SUSTAINABLE AVIATION FUELS ROAD-MAP

Fueling the future of UK aviation

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EXECUTIVE SUMMARY

As demand for aviation from both consumers and businesses continues to grow, the main challenge facing the UK's aviation sector is how to meet that demand and deliver the social and economic benefits of aviation, whilst also making essential reductions in greenhouse gas emissions.

It is no secret that aviation is a challenging sector to decarbonise. However, real progress has been made, with the UK sector having broken the link between growth in passenger numbers and growth in emissions primarily through the introduction of newer, more efficient aircraft. Going forward, Sustainable Aviation believes that through an international approach, combining the right Government support with substantial investment from industry, net zero emissions are within reach for UK aviation.

Electrification of aviation is already being developed and by building on the promising work of Sustainable Aviation members like Rolls-Royce and Airbus could offer the UK the opportunity to become a world leader in electric propulsion. At present, the performance of battery technology cannot match the performance of liquid hydrocarbon fuels which means that in the short and medium term for short haul flights – and in the long term for long haul flights – flying will remain jet-fuel based.

The development and commercialisation of sustainable aviation fuels over the next decade is vital to providing a solution to greenhouse gas emissions in flying now. Sustainable aviation fuels represent an essential near-term 'bridge' to technologies like hybrid-electric and all-electric aircraft. They offer significant life-cycle carbon reduction gains (at least 70%) and are cleaner burning, with up to 90% reduction in particulates. Alongside the introduction of new, cleaner fleet and engine technology, airspace modernisation and market-based carbon offsetting measures, together these represent UK aviation's plan to decarbonise.

Critically, these fuels exist today and with the right policy support could reduce UK emissions in 2050 by at least **32%** whilst making the UK a world-leader in the technology.

This Road-Map updates the 2014 study to identify and forecast the potential for sustainable fuel production to 2050. Its specific objectives are:

- To highlight the potential contribution that sustainable aviation fuels can make to supporting the decarbonisation of the UK economy;
- To outline the potential for job creation and economic growth in the sustainable fuels sector both in the UK and globally;
- To build on the UK Government's existing support to develop a strategy for UK sustainable fuels and to provide a cross departmental focus on SAF to progress development and commercial deployment, through a new Office for Sustainable Aviation Fuel (OSAF) or similar cross-departmental body with appropriate governance structure, membership and resources.

Today sustainable aviation fuel is at a global tipping point, with a number of projects on the verge of commercial-scale production due to technological, political and commercial developments. Globally, fourteen airports now supply sustainable aviation fuels, although overall fuel volumes remain low.

A number of airlines and some fossil fuel companies are now making investments in sustainable aviation fuels through joint ventures. We are also more optimistic than the previous Road-Map about the potential of integrated Carbon Capture and Storage and see potential for this to be deployed alongside fuels production increasing overall carbon reductions significantly.

The UK is well-placed to seize this opportunity and benefit from the economic, environmental, fuel and food security benefits that the increased use of sustainable aviation fuels will bring. Through the introduction of aviation into the Renewable Transport Fuels Obligation (RTFO), the UK took an important first step towards establishing itself as a global player in the emerging sustainable fuels sector. However, we're not there yet: the UK currently follows, rather than leads, on sustainable fuels. The US (particularly California), Norway, Sweden, Finland and the Netherlands are moving further, faster on sustainable fuels. We cannot afford to be left behind.

EXECUTIVE SUMMARY

Future opportunity of sustainable aviation fuels

Sustainable Aviation is committed to the development of sustainable fuels that meet strict safety conditions, significantly reduce life cycle greenhouse gas (GHG) emissions over conventional fossil fuel, meet stringent sustainability standards and avoid direct and Indirect Land Use Change (ILUC). The UK has the opportunity to establish a leadership position in Recycled Carbon Fuels (RCF), which are manufactured from waste materials such as waste industrial gases and municipal solid waste (MSW).

Sustainable Aviation commissioned independent consultants E4tech to model the future potential of sustainable aviation fuels. Their analysis estimates that in 2035 there may be between 14.5 and 30.9 million tonnes per year of sustainable aviation fuels produced globally. This would correspond to 4%-8% of global aviation fuel use.

If UK production were to grow in line with global production, **sustainable aviation fuels produced in the UK could provide between 3.3% and 7.8% of the UK's 2035 aviation fuel demand.** In 2050, **32%** of the UK demand for kerosene could be met by domestically produced sustainable aviation fuel, requiring 4.5 mt/year of sustainable aviation fuel production. This corresponds to an annual growth rate from 2035 that is not dissimilar to historic growth rates in global biofuels production.

By 2035, the development of a domestic industry for the production of sustainable fuels could generate a Gross Value Added (GVA) of up to £742m annually and support up 5,200 UK jobs. A further 13,600 jobs could be generated from the growing market for sustainable aviation fuels through global exports.

This export market is worth up to an additional £1.952bn to 2035, bringing the full value to the UK of £2.7bn from UK production and global exports. In addition to this, UK manufactured fuels could deliver a £550m per annum benefit to the UK's balance of payments.

