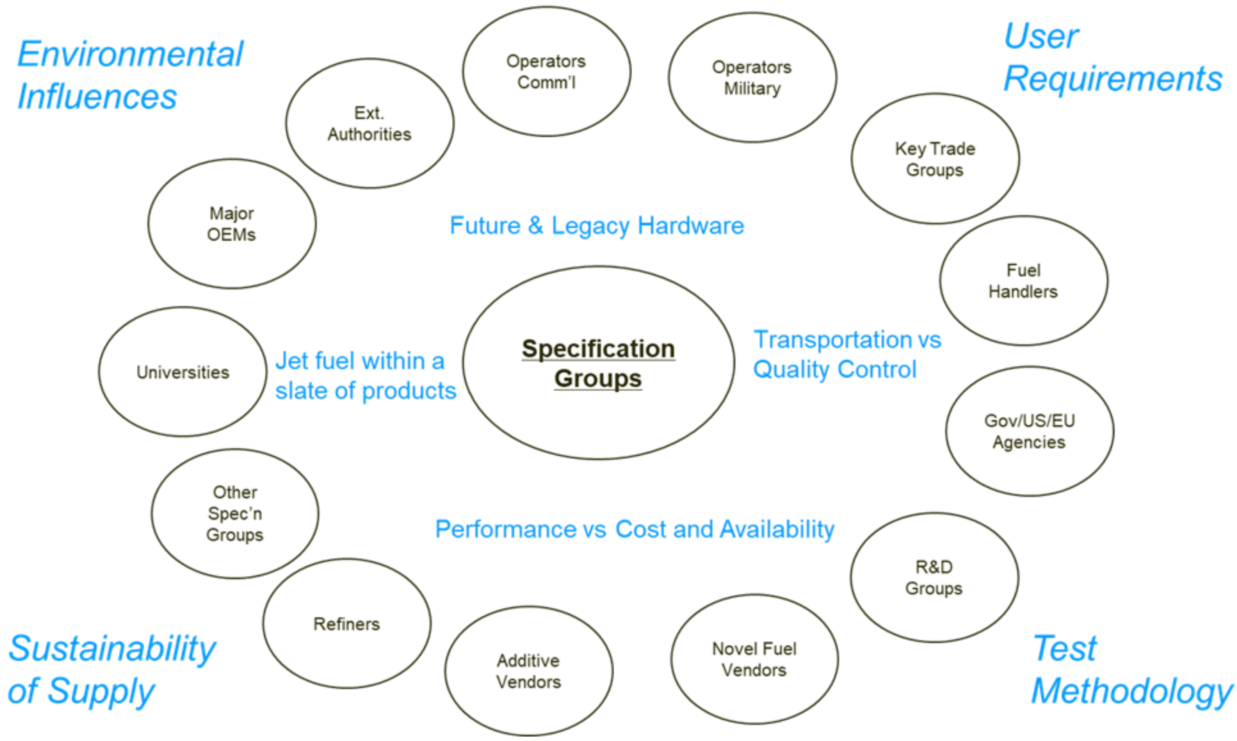

Figure 3 ASTM stakeholder summary

Note that in the UK the Defence Standard 91-091 "Def Stan" and military analogues cover Jet A-1 fuel requirements. In general, new fuel blends must go through the ASTM D4054 process and be included in D7566 before the Def Stan will consider them for inclusion. If all the evidence is deemed acceptable, allowance for the new blendstock/blend will be incorporated into Def Stan 91-091. In a similar manner to allowance to re-designate the fuel as ASTM D1655, fuel made to ASTM D7566 and that meets Def Stan requirements can be re-designated as Def Stan 91-091 Jet A-1.

It should be noted that Def Stan 91-091 and ASTM D1655 are generally the most developed and up to date as regards allowing and controlling fuels form alternative sources. These two specifications therefore tend to be the most widely quoted and used across Europe. Also of note is the fact that documents used for shared facilities such as the Joint Check List generally use the most stringent requirements and therefore reflect these two leading specifications.

3.1.3 ASTM approval process – Fast Track process

The evaluation process is, with an increasing number of novel blendstocks, placing a high burden on the industry and particularly the OEMs, who have limited resources to commit to this non-core business activity. Furthermore, the time and cost of funding these programmes plus the cost of producing large quantities of fuel for testing has presented a significant barrier to potential sustainable fuel vendors. In the past, this has proven to be a necessary burden, but the ASTM D4054 process has been examined to facilitate quicker and more cost-effective approval and deployment of future renewable fuels without compromising final blend performance.

The planned way forward to reduce this burden is by defining within ASTM D4054 a rationalised process termed "Fast Track". This comprises a set of very stringent controls on any new blendstock which is to be submitted to Fast Track evaluation and approval. If the product meets these requirements (in summary: declaration of raw materials and processing, bulk properties, bulk hydrocarbon composition and purity, and down selected fit-for-purpose tests) then approval by the usual ASTM D4054 route is allowed but only Tier 1+ testing is required. Further testing at rig, engine or aircraft level will be waived, subject to formal ballot and approval process.

In summary, Fast Track controls on the neat blendstock and the final blend are as follows:

- Ensuring molecule type and range will be well within the scope of those products already approved and within the conventional jet fuel experience base. Note that narrow or single molecule materials have been excluded.

- Stringent purity controls will exclude any trace materials to the point where no adverse effects are predicted, and be linked to the blendstock materials and process chemistry.

- A very conservative maximum blend limit of 10% max. has been imposed.

Bulk composition and therefore molecular type, range and mix are controlled by a combination of standard physical, chemical and performance requirements. Physical property limits such as density, viscosity, flash/freeze points and careful control of distillation are used along with bulk chemical composition requirements such as aromatics. Additional requirements, over and above typical conventional fuel requirements, control bulk composition by 2DGC[25] etc. Trace materials are also controlled by both traditional specification requirements (e.g. acidity, thermal stability etc.) and additional instrumental analysis of trace organics and inorganics. In some instances where traditional specification tests are used more stringent limits are applied to ensure adequate control.

The Fast Track process was ratified by ASTM in May 2019. The new route leads to a modified ASTM D4054 process as shown in Figure **4**

At the time of preparing this report no new products have yet been through the Fast Track evaluation to completion. However, IHI Bb-oil, as the first candidate material to be subjected to Fast track approval, is currently (June 2019) under review by the OEMs and expected to be balloted later in 2019.

[25] Two-dimensional gas chromatography

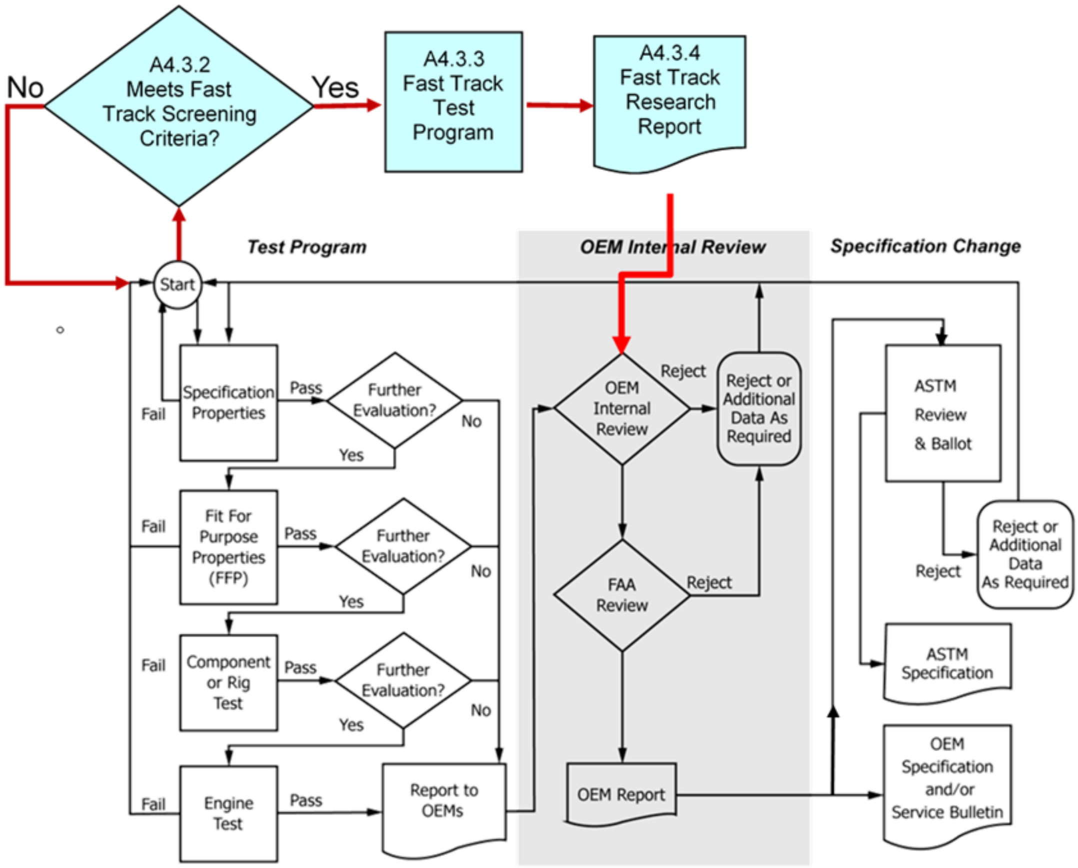

Figure 4 ASTM D4054 revised evaluation and approval process including Fast Track

3.1.4 Pre-screening concept development

Pre-screening and fuel databases

Efforts in Europe within the JETSCREEN[13] programme and in the US under ASCENT and the National Jet Fuels Combustion Program (NJFCP)[26] are looking at ways for the industry to work smarter in the evaluation of new fuel blendstocks and blends. These efforts which are increasingly being coordinated are focussed on:

- Improved prediction of fuel properties at rig, aircraft and/or engine scale based on laboratory analysis to de-risk low TRL (FRL) products and/or avoid the need for Tier 3 and 4 testing which take most time, cost and fuel volumes.
- Create a regime for pre-screening new products prior to entry into the ASTM D4054 process to assess their potential to gain approval or indicate how the product may be improved. This de-risk and optimisation would be carried out on very low fuel volumes of 1-2 litres (estimated) and thus allow low cost what-if experiments.
- Creating a rationalised database of fuel composition, physical and performance properties and how these relate to in-service performance based on extensive rig testing. This predictive capability not only supports and de-risks early stage product development but can also be used to explore expansion of the acceptable envelope of properties. This latter point responds to the fact that all currently approved and under evaluation materials have to meet very stringent requirements that limit yield and increase

[26] Colket et al. (2017), 'An Overview of the National Jet Fuels Combustion Program', *AIAA Journal*, 55 (4) pp. 1087-1104. Available at https://arc.aiaa.org/doi/abs/10.2514/1.J055361

cost. Opening up the acceptable envelope would have benefits in yield, efficiency of production (and therefore environmental benefits) and cost reduction. Databases which start to explore this are being prepared by research projects in Europe (JETSCREEN) and by US programmes (ASCENT). These two groups have worked together to propose a standardised data storage schema (or formatting) to permit coupling of the databases for specific tasks in the future.

Whilst a detailed discussion of these programmes is outside the scope of this report it is worth noting that these efforts are not a substitute for the ASTM D4054 process but meant to support and improve it. The NJFCP has created a concept of two new levels prior the ASTM entry "Tier α and Tier ZERO" which allow the pre-screening of potential products with very low volumes of circa 0.5 litres. This would provide guidance on potential to be approved and support optimisation of the whole process from feedstock to final blend.

3.1.5 ASTM process summary

In summary, the process to get a novel blendstock approved can be a complex and therefore, costly and lengthy one that requires the attributes of a high level of technical expertise, access to specialist test facilities and positive and coordinated engagement with key industry stakeholders. Further, as a rational process, D4054 allows for selection of testing and evaluation and ensuring such testing is focussed on key attributes at each stage reduces cost and risk but this requires skills and experience. The Fast track process provides a more rational and lower cost route for products that meet the entry criteria but the process is still relatively complex and costly. Further, R&D efforts are ongoing to be able to work the ASTM process more intelligently by predicting with increased confidence fuel behaviour at aircraft and engine scale based on laboratory-based analysis.

3.2 Fuels approval testing capabilities

The Commercial Aviation Alternative Fuels Initiative (CAAFI) in the US surveyed the most prominent testing facilities worldwide in order to map their capabilities against the requirements of the D4054 process. This included airframe and engine OEMs, universities and other research institutions. The results of this survey were compiled in the 'ASTM D4054 Users' Guide'[27]. Table 4 lists the European facilities listed in that document, all of which have the technical capability to perform some of the testing required by D40504.

➨ **Table 4** List of main European facilities with capabilities to carry out D4054 testing, from ASTM D4054 Users' Guide

Facility Name	Location	Tier*	Notes
University of Sheffield	UK	2, 3, 4	Capabilities in Low Carbon Combustion Centre
DGA Essais propulseurs	France	1, 2, 3, 4	French Ministry of Defence facility
DLR	Germany	1, 2, 3	Capabilities in Institute of Combustion Technology
ASG Analytik-Service	Germany	1, 2	
ONERA	France	2, 3, 4	
Airbus	UK	3,4	
Rolls Royce	UK	3 4	
Safran Aircraft Engines	France	3, 4	

[27] http://www.caafi.org/information/pdf/D4054_Users_Guide_V6_2.pdf

*a facility may not necessarily have capability for all tests within a given Tier

It should be noted that the above list of test facilities is based on those entities who are involved with ASTM and volunteered to have their facilities listed. The list is therefore not extensive i.e. it does not include all potential suppliers in Europe. Further, many fuel refining companies have fuel test facilities within their organisations that may be capable of carrying out some of the Tier 1 analysis. Lastly, many commercial test organisations, for example Intertek Testing Services, have specialist laboratories across Europe that most likely can carry out basic specification, ASTM D7566 and Tier 1 testing.

4. Methodologies for certifying emissions reductions

See Chapter 5 of Sustainable Aviation Fuel 'Monitoring System' report for more information [7]

4.1 Overview of existing Sustainability Certification Schemes

For a SAF producer to guarantee the sustainability of their product, certification from a Sustainability Certification Scheme (SCS) is required (obtaining accreditation from an SCS is technically voluntary, however). This involves a detailed audit of the entire supply chain, carried out by a Certification Body (CB). Roughly, and depending on the number of facilities and stakeholders involved in the supply chain, obtaining a certificate from an SCS can cost on the order of thousands of euros and can take months (the costs and timescales also depend on the SCS pursued). Compared to full evaluation under the ASTM approval process (see section 3.1.2), the SCS process is significantly easier and cheaper.

For a new SAF producer with no experience of sustainability certification, understanding the differences between the many available SCS, and hence which to pursue, can be a daunting task. A further complicating factor is national and supranational sustainability regulations, such as the UK's Renewable Transport Fuel Obligation (RTFO) and the EU's Renewable Energy Directive (RED II), which may have differing criteria and definitions of sustainability. However, once a producer has chosen which SCS to pursue and which CB to work with, all the necessary guidance to navigate the process smoothly is provided.

According to stakeholder input, the strictest (and most widely used) SCS for aviation is the Roundtable for Sustainable Biomaterials (RSB). The International Sustainability and Carbon Certification (ISCC) SCS is also highly applicable to transport biofuels, but geared slightly more to road biofuels. Each SCS usually offers multiple certificates geared towards different products and markets; for instance, RSB offers 5 different types of certification whilst ISCC offers 4. The decision over which certificate to pursue is ultimately made by the producer depending on their needs. In the case of the RSB, the 'RSB EU RED Standard' certification is recommended for producers wishing to sell in the EU, whereas the 'RSB Advanced Fuel Standard' is recommended for producers wishing to sell in other regions.

In the EU, there are 15 approved voluntary SCS[28]. These are summarised in Table 5.

[28] https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/voluntary-schemes

Table 5 Overview of SCS approved in the EU

SCS Name	Feedstock type	Feedstock origin	Supply chain coverage
International Sustainability and Carbon Certification (ISCC)	Wide range of feedstocks	Global	Full supply chain
Bonsucro EU	Sugar cane	Global	Full supply chain
Roundtable on Responsible Soy (RTRS) EU RED	Soy	Global	Full supply chain
Roundtable on Sustainable Biomaterials (RSB) EU RED	Wide range of feedstocks	Global	Full supply chain
Biomass Biofuels voluntary scheme (2BSvs)	Wide range of feedstocks	Global	Full supply chain
Red Tractor Farm Assurance Combinable Crops & Sugar Beet Scheme	Cereals, oilseeds, sugar beet	UK	Until the first feedstock delivery point
Scottish Quality Farm Assured Combinable Crops (SQC)	All cereals and oilseeds	North Great Britain	Until the first feedstock delivery point
REDcert	Wide range of feedstocks	Europe	Full supply chain
Better Biomass	Wide range of feedstocks	Global	Full supply chain
Roundtable on Sustainable Palm Oil (RSPO) RED*	Palm oil	Global	Full supply chain
Gafta Trade Assurance Scheme	Wide range of feedstocks	Global	Chain of custody from farm gate to first processor
KZR INiG System	Wide range of feedstocks	Europe	Full supply chain
Trade Assurance Scheme for Combinable Crops	Combinable crops such as cereals, oilseeds and sugar beet	UK	Chain of custody from farm gate to first processor
Universal Feed Assurance Scheme	Feed ingredients and compound feeds as well as combinable crops	UK	Chain of custody from farm gate to first processor
US Soybean Sustainability Assurance Protocol (SSAP) EU	Soy	US	From cultivation to place of export

*applicable to biodiesel only

4.2 Sustainability criteria for CORSIA and RED II

Today, there are no international sustainability criteria that apply to all SAFs. However, the International Civil Aviation Organisation (ICAO) is attempting to create a global standard as part of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which will aim to reduce uncertainties for both fuel producers and airlines. In the EU, RED II is the applicable document which regulates sustainability requirements. RED II applies to all biofuels supplied within the EU, including SAFs, regardless of feedstock origin.

4.2.1 RED II requirements

RED II sets a target for member states to supply a minimum of 14% of the energy consumed in the transport sector from renewable sources by 2030 (up from 10% in the original RED). This is expected to come primarily from road and rail transport. Any renewable fuel use in aviation will contribute to the target but the aviation sector is not obligated to supply at least 14% of its energy demand from renewable sources. Any non-food SAFs used will contribute 1.2 times their energy content the 14% target. There are also specific targets for biofuels within the overall 14% requirement, namely requiring 'advanced biofuels' – produced from one of 18 different feedstocks listed in Part A of Annex IX – to contribute at least 3.5% of the target by 2030, and capping the contribution of biofuels produced from one of the two feedstocks listed in Part B of Annex IX at 1.7% in 2030[29]. For a biofuel to qualify as renewable under RED II (and hence count towards the targets and be eligible for public funds), it must achieve a 65% reduction in Greenhouse Gas (GHG) emissions compared to a fossil fuel baseline of 94 gCO_2eq/MJ if produced from a plant commencing operation after January 2021. For Renewable Fuels of Non-Biological Origin (RFNBOs) the requirement is a 70% reduction. Furthermore, sustainability criteria with regard to land-use change must also be met; this requires that biofuels are not produced from raw materials originating from:

- High biodiversity land such as primary forest
- High carbon stock land such as wetlands
- Land that was peatland in January 2008

Normally, it is sufficient for a producer to obtain certification from one of the SCS listed in Table 5 to ensure their product meets the various requirements of RED II.

4.2.2 CORSIA requirements

ICAO's CORSIA, like RED II, sets sustainability criteria for SAFs to be CORSIA eligible. These specify that a SAF should achieve life cycle GHG emissions reductions of at least 10% compared to a fossil aviation fuel baseline and that it should not be made from biomass obtained from land with high carbon stock[30] (further criteria are set to be added in the future). Unlike RED II, CORSIA provides a supporting document titled "CORSIA Eligible Fuels – Life Cycle Assessment Methodology"[31], which calculates default core LCA values for all CORSIA eligible fuels in addition to Induced Land Use Change (ILUC) values. The document allows for the addition of values for new fuel production pathways, which would be calculated by ICAO's Committee on Aviation Environmental Protection (CAEP).

Providing default values for LCA and ILUC for different production pathways can give producers confidence that their products would be CORSIA eligible before they start commercial production. Nevertheless, ICAO is in the process of publishing the documents "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes" and "CORSIA Approved Sustainability Certification Schemes"[32]. Once these are available, SAF producers should be able to demonstrate that their fuels are CORSIA eligible in the same way they would demonstrate compliance with RED II, by obtaining certification from an approved SCS.

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[29] https://theicct.org/publications/final-recast-renewable-energy-directive-2021-2030-european-union

[30] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria.pdf

[31] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20Supporting%20Document_CORSIA%20Eligible%20Fuels_LCA%20Methodology.pdf

[32] https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

5. Options for a European forum / Clearing House

5.1 Review of current barriers to SAF development and deployment

5.1.1 Key requirements

For a fuel to be truly viable it must gain approval across the industry, deliver on environmental benefits and be commercially viable in production. These three criteria can be summarised as follows:

- **Technically Suitable:** All new fuels must meet the rigorous composition, purity and performance requirements needed for jet fuel as a high-performance product. This must be assessed by the processes and procedures discussed in detail earlier (see section 3.1). Importantly, the key industry stakeholders including but not limited to: specification owners, airworthiness authorities, fuel producers and handlers, ground equipment owners, additive vendors, commercial and military operators and OEMs will also require demonstration of product performance and production at industrial scale to show that the process and product have a high enough Technology Readiness Level (TRL) or Fuel Readiness Level (FRL).
- **Sustainable:** If a fuel supplier claims that their new fuel is "Sustainable", whole life cycle analysis is required to assess from raw material production through to final blends, to demonstrate environmental performance and credentials (see Chapter 4) with respect to:
    - Land use including Direct/Indirect Land Use Change, water and other resources such as fertilizer during production of raw materials (if plant based). Use of waste productions e.g. used cooking oil or municipal waste has pros and cons that need assessment as do emerging schemes such as production from solar energy etc.
    - Use of any fossil fuel throughout the process (including transport), energy, water, CO_2, etc. during processing.
    - Any waste products or pollutants.
    - Must not complete with food or other essential crops.
    - Local environment, societal and economic impacts etc.
- **Commercially Viable:** The product must be able to be manufactured in sufficient quantities and at a price (including offsets and/or incentives if applicable) such that there will be sufficient take-up that will make a significant impact in terms of CO_2 and other emissions savings. The product must also meet other key legislative requirements including safety in handling, REACH[33] compliance, etc.

Each of these aspects needs assessment by different groups with the specific skill sets. The current industry norm is to:

1. Make initial small-scale batches of product to make an initial assessment of technical suitability.
2. Assess the (potential) sustainability and commercial viability.
3. If 1. and 2. are successful then approach the industry to carry out a full technical suitability assessment via the ASTM process.

Note that currently such evaluation and approval for use programmes are centred on the ASTM groups. Other national specifications and key stakeholders, particularly the airworthiness bodies, and importantly, major OEMs, are involved in and recognise the ASTM process as the industry standard.

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[33] https://echa.europa.eu/regulations/reach/understanding-reach

It is important to note the industry has finite resources, therefore selection of candidates that meet all 3 criteria early on is imperative to minimise time spent on fuel candidates that will later prove to be non-viable. The current industry norm is for vendors only to approach ASTM once items 1 and 2 have been assessed. This makes business sense for investors as the ASTM process is the highest cost/time/risk item, and, it makes sense for ASTM as this means the very limited resources of the key stakeholders are only focused on the most viable products. It should be a consideration for this business case study whether an independent organisation, as part of an EU Clearing House, needs to assess potential products at each stage against these criteria to ensure there is maximum benefit from resources and effort put in.

Importantly, it should be noted that ASTM maintains a purity of purpose. The process is unaffected by commercial or environmental factors and only focuses on the first point, i.e. technical suitability. In other words, new fuels are assessed for the other factors before they enter the ASTM process and, on that basis, selected to get into an ASTM programme but once in, technical suitability is the only assessment and influence.

5.1.2 Approval cost challenges

Apart from the specific technical challenge of producing a technically suitable product, the cost of gaining approval to be included in ASTM D7566 is high. It is difficult to be specific on timescales and cost for achieving approval for use via the ASTM D4054 process. However, anecdotal evidence suggests that early products typically required 3 years or more and perhaps $2 million plus. This cost is decreasing and products that are similar to those already approved or ultimately fit into the Fast Track scope may gain approval with significantly lower cost and shorter timescales. However, for products that are radically different the above figures for a full and detailed ASTM D4054 evaluation probably still stand.

The recent study carried out by Element Energy[6] provided the following estimates and Rough Order of Magnitude (ROM) costs. Table 6 provides a summary of the major costs in a range of activities that would be typically required from pre-screening through to Tier 1-4 testing. Table 7 provides an accompanying estimate of the fuel volumes required for each Tier of D4054 testing.

➨ **Table 6** ROM costs for typical fuel evaluation and approval (from Element Energy6)

Activity	ROM Cost (€)
Pre-Screening: Determining the potential of a product to enter the aviation fuel market (including examining screening test results for chemical composition and physical properties)	1,000 – 10,000*
Comparing the existing production route and product against existing D7566 Annexes to determine whether product falls under one of them (hence requiring screening tests only - not full approval testing)	4,000 – 6,000*
Determining whether the product can go through the Fast Track route in D4054 (hence requiring screening tests only – not full approval testing)	5,000 – 10,000*
Providing detailed guidance on the types of tests required for each Tier of testing in the D4054 process	3,000*
Providing information on, and access to, facilities which can carry out D4054 testing	4,000*
Providing access to facilities which can supply conventional jet fuel for blending, including expertise in handling and transporting jet fuel and performing blending	1,000+**

D4054 Fast Track testing	40,000***
D4054 Tier 1 testing	30,000 – 50,000***
D4054 Tier 2 testing	40,000 – 120,000***
Production and review of first research report (roughly $50,000 - $100,000 required per OEM	50,000 – 500,000
Reviewing and commenting on research reports	3,000+*
D4054 Tier 3 testing	600,000 – 1,000,000***
D4054 Tier 4 testing	250,000 – 1,000,000+***
D7566 due diligence testing (for products that fit an existing Annex)	10,000 – 20,000***
Specialist Support - Technical Consultancy on Product Suitability	3,000 – 10,000*
Providing guidance on potential commercialization routes	3,000*
Providing information on the process and requirements for LCA analysis e.g. via the CORSIA methodology in addition to access to experts	4,000*
Providing information on the process and requirements to achieve product stewardship, in addition to access to experts	4,000*
Achieving REACH compliance for product	100,000+

*based on estimated number of consulting hours required, at a cost of €100/h
**highly variable, depending on amount of conventional fuel required and blending difficulty
***based on cumulative cost of several tests, as quoted by testing facilities

Table 7 Typical fuel volumes required for evaluation and approval.

D4054 Tier	Tier testing description	Fuel volume required in US Gallons (Litres)	Note
1	Fuel Specification Properties	10 (37.8)	
2	Fit-for-Purpose Properties	80 (320.8)	Would be required for Fast Track
3	Component and Rig Tests	250 to 10,000 (946.3 to 37,854.1)	Fuel volume depends on component type
4	Engine Test	450 to 225,000 (1,703 to 851,718)	Fuel volume depends on engine type and whether it is a performance or endurance test

Note that volumes shown above are 1. for a single test fuel; in most cases, a baseline fuel of equal volume will be required in addition to the new fuel blend stock, new fuel unfinished blend, or fuel additive blend being evaluated. 2. for a single test; multiple tests may be required. 3. purely for testing; industry stakeholders will require significant volumes to be produced to demonstrate process maturity.

The availability of a Clearing House type organisation within Europe could reduce the overall cost of the evaluation programme by improved planning and targeted analysis on critical aspects at each Tier, therefore reducing both technical and financial risk. Further, assisting vendors to engage and coordinate dialogue with key stakeholders will avoid duplication of effort as happened in the past. Lastly, dependent on the funding model adopted by the Clearing House some financial assistance may be available.

Therefore, coordination of effort and technical guidance will reduce cost and timescales to the minimum required as discussed later.

5.1.3 Approval timescale challenges

It is not within the remit of this study to comment on the time it takes to design and develop a new feedstock and process route or design and construct the required processing plant. However, on the assumption that small scale (sub-pilot) volumes of fuels have been produced and shown to have potential for approval then the timescales from initial samples through to evaluation and onto approval can be considered as the challenge that is part of this study.

Being specific about timescales is difficult given a number of variables which include but are not limited to:

- Availability and volumes of new blendstock.
- Finances to support fuel production at increasing volume scale and cost of testing.
- Availability of test facilities:
  - Tier 1 and some Tier 2 testing which is standard laboratory based can usually be completed within a few weeks.
  - Some bespoke Tier 2 testing may take several months to complete and may be delayed by availability of equipment.
  - Tier 3 and 4 testing often takes several months or more to arrange and often these facilities are owned and operated by the OEMs. Fuel approval work can therefore be subject to delays awaiting a test slot versus core test activity on what is often highly utilised facilities. Further, such testing is often integrated as part of an ongoing test programme (piggy backed) to reduce the cost to a realistic level and this can cause significant delays.
- Priority and availability of key stakeholders within the ASTM group and the bi-annual balloting process and associated 2 meetings per year ASTM uses. Further, the ASTM balloting system which has to deal with negatives is notoriously difficult to predict and so several rounds of ballots may be required.

With all these variables in mind the following timescales are offered as guidance only. Assuming the availability of sufficient fuel for testing and proving sufficient TRL of process at industrial scale timescale guidance is provided in Table 8.

Table 8 Estimated timescales for the various testing routes a new SAF may have to go through

Fuel Description	Testing Requirements	Testing Level	Estimated Timescales	Comments
Approved product from a new producer	Due Diligence	ASTM D7566 Tier 1+	3 months	No formal approval, ballot or Annex required*
New product "Fast Track" ready	ASTM D4054 Fast Track Requirements	Tier 1++	1-2 years	Estimated
New product Full Evaluation (similar to existing)	ASTM D4054 Rationalised Evaluation	Tier 1-4 (limited)	3 years +	Based on experience
New product Full Evaluation (radical)	ASTM D4054 Full Evaluation	Tier 1-4 (full)	3-5 years +	Based on experience

*It is still recommended that new producers present due diligence findings and test results to ASTM and/or Defence Standards groups to provide stakeholder review and feedback.

5.2 Summary of US Clearing House concept

Mark Rumizen presented a summary of the Clearing House concept at the Aviation Fuels Committee in 2017[34] and the ICAO Seminar on Alternative Fuels 2017[35]. In this the list of risks of the then current US system included the following, which were slowing down the adoption of sustainable fuels:

- Challenge of the availability of resources
- Fuel development and production costs
- OEM rig/engine testing and technical review costs
- Overhead and administration costs.

The proposal was to put in place a "Clearing House" that, as far as possible, offset as many costs, barriers and risks as possible. The concept is summarised in Figure 5 below. This model served to help coordinate and guide potential fuel vendors in all the activities required to achieve approval for use. Since the US challenges, barriers and risks are very similar to those facing the EU, the "Clearing House" concept has many parallels with what would be required for the EU. This "Clearing House" has now been established with the University of Dayton Research Institute (UDRI) with Dr Steve Zabarnick as the lead.

Note that the US Clearing House also includes an element of cost share which can reduce the financial burden on potential fuel vendors. To date, the US Clearing House has received a few million dollars of funding from the FAA, which has been used to support several fuels.

It is also important to note when considering the business case and cost for setting up an EU based clearing house that UDRI have been very active in the testing, analysis and evaluation of novel fuels (and additives) for many years. UDRI have, over these years, been funded to carry out fuel evaluations by various sources including but not limited to the US DoD, FAA, fuel/additive vendors and other stakeholders etc. and in so doing built up the capability and expertise they currently have. This means that the facilities, capability, skills, knowledge and experience was in effect already available to take on the role of Clearing House when the concept was proposed and funded by the FAA. Any proposal must account for cost and timescales to in effect catch up with UDRI vs sub-contracting to them. Actually determining such a cost would require a specific task which is outside the scope of this report.

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[34]Mark Rumizen, *D4054 Clearinghouse*, presented at Aviation Fuels Committee Meeting, March 21, 2017

[35]Mark Rumizen, *Alternative Jet Fuel (AJF) Certification*, presented at ICAO Seminar on Alternative Fuels, February 8-9, 2017 https://www.icao.int/Meetings/altfuels17/Documents/Mark%20Rumizen%20-%20FAA.pdf

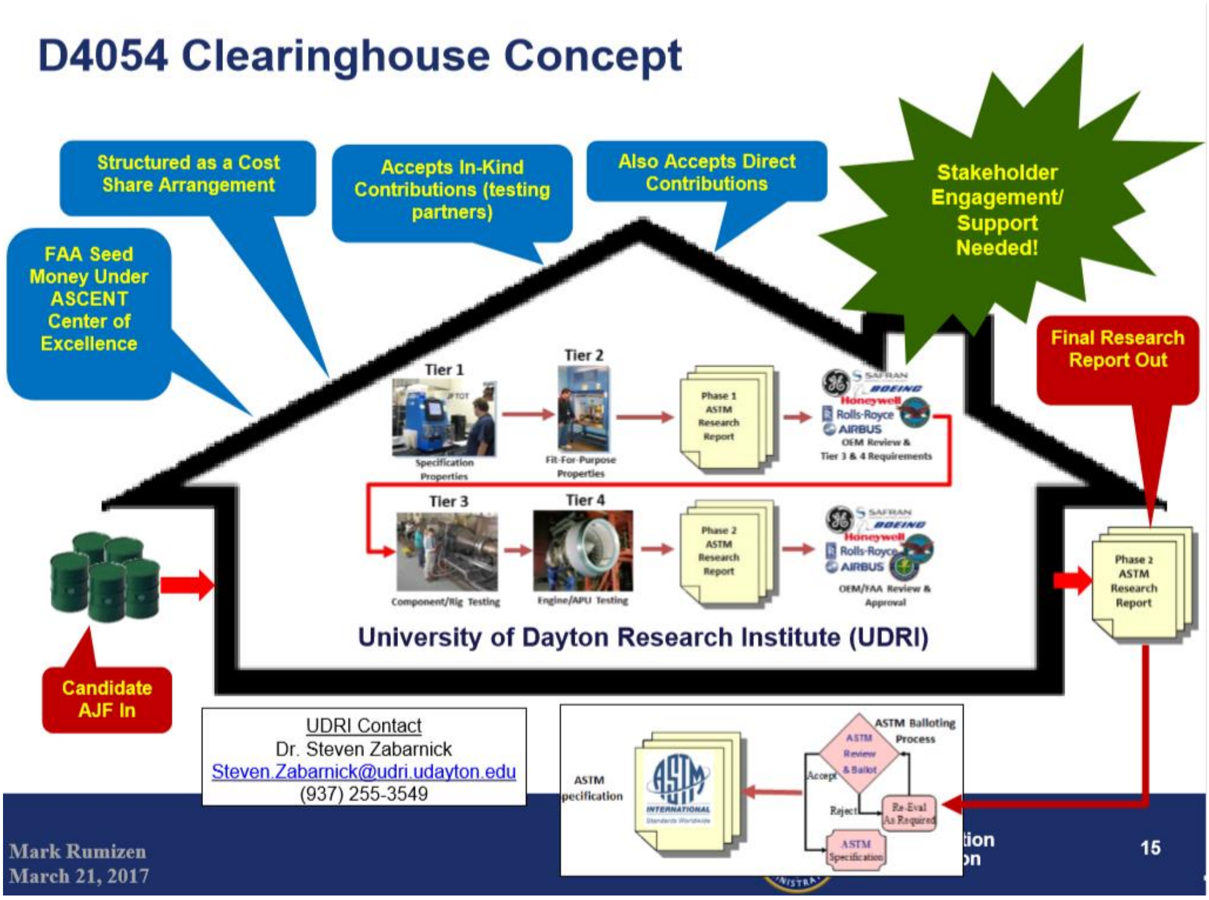

Figure 5 US Clearing House concept

5.3 The role of OEMs

The industry is currently trying to address a significant barrier to the deployment of new fuels and additives. This arises from the varying levels of engagement, and also priority, that OEMs give to updating documentation and operating manuals. Figure 6 summarises the required OEM involvement in the D4054 approval process.

The approved fuels and additives are defined at aircraft, engine, Auxiliary Power Units (APU) and other hardware level during certification. They are classed as an "operational limitation" and therefore compliance with the fuels/additives list is a requirement for ongoing airworthiness. Approved fuels and additives are defined at aircraft level documentation that reflects the approval status of all hardware. This means that, for example, if a new fuel is approved by all the hardware OEMs on a particular aircraft except one or more, the aircraft documentation cannot be updated. At any given time this means that an OEM's documentation may be out of synchronisation with what is in the specifications (in this case ASTM D1655/Def Stan 91-091 and therefore the permitted non-conventional fuel blends). This loss of synchronisation can be attributed to several causes:

- Even if an OEM approves the update of a specification this does not automatically mean that such fuel is approved for use. Their documentation may have to be updated, dependent on how they list fuels/additives.
- The high burden and/or lack of priority or funding to update documentation – which are formally controlled documents.

- For OEMs who are committed to group engagement and updating of documentation this may be delayed due to document update cycles.
- Some OEMs are not sufficiently engaged with the key stakeholder groups that control and update specifications and so are not up to date with the changes.

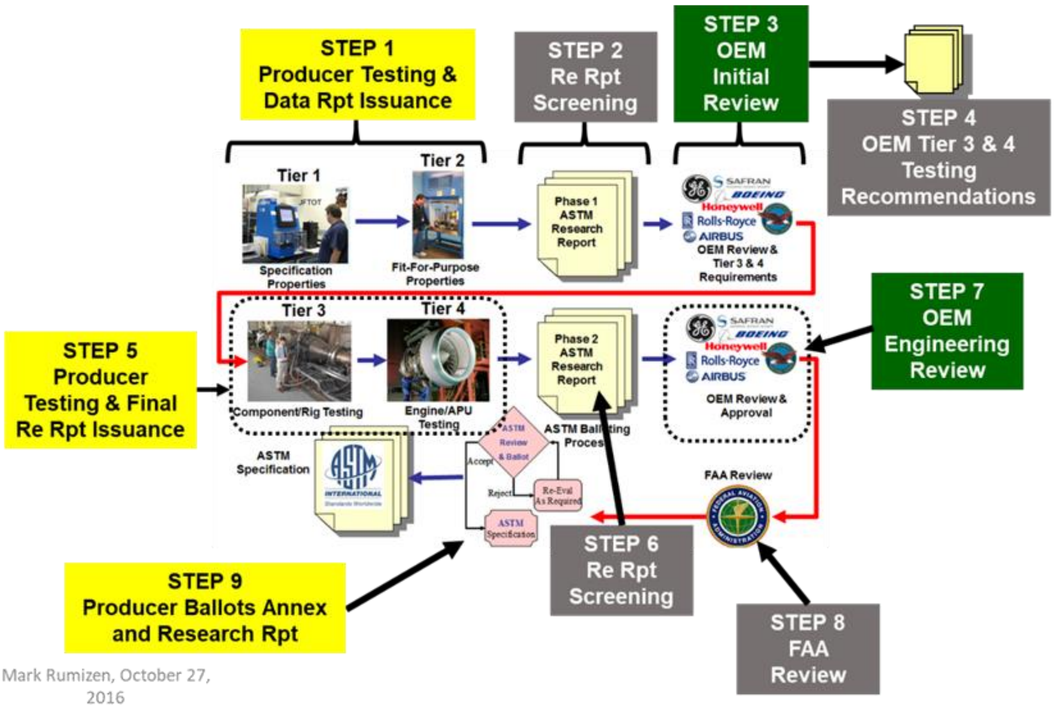

Figure 6 ASTM D4054 Process and OEM involvement

Both the FAA and the EASA state that control of fuels/additives is an integral part of the OEM's Design Authority approval. During certification the FAA and EASA rules apply (FAA: PART 33—AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES - §33.67 Fuel system and EASA: Certification Specifications for Engines. CS-E 560 Fuel System). Further, recognising the issue of increasingly rapid changes of fuel specifications, both authorities re-iterated the OEM's responsibility (FAA: Advisory Circular AC No 20-24C (30/6/14) and EASA: Certification Memorandum: EASA CM-PIFS-009 Iss 1. (28/02/13)).

Despite these requirements, the industry is aware of instances where lack of synchronisation exists. The UK Ministry of Defence (MoD), for example, has reported at several Aviation Fuel Committee and Executive Committee meetings (that maintain and update the Defence Standard specifications) that many military platforms do not yet approve the use of non-conventional (aka synthetic) fuels and such fuels are not allowed in military aircraft at this time. This is not unique to UK military OEMs but is encountered with European ones as well.

It should be noted that there is currently a debate within the industry regarding the level of engagement of key stakeholders, and particularly OEMs, within ASTM and Def Stan so this issue is across the whole industry. OEM engagement varies from lack of real ongoing engagement, through some limited input to those OEMs that fully support the formulation and development of the specification and approval process, and the subsequent support to new fuel and additive approvals. ASTM D4054 (see section 3.1) recognises the efforts and input by major OEMs in the following extract:

"OEMs—Engine OEMs include but are not limited to Pratt & Whitney (P&W), GE Aviation (GE Av), Rolls Royce (RR), and Honeywell. Airframe OEMs include but are not limited to Boeing, Airbus, Bombardier, and Lockheed. OEM approval is required for use of a new fuel or additive in aviation gas-turbine engines OEM review and approval is required to ensure safety of flight, engine operability, performance, and durability requirements are not impacted by the new fuel or additive."

The list of OEMs in ASTM D4054 recognises the pro bono input and effort from these organisations to create and develop the process, and, generally reflects the list of major OEMs that support key stakeholder specification groups (UK Aviation Fuels Committee Def Stans, ASTM etc.) and associated research groups (CAAFI, CRC) etc.

This debate about support and engagement applies both in Europe and the US. Further, most OEMs provide hardware for both commercial and military applications and so impacts on both types of fuel[36]. It always remains the duty of the OEMs (as the Design Organisation) to determine and define approved fuels and additives as part of their duty to the External Airworthiness Authorities. Generally, within the major OEMs the ultimate authority to approve fuels/additives sits with the Chief Engineers of each mark of hardware and sometimes this is delegated to hardware suppliers (components and systems) within the supply chain. Within the MoD the ultimate decision to approve fuels/additives sits with the platform owner, who generally would look to the OEMs for technical guidance. These respective organisations need to have clear designated roles and processes in place to cascade decision making through the organisation since a change to a fuel specification impacts all hardware across the fleet.

Regardless of the type of organisation the key to a smooth process is engagement at every stage of the ASTM D4054 process so that each OEM as a prime stakeholder can rationally assess the risks and define within the industry-wide programme their specific requirements. Review of data after the fact often raises new questions and need for testing (which could have been integrated into the industry programme) and therefore causes – often unnecessary – further cost and delays[37].

It is noteworthy that compared to the EU/UK, the US military (USAF, Navy and Army) are particularly active and supportive (in terms of commitment, in kind support and funding) of commercial and military fuel specification development. Indeed, the US military actively participate in key stakeholder groups both in the US and Europe, and, in many cases fund group activities for example being Charter Members (by contribution) of the CRC Aviation Fuel Technical Committee.

In summary full engagement of OEMs and military users is key to a smooth and efficient process, and while some OEMs and military organisations do this and support the industry, this engagement is by no means consistent across the industry. This inevitably causes delays and incurs unnecessary costs to the approval process which could be avoided with better cross-industry coordination.

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[36] In simplistic terms military fuels are the same base hydrocarbons but with additional requirements including, but not limited to, mandatory use of certain additives which are optional in commercial fuels. Thus, the process of evaluation and approval of n ew synthetic fuel blends equally affects military and commercial fuels.

[37] It must be noted that in an ideal programme all risks are identified and mitigated as an industry wide shared programme. However, it must always be recognised that OEMs must have the right to do bespoke testing when they have specific concerns that cannot be shared with competitors.

5.4 The role of CAAFI

The Commercial Aviation Alternative Fuels Initiative (CAAFI)[38] was started in 2006 by a group of key stakeholders who created CAAFI as a forum to assist in the deployment of alternative and renewable fuels to "enhance energy security and environmental sustainability for aviation through the use of alternative jet fuels". CAAFI includes international stakeholders such as airlines, OEMs, fuel producers, researchers, specification and Airworthiness agencies and other government agencies. CAAFI recognises and supports the need for "drop in fuels" that offer environmental and security of supply benefits and that are commercially viable.

CAAFI therefore serves as a forum to bring all stakeholders together, share information and provide guidance and/or support where required. CAAFI does this by hosting technical workshops, participating in energy and financial industry forums, and promulgating information and data via webinars, presentations, and print media. CAAFI members meet regularly to share updates on the state of alternative jet fuel developments, identify gaps and challenges, and determine next steps in the research, development, and deployment process.

CAAFI is primarily comprised of four key focus groups:

- **Fuel Certification and Qualification**: Supporting the technical evaluation and certification of new fuels through the ASTM process by bringing key stakeholders together, often in task forces, and collating and presenting data.
- **Research and Development**: Improving fundamental understanding of the relationship between new raw materials and processes and subsequent properties of the blendstocks and final blends. And, supporting initiatives that help the industry to work smarter.
- **Sustainability**: Supporting the development and application of methods to reliably measure environmental, social, and economic risks/benefits and performance metrics in the whole life cycle assessment of new fuels.
- **Business**: Assisting in the connecting of fuel producers, blenders and users and supply chain integration.

5.5 Potential scope of a European forum / Clearing House

Based on discussions with a wide range of stakeholders, from OEMs to fuel producers to regulators, it is clear that there is scope to establish a European initiative which would have the explicit aim of supporting the increased penetration of SAFs in Europe. This can be divided into two distinct bodies, namely an EU Clearing House which would focus on helping SAF producers successfully bring their products to market, chiefly through providing support in navigating the ASTM approval process (as the US Clearing House does), and a forum bringing together different stakeholders, which would promote SAFs in other ways (as CAAFI does in the US).

The activities an EU Clearing House would carry out can be divided into several categories (with reference to the 4 CAAFI focus groups):

- Fuel certification and qualification activities
- Sustainability activities
- Business/commercialisation activities

Details on the exact activities an EU Clearing House would carry out in each of the above categories are given in the following sections. The one common theme between all activities is the need for funding.

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[38] For more information visit: http://www.caafi.org/

5.5.1 Scope of activity

5.5.1.1 Fuel certification and qualification activities

In this category, the US Clearing House serves as a model. Funds provided to it by the FAA are directed at two main activities, namely funding the various tests a new fuel must be subject to and funding OEMs to review the research reports produced after testing. The success of the US Clearing House suggests that these are the areas where European funding should be directed. In testing, two promising models have emerged based on stakeholder input (particularly the FAA's). These are referred to in this report as the 'fully-integrated' and the 'partially-integrated' options.

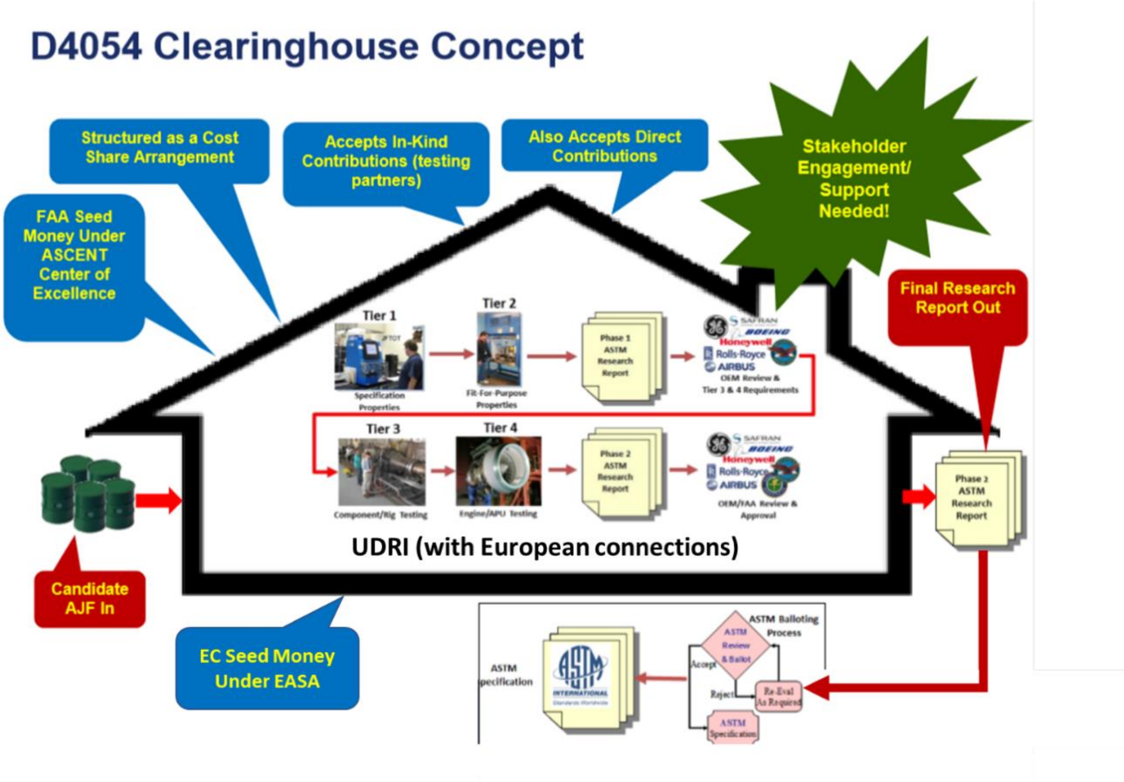
'Fully-integrated' option

The 'fully-integrated' option, which could potentially be named the US-EU Clearing House, involves very close collaboration between the FAA, UDRI and EASA. This option would require a Clearing House representative to be based in the EU, potentially within EASA. The representative would act as a first point of contact for (primarily European) producers wishing to commence the approvals process and would provide all the guidance and expertise currently provided by UDRI (including defining tests to be done, interpreting results and assisting with the production of the research report). Once contact is made, the producers would be referred to UDRI, where testing would commence. In case UDRI's facilities are unavailable for any reason, the early-stage, lab-based tests (Tier 1 and Tier 2) would be performed at a European facility instead. The facility would be chosen by the Clearing House, from a list of 'pre-approved' facilities compiled in advance by the Clearing House, with input from all major OEMs. The Phase 1 research report would subsequently be produced by the facility that performed the testing, again with input from UDRI (who possess unique expertise regarding the content and format of the research report expected by the OEMs). A similar approach would be taken for Tier 3 and Tier 4 tests, bearing in mind that the number of facilities capable of conducting such tests is more limited, and often includes OEM's own rigs. This model is illustrated in Figure 7.

In terms of funding, any testing performed at UDRI (or at other US facilities) would be funded by the FAA via the ASCENT programme in the normal way whereas testing at a European facility would be funded by the equivalent European fund. For research report review by the OEMs (which involves both European and US OEMs), the FAA would fund the major US OEMs (Boeing, GE etc.) as is done today, whereas EASA would fund the major European OEMs (Airbus, Rolls Royce etc.).

The chief advantage of the above approach is the complete avoidance of any duplication of effort or capability. By simply adding a European 'branch' of the US Clearing House and recruiting several European testing facilities to work with UDRI, prospective fuel producers – especially European ones – would benefit by having a 'local' point of contact and by potentially being able to carry out their testing in relative proximity to production facilities. Directing all testing to UDRI in the first instance would ensure their unique expertise and capabilities – acquired over many years – are utilised as much as possible, likely leading to the minimisation of costs (see section 5.2). Ultimately, the choice of where to carry out initial, lab-based testing, would probably have to be made on a case-by-case basis, once a comprehensive gap analysis identifying the capabilities and expertise of European facilities has been conducted. Furthermore, any prospective bottlenecks caused by too many fuel producers approaching UDRI to commence testing would be avoided by having the option to use European testing facilities. On the other hand, the one potential disadvantage of such an approach would be the lack of a European facility acting as a testing base and coordinating activities across Europe, as UDRI does in the US.

This would keep UDRI as the only global hub for SAF approval, which may become problematic if the number of producers seeking approval increases substantially in future.



➨ **Figure 7** 'Fully integrated' US-EU Clearing House concept

'Partially-integrated' option

The 'partially-integrated' option would involve the establishment of a stand-alone EU Clearing House, based at a leading European testing facility. Due to the lack of a European facility with the breadth of capability of UDRI, the EU Clearing House would need to have close relationships with other European testing facilities, to ensure it can carry out as many tests within the D4054 process as possible. Potential candidates which can host an EU Clearing House include DLR in Germany and the University of Sheffield's Low Carbon Combustion Centre in the UK, amongst others (see Table 4).

In this scenario, the US and EU Clearing Houses would exist in parallel and in co-ordination, but operate independently, with the European version helping producers navigate all the steps of the approval process, including testing and production of research reports. In the simplest case, the question of which Clearing House helps which producers can be settled geographically i.e. US producers utilising the US Clearing House and European ones the EU Clearing House.

The establishment of a new facility would probably require the consensus of ASTM and the major OEMs, to ensure that test results and research reports produced by the EU Clearing House are accepted. In the same vein, it is likely that during its early days, the EU Clearing House would collaborate closely with UDRI in order to gain the required expertise regarding the correct procedures of carrying out tests and writing research reports; building up this expertise may take a long period of time and involve substantial additional costs, in contrast to the easier to implement 'fully-integrated' option.

As with the 'fully-integrated' option, access to funding from a European body, whether that be EASA or the EC, would be imperative. This would again be used to fund the tests themselves and fund European OEMs to review the research reports. Compared with the 'fully-integrated' option, this approach would lead to the creation of an independent European body which operates distinctly from – but collaborates with – the US Clearing House and UDRI. The EU Clearing House would hence have more autonomy, with the potential to adjust its working methods or areas of focus based on feedback from all stakeholders involved. Additional areas of focus could include:

- Working with airframe OEMs e.g. Airbus to ensure that all tests they require to approve a SAF are carried out (some of which are slightly beyond the scope D4054 and hence are not carried out by UDRI)
- Increasing the European presence in the approval community e.g. ASTM meetings, to possibly promote the work being done in Europe in pre-screening and model-based approvals (via research projects such as JETSCREEN)

The disadvantage of this option is the duplication involved; there would be 2 separate Clearing Houses, which may lead to some confusion, for example if a European producer believed that they must go through the EU Clearing House to be able to sell their product in Europe. Such problems can be avoided by ensuring clear communication from both Clearing Houses, the FAA and EASA to the wider community, which includes fuel producers and airline operators.

5.5.1.2 Sustainability activities

Whilst ensuring a SAF is sustainable is not strictly a requirement to putting it on the market (unlike obtaining approval), proving the sustainability of their product to customers is a key requirement for SAF producers, as explained in Section 5.1.1. It is also essential if a SAF is to be considered renewable according to regulatory definitions, such as those of CORSIA or RED II. Many airlines emphasise that any SAF they may buy would need to be 'fully sustainable' i.e. not just providing lower greenhouse gas emissions compared to fossil jet fuel, but also produced from sustainable feedstocks in a socially and economically sustainable manner. This is due to the perceived reputational and business risk of using a SAF which may not be fully sustainable (by being produced from palm oil feedstock, for example).

In contrast to approval, which can only be obtained by going through ASTM and the D4054 process, there are a number of Sustainability Certification Schemes (SCS) for producers to choose from (see Section 4.1). The choice of which certification to pursue is largely market-based. A producer wishing to sell SAF in the EU for example, would probably need to ensure their product is certified sustainable according to the Renewable Energy Directive's (RED II) criteria to be competitive in that market. Furthermore, once a producer has chosen a certification they wish to acquire, ample support in navigating the process is provided by certification bodies, which are widespread. As an example, the International Sustainability & Carbon Certification (ISCC), an SCS, lists 29 certification bodies which it cooperates with.

Given the above, there is limited scope for an EU Clearing House to provide assistance to producers when it comes to sustainability. Nevertheless, making available an information document and perhaps consultancy, which could include a list of the most commonly used SCSs and the sustainability criteria of various national and international regulations (EU RED, CORSIA, the UK's RTFO), may be useful for prospective SAF producers as it would allow them to easily check the sustainability requirements of different markets and subsequently make an educated decision about which certification to pursue. Funding part of producers' costs associated with the certification process will undoubtedly be helpful; however, limited funding would be better directed at the approval activities, specifically to fund reviews of research reports by OEMs, as this has been one of the obstacles to approvals in the past (in combination with the fact that reviewing research report is not a core activity of OEMs, and hence is usually not given utmost priority).

It is also worth noting that – according to the SWAFEA programme – the availability of biomass to meet the demands for fuel production by 2050 is critical and either radically more efficient biomass processing or non-biomass sources of carbon are required to meet the needs of aviation without compromising other biomass requiring industries. Making producers aware of this reality is also an important point.

Given that the US Clearing House is not involved in this area, an EU Clearing House could provide such services as a unique selling point.

5.5.1.3 Business/commercialisation activities

The difficulty in overcoming the price gap between SAFs and fossil jet fuel has been one of the main obstacles to increased SAF uptake, as illustrated by that fact that SAFs available today are 2 to 8 times more expensive than fossil jet fuel[15]. Several solutions have been proposed to address this problem:

- Introducing new environmental taxes to fossil-based fuels, which would add to the costs of flying for consumers, would reduce the price gap and proceeds could be used to finance SAF projects
- Introducing mandates for the use of SAFs (similar to those in place for biodiesel in the road transport sector), spurring innovation in SAF production and incentivising airlines to purchase more SAF
- Providing financial instruments for SAF producers to allow them to build better business cases. This could include providing guarantees on any loans taken out to expand production capacity or arranging Contracts for Difference – similar to those used in the electricity sector – between producers and airlines (effectively guaranteeing that producers would receive a stable price for their products); see Canada's Biojet Supply Chain Initiative's (CBSCI) report on policy tools for promoting SAFs for more information on such mechanisms[39]
- Bringing together suppliers and producers to encourage offtake agreements

Clearly, EASA cannot issue Europe-wide SAF mandates or introduce an additional aviation tax. In the case of mandates and targets, the European Commission and national governments would normally play a leading role. The French government, for example, has set non-binding targets of 2% of total aviation fuel to be sustainable by 2025, 3% by 2030 and – as part of a wider National Low Carbon Strategy – 50% by 2050[40]. The UK outlined a less ambitious target of 5% of total aviation fuel to be sustainable by 2050 in its 2019 Net Zero report[41]. ICAO has set a deadline of 2025 to define a quantitative target for SAF uptake as part of its 2050 Vision for Sustainable Aviation Fuels[42]. Such targets can spur investment in SAFs, but without a Europe-wide commitment, there could be worries over competitiveness.

In the case of providing financial instruments, this again would probably be within the remit of national governments, or European investment bodies, such as the European Investment Bank (EIB). It is worth noting, however, that EU state aid rules may prevent national governments from directly funding local producers. The

[39] https://cbsci.ca/reports/

[40] 'The challenge of Sustainable Aviation Fuels development', Claire Rais Assa, DGAC France. Presented at the 2019 ICAO stocktaking seminar on SAFs: toward the 2050 vision for sustainable aviation fuels

[41] https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf

[42] https://www.icao.int/environmental-protection/GFAAF/Pages/ICAO-Vision.aspx

European Commission (EC) funds some projects which aim to produce SAFs, such as flexJET[43], but these are inevitably on a small-scale.

Based on the above arguments, it is recommended that any activities EASA carries out in the SAF commercialisation area should be focused in bringing the various stakeholders together (as discussed in the next section), in order to promote a more coherent message with regard to SAFs, ideally leading to the establishment of Europe-wide target for SAF use. Wherever new policies are implemented, whether by the EC or member states, EASA could support these by monitoring their effects and assessing their effectiveness, given its unique position and knowledge in the sector.

5.5.2 Stakeholder involvement

In addition to an EU Clearing House that would focus on helping producers through the ASTM approval process, there is a strong need in Europe for a forum to bring together the various stakeholders in Europe, as CAAFI does in the US. It could be argued that such a forum is of even greater importance in Europe, due to several reasons:

- Unlike the US, the EU is divided into member states, each with its own national government. A disjointed approach to setting SAF targets for example (as is the case now), is inefficient and may not be effective.
- The EC also has several bodies involved in SAF, which currently do not communicate as effectively as possible. These include DG ENER, DG CLIMA and DG MOVE.
- A unique problem in Europe is the ban on transporting any synthetic aviation fuels (including SAFs) using infrastructure shared between the civil and military aviation sectors, such as the NATO Pipeline System (NPS); addressing this requires increased coordination with and engagement from OEMs to streamline and accelerate cross-industry approval. EASA is uniquely placed to play a coordinating role in this area with the European Defence Agency (EDA)
- Some European regulations, such as RED II, are arguably setting GHG reduction targets for new fuels which are discouraging some production pathways for SAFs e.g. requiring SAFs produced from 2021 from biological feedstocks to achieve a 65% GHG reduction compared to a fossil fuel baseline of 94 gCO_2eq/MJ (70% for Renewable Fuels of Non-Biological Origin (RFNBOs))[44] if they are to be counted towards a member state's renewable energy target

The stakeholder groups whose involvement would be required in such a forum are listed in Table 9.

[43] http://www.flexjetproject.eu/

[44] https://theicct.org/publications/final-recast-renewable-energy-directive-2021-2030-european-union

Table 9 List of stakeholder groups which could be involved in a European SAF forum

Group	Potential representatives
Regulatory agencies and supranational bodies	EASA, EC, DG ENER, DG MOVE, DG CLIMA
Member states	DGAC[45] France, DGAC Spain
Research organisations / funding bodies	Horizon 2020, Innovation Fund
SAF producers / suppliers	SkyNRG, Neste, Shell
SAF end-users (airlines)	Air France, Lufthansa
Industry associations	Airlines for Europe (A4E), FuelsEurope
Major OEMs	Rolls Royce, Pratt & Whitney, GE Aviation, Honeywell, Airbus, Boeing, Bombardier, Lockheed
Military airworthiness representatives	EDA, NATO, member state defence departments

A forum including representatives of all the above groups could carry out activities including:

- Attempting to streamline the SAF uptake targets of different member states, and – in cooperation with the EC – work towards a common European target
- Recommending changes to national and EU regulations, such as RED II, which would lead to increased SAF production and uptake
- Improving coordination and engagement of OEMs, which could increase the speed of cross industry approval and therefore reduce time to market
- Attempting to help SAF producers overcome commercialisation challenges, potentially through the establishment of a fund led by the EC and member states

A prominent role for EASA in such a forum would be the dissemination of information to airlines, many of whom are not aware that once a SAF has gone through the ASTM approval process and entered the market, it can be used without the need for further consultation or permissions from EASA or national regulators. In the US, such communications are provided via the FAA's Special Airworthiness Information Bulletins (SAIBs). EASA's Safety Information Bulletins (SIBs) could serve this purpose in Europe.

Rather than establishing a new body, the activities described above could be carried out via the Alternative Renewable Transport Fuels Forum (ARTFF), which was established by DG ENER and includes an Aviation Working Group with representatives from many of the stakeholder groups listed in Table 9.

5.5.3 Recommended form of a European forum / Clearing House

Based on the arguments in the previous sections, this report recommends that a European initiative be established to promote the production and use of SAFs. This would be split into two distinct bodies, each carrying out different activities. The first would be an EU Clearing House, modelled on the US Clearing House and carrying out similar activities, including:

- Providing guidance to SAF producers on the prospects of their products to gain approval under ASTM D4054, via 'pre-screening'. This could follow the US model, using the concept of Tier α and Tier Zero testing, or attempt to make use of European research on model-based pre-screening (via the JETSCREEN programme for example)

[45] Directorate General for Civil Aviation

- Once producers enter the D4054 process, acting as a link between the producer and OEMs, providing guidance on which tests need to be carried out, carrying out and funding those tests
- Working with testing facilities to produce the required research reports following testing, and funding European OEMs to review those reports
- Providing guidance on the various sustainability certification schemes available for SAF producers, and on the sustainability requirements for meeting national and supranational regulations in Europe, including RED II
- Collaborating closely with the US Clearing House and engaging with ASTM to increase European representation in the community

Of the two possible options for an EU Clearing House (discussed in section 5.5.1), it is recommended that the 'fully-integrated' option is pursued initially. Compared to the 'partially-integrated' option, this would be easier and quicker to implement, especially because it would avoid the delays associated with selecting a European testing facility to act as the central hub of the EU Clearing House. The 'partially-integrated' option could be pursued at a later point, after European facilities gain more expertise in D4054 testing with the guidance of UDRI.

The second body of the European initiative would take the form of a forum, modelled after CAAFI in the US, which brings together the different stakeholders in the SAF industry, including producers, airlines, regulators, OEMs, and military airworthiness representatives. This forum would work to:

- Support the EU Clearing House, specifically by coordinating funding, which could come from EASA or from the EC
- Increase communication between national governments and European regulatory bodies to deliver a coherent message on SAFs (with the potential aim of introducing EU-wide production targets)
- Focus on bringing all OEMs together, including improved engagement where relevant, to accelerate cross-industry approval, for instance to eventually allow the use of shared civil/military infrastructure to transport synthetic fuels including SAFs
- Increase awareness of the regulatory status of approved SAFs, via EASA's Safety Information Bulletins

Creating the bodies described above would not only help to promote SAFs in Europe and smooth the path to approval, but would also significantly boost the European presence in the SAF community, which is currently dominated by US bodies such as the US Clearing House, the FAA and CAAFI.

6. Conclusions and recommendations

This study analysed the status of Sustainable Aviation Fuels (SAFs) in Europe today, including both more established technologies and ones at a lower Technology Readiness Level (TRL). It highlighted the fact that SAF penetration is extremely low today, partly due to the absence of any significant production capacity. As of the time of writing, most publicly announced offtake agreements, even those involving European airlines, rely on fuel produced in the US. However, European production is set to increase significantly in the medium term; it is plausible that SAF production capacity within Europe could reach 500,000 tonnes per year by the mid 2020s.

Due to the limited availability of data on SAF usage today, it is difficult to estimate the CO_2 savings being achieved. EASA's Environmental Portal could in future act as a central repository for such data, which will be collected via various mechanisms run by the EU, ICAO and IATA.

The challenges that face a novel SAF in entering the aviation market were highlighted, with a particular focus on approval barriers, specifically the D4054 process. The solution implemented in the US, namely the Clearing House run by the University of Dayton Research Institute and funded by the FAA, which streamlines the D4054 process, was reviewed. This review noted that that whilst the FAA has funded UDRI to set up the specific Clearing House organisation, many of the required facilities and capabilities already existed. These were created and funded by many years of activity in the area of fuel evaluation. Any business case needs to look at options of creating a facility like UDRI versus buying in capability and/or creating capability in the longer term. This has to be balanced against the number of fuels likely to be presented and in what timescales.

The issue of sustainability was also examined, via an analysis of the role of Sustainability Certification Schemes (SCS) and how they interact with regulatory sustainability requirements, particularly those in the EU's Renewable Energy Directive (RED II) and the International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Through interviews with a wide range of stakeholders, this study determined how SAF penetration can be increased in Europe by establishing a facilitation initiative led by the European Aviation Safety Agency (EASA). Since one of the main obstacles preventing SAF uptake is the complexity of the approval process, it is recommended that such an initiative should include a body acting as an EU Clearing House (cooperating closely with the US Clearing House). In addition, a stakeholder forum, similar to the Commercial Aviation Alternative Fuels Initiative (CAAFI) in the US, would be beneficial for addressing several other obstacles, chief amongst them the high price of SAFs compared to fossil jet fuel, which requires effective, coherent policy (such as production or use of mandates or incentives for producers) to overcome.

Two EU Clearing House models were investigated, the difference between the two being the level of collaboration with the existing US Clearing House. These were named the 'partially-integrated' and 'fully-integrated' models. It is recommended that the 'fully-integrated' option is pursued, at least initially, to ensure the EU Clearing House is as effective as possible from the start. Activities carried out by an EU Clearing House would include:

- Providing guidance to SAF producers on the prospects of their products to gain approval under ASTM D4054, via 'pre-screening'. This could follow the US model, using the concept of Tier α and Tier Zero testing, or attempt to make use of European research on model-based pre-screening (via the JETSCREEN programme for example)

- Once producers enter the D4054 process, acting as a link between the producer and OEMs, providing guidance on which tests need to be carried out, carrying out and funding those tests
- Working with testing facilities to produce the required research reports following testing, and funding European OEMs to review those reports
- Providing guidance on the various sustainability certification schemes available for SAF producers, and on the sustainability requirements for meeting national and supranational regulations in Europe, including RED II; this can be a unique selling point as such services are not provided by the US Clearing House
- Collaborating closely with the US Clearing House and engaging with ASTM to increase European representation in the community

The recommended stakeholder forum could either build on existing arrangements, such as DG ENER's Alternative Renewable Transport Fuel Forum (ARTFF), which already brings together many of the required stakeholders, or be a new initiative run solely or jointly by EASA. Some of the stakeholder groups whose involvement would be required are SAF producers, airline operators, member states, EU bodies and aviation Original Equipment Manufacturers (OEMs). The forum's activities would include:

- Supporting the EU Clearing House, specifically by coordinating funding, which could come from EASA or from the EC
- Increasing communication between national governments and European regulatory bodies to deliver a coherent message on SAFs (with the potential aim of introducing EU-wide production targets)
- Focus on increased engagement and coordination of OEMs and other key stakeholders e.g. military groups to accelerate cross-industry approval, for instance to eventually allow the use of shared civil/military infrastructure to transport synthetic fuels including SAFs
- Increasing awareness of the regulatory status of approved SAFs, via EASA's Safety Information Bulletins

6.1 Future work

Following a review of this report by EASA and its circulation to the relevant European Commission Directorates-General, including DG ENER, DG MOVE and DG CLIMA, next steps could include:

- Liaising with the FAA and the US Clearing House to clarify the way forward to establishing an EU Clearing House
- Carrying out a facility, capability, skills and knowledge gap analysis of EU based organisations. Based on this conduct analysis of cost of:
  - Coordinating EU facilities to create a virtual Clearing House
  - Creating a Clearing House as a new entity.
  - Defining the business case for creating vs buying in (e.g. use of UDRI) test capability not present.
- The above business case should be supported by a best estimate prediction of how many fuels are likely to be presented to the Clearing House to determine the most cost-effective use of funding (do or buy-in).
- Approaching major European testing facilities to scope out potential candidates to host an EU Clearing House
- Liaising with other European agencies to establish the best way forward for creating the recommended stakeholder forum
- Investigating the possibility of expanding the ARTFF or alternatively spinning off its aviation working group into a separate entity
- Creating a business model for an EU Clearing House, with a focus on determining potential funding sources

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Annex A Sustainable and alternative fuel approval status and TRL levels

A.1 Fuel types currently approved with ASTM D7566

As explained elsewhere (Section 3.1) ASTM D7566 controls synthetic fuels blends by the following structure:

- Requirements for each synthetic product in separate Annexes that define raw material, processes, finishing requirements and specification test methods and limits. These are tailored to each specific product.
- Requirements for the final blend including blend ratio limits, specification testing (as per ASTM D1655 Jet A and A-1) and any specific controls for final blends related to the use of synthetics.

Table 10 provides a summary of the currently approved products which have been assessed via ASTM D4054 and completed the formal ballot and certification process as of version ASTM D7566-19[46] and have their Annex included.

Fuels thus defined can therefore be manufactured by any fuel producer assuming that they can meet the specification requirements and have the appropriate quality assurance and management of change processes in place. Note that good industry practice is to go beyond ASTM D7566 for early production and share this with industry stakeholders to show due diligence.

A.2 Current fuels in the ASTM D4054 evaluation phase.

According to CAAFI[47] as of July 2019 products which are currently in the process of evaluation are summarised in Table 11. The table summarises the raw material, process and product designation. Note that work is ongoing and therefore the status of the fuels will be constantly changing.

A.3 Co-processing

ASTM D1655 has recently (2018) included, following evaluation by ASTM D0454, an allowance to co-process mono-, di-, and triglycerides, free fatty acids, and fatty acid esters (plant oils, animal fats and greases etc.) within a conventional refinery. Basically, this raw material is the same as would be used for HEFA or FT processing. The allowance means that up to 5% of the final jet fuel product with the balance being conventionally derived jet can be produced by feeding the refinery with these bio-oils mixed into the crude. The requirements define both the processes that need to be used and additional controls on the final product to recognise the presence of these new materials.

The whole concept of co-processing relies on the fact that most of the finishing processes applied to alternative blendstocks are typically found in a conventional refinery and used to upgrade product. Further, the ability to co-process at one place has potential to save on energy, hydrogen consumption and cost of transport and logistics of bringing the conventional and alternative blendstock together.

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[46] ASTM specifications have the number –XX to denote the version which is normally the last two digits of the year of issue and may add a, b, c etc. for multiple year issues

[47] http://www.caafi.org/focus_areas/fuel_qualification.html#qualification

This provides an alternative and perhaps more technically, environmentally and commercially viable route to producers of raw materials to produce SAF that would in the past have had to be fed into one of the approved D7566 processes.
As of time of preparing this report work is ongoing to expand co-processing to allow up to 5% FT waxes into the refinery feed by the same logic as that used for the bio-oils.

Table 10 Currently approved synthetic products as per ASTM D7566 (July 2019)

Description	ASTM D7566 Annex	Year of Certification	Blend Level	Feedstock	ASTM Description[46]
Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)	A1.FISCHER-TROPSCH HYDROPROCESSED SYNTHESIZED PARAFFINIC KEROSINE	2009	Up to a 50% by volume	Biomass any carbon containing biomass (BtL), coal (CtL) or natural gas (GtL)	FT-SPK synthetic blending components shall be comprised of hydroprocessed synthesized paraffinic kerosine wholly derived from: Paraffins and olefins derived from synthesis gas via the Fischer-Tropsch (FT) process using Iron or Cobalt catalyst. Subsequent processing of the product shall include hydrotreating, hydrocracking, or hydroisomerization and is expected to include, but not be limited to, a combination of other conventional refinery processes such as polymerization, isomerization, and fractionation
Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)	A2.SYNTHESIZED PARAFFINIC KEROSINE FROM HYDROPROCESSED ESTERS AND FATTY ACIDS	2011	up to a 50% blend by volume	Plant and animal fats, oils and greases i.e Mono-, di-, and triglycerides, free fatty acids and fatty acid esters (for example, fatty acid methyl esters) .	Synthetic blend components shall be comprised of hydroprocessed synthesized paraffinic kerosine wholly derived from: Paraffins derived from hydrogenation and deoxygenation of fatty acid esters and free fatty acids. Subsequent processing of the product shall include hydrocracking, or hydroisomerization, or isomerization, or fractionation, or a combination thereof, and may include other conventional refinery processes.
Hydroprocessed Fermented Sugars to Synthetic Isoparaffins (HFS-SIP)	A3.SYNTHESIZED ISO-PARAFFINS FROM HYDROPROCESSED FERMENTED SUGARS	2014	Up to a 10% by volume	Sugars	Synthetic blend components shall be comprised of hydroprocessed synthesized iso-paraffins wholly derived from farnesene produced from fermentable sugars. Subsequent processing of farnesene into iso-paraffins shall include a combination of hydroprocessing and fractionation operations, and may include other conventional refinery processes. In particular, hydroprocessing operations consist of reacting hydrogen with farnesene feedstock and fractionation operations consist of gas/liquid separation and isolation of synthesized iso-paraffins. For example, fractionation typically includes a distillation step
Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics (FT-SPK/A)	A4.SYNTHESIZED KEROSINE WITH AROMATICS DERIVED BY ALKYLATION OF LIGHT AROMATICS FROM NON-PETROLEUM SOURCES	2015	Up to 50% by volume	Biomass any carbon containing biomass (BtL), coal (CtL) or natural gas (GtL)	SPK/A synthetic blending component shall be comprised of FT SPK as defined in Annex A1 combined with synthesized aromatics from the alkylation of non-petroleum derived light aromatics (primarily benzene). Subsequent pro- cessing of the product shall include hydroprocessing, fractionation, and other conventional refinery processes
Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK)	A5 ALCOHOL-TO-JET SYNTHETIC PARAFFINIC KEROSENE (ATJ-SPK	2016	Up to 50% by volume	Starches, sugars, cellulosic biomass	ATJ-SPK synthetic blending components shall be comprised of hydroprocessed synthesized paraffinic kerosene wholly derived from ethanol or isobutanol processed through dehydration, oligomerization, hydrogenation, and fractionation.

Table 11 Synthetic products currently in ASTM D7566 Evaluation (CAAFI, July 2019)

Fuel Producer/Task Force Lead	Feedstock	Description	Status (See Figure 6 summary with steps)
Virent – (inactive)	Sugars and cellulosics	Hydro-deoxygenation Synthetic Kerosene (HDO-SK)	Tier 1 and Tier 2 testing commenced (Step 1)
ARA	Renewable plant and animal fats, oils and greases	Catalytic Hydrothermolysis Synthetic Kerosene (CH-SK)	Tier 1 and Tier 2 testing commenced (Step 1)
Boeing	Renewable plant and animal fats, oils and greases	High Freeze Point Hydroprocessed Esters and Fatty Acids Synthetic Kerosene (HFP HEFA-SK)	Tier 1 and Tier 2 testing completed Phase 1 Report under OEM Review (Step 3)
Virent	Sugars and cellulosics	Hydro-deoxygenation Synthetic Aromatic Kerosene (HDO-SAK)	Tier 1 and Tier 2 testing completed and reported. (Step 2)
Byogy, Swedish Biofuels	Sugars and lignocellulosics	Alcohol-to-Jet Synthetic Kerosene with Aromatics (ATJ-SKA)	Tier 1 and Tier 2 testing commenced (Step 1)
Shell	Multiple	Integrated Hydropyrolysis and Hydroconversion (IH^2)	Tier 1 and Tier 2 testing commenced (Step 1)
IHI	Hydrocarbon-rich algae oil	Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)	Tier 1 and Tier 2 testing completed (Step 1) Research Report Prepared (Step 2) and under OEM review (Step 3) Note: IHI are planning approval under Fast Track process.
KiOR (inactive)	Forest residues	Hydrotreated Depolymerized Cellulosic Jet (HDCJ)	Tier 1 and Tier 2 testing commenced (Step 1)

Annex B List of stakeholders contacted

Table 12 List of stakeholder calls conducted for this study

Contact name	Contact details	Organisation
Anna Soltorp	Anaa.soltorp@flygbra.se	BRA – Braathens Regional Airline, Swedish airline which regularly uses SAFs in operations
Aysha Ahmed	Aysha.ahmed@dft.gov.uk	UK Department for Transport
Bastian Rauch	Bastian.rauch@dlr.de	DLR – German Aerospace Centre, a leading research and testing facility
Bruno Silva	Bsilva@icao.int	ICAO – specialised aviation agency of the UN
César Velarde	Cesarvelarde.consultant@gmail.com	Independent consultant
Claire Rais Assa	Claire.rais-assa@aviation-civile.gouv.fr	DGAC France – French civil aviation authority
Daniel Leucx & Emanuella Sardellitti	Daniel.leucx@fuelseurope.eu Emanuela.sardellitti@fuelseurope.eu	FuelsEurope – association representing European petroleum refining industry
Darío Perez Campuzano & Martina Di Palma	dperez@euroairlines.es Martina.DiPalma@eraa.org	Euroairlines – Spanish air taxi operator ERAA – association representing European aviation industry (including 51 airlines)
Diederik Pen & Agnes Lammel	Diederik.pen@wizzair.com Agnes.lammel@wizzair.com	WizzAir – Hungarian low-cost airline
Grégoire Le Comte	Gregoire.le-comte@ec.europa.eu	DG MOVE – EU Directorate General for Mobility and Transport
Ivan de Lepinay & Anatolij Oniscenko	Ivan.de-lepinay@easa.europa.eu anatolij.oniscenko@easa.europa.eu	EASA – Environmental Portal focal point
Karlijn Arts	karlijn@skynrg.com	SkyNRG – market leading SAF supplier
Kyriakos Maniatis	Kyriakos.maniatis@ec.europa.eu	DG ENER – EU Directorate General for Energy
Laurel Harmon	laurel@lanzatech.com	LanzaTech – US-based SAF supplier
Mickael Matrat, Alain Quignard & Maira Alves Fortunato	Mickael.matrat@ifpen.fr Alain.quignard@ifpen.fr Maira.fortunato@ifpen.fr	IFPEN – French petroleum research institute, a leading research and testing facility
Mark Misselhorn	Mark.misselhorn@caphenia.com	Caphenia GmbH – low TRL SAF producer
Mark Rumizen	Mark.rumizen@faa.gov	FAA – US Federal Aviation Administration
Mike Famery	Mark.farmery@clearandbright.com	Independent consultant
Renco Beunis	renco@skynrg.com	SkyNRG – market leading SAF supplier

Robert Midgley	Robert.midgley@shell.com	Shell
Simon Christie	s.christie@mmu.ac.uk	Manchester Metropolitan University
Simon Weeks	Simon.weeks@ati.org.uk	ATI – UK aerospace research institute
Stan Seto	Stan.seto@belcan.com	ASTM
Steve Csonka	Csonka.caafi.ed@gmail.com	CAAFI – US stakeholder forum promoting SAFs
Steven Le Moing & Solange Baena	Steven.le-moing@airbus.com Solange.baena@airbus.com	Airbus

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