UK POTENTIAL: SUSTAINABLE FUELS ROAD-MAP

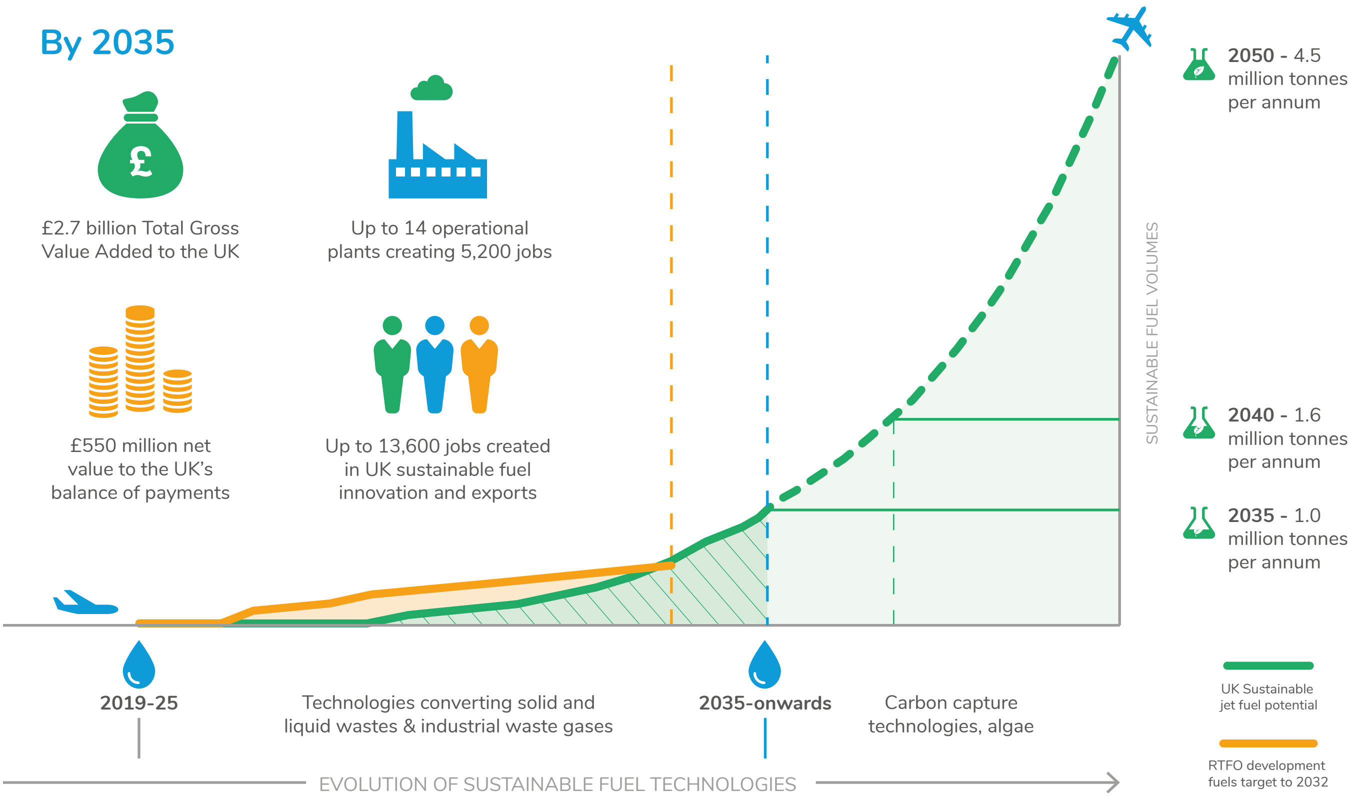
By 2035

£2.7 billion Total Gross Value Added to the UK

Up to 14 operational plants creating 5,200 jobs

£550 million net value to the UK's balance of payments

Up to 13,600 jobs created in UK sustainable fuel innovation and exports



The Renewable Transport Fuel Obligation (RTFO) is the Government's policy to reduce greenhouse gas emissions from fuel by providing incentives for sustainable fuels. To encourage investment in fuels manufactured from wastes and residues in line with the UK's long-term strategic needs, a 'development fuels' target was set as part of the RTFO from 2019. This includes sustainable aviation fuels. The RTFO only extends to 2032 at present.

2035 figures refer to domestic production of sustainable fuels

Making the opportunity a reality

Given the global climate change challenge and UK plans to cut emissions, supporting the uptake and commercialisation of sustainable aviation fuel should be a strategic UK priority. Industry is rising to the challenge. SA members are currently committed to developing a number of sustainable fuel initiatives and are collectively planning to invest £3.5 billion in supporting new plant construction, fuels testing and R&D, as well providing bankable fuel offtake agreements, over the next 20 years.

However, the success of these and future projects is dependent on industry continuing to work with the Government to create a shared vision for sustainable fuels. In July 2019, the Department for Business, Energy and Industrial Strategy (BEIS) unveiled an £80m investment to help develop the next generation of electric vehicles and new hybrid aircraft. The Business Secretary cited this welcome announcement as helping to 'create the next generation of net zero carbon emission technologies that will transform entire industries', including aviation.

Sustainable aviation fuels, however, require a similar kind of investment and focus as the more immediate, near-term opportunity to decarbonise aviation. Long-term policy stability and financial support for the scaling-up and rollout of sustainable fuel production capacity is needed to deliver on the opportunity outlined in this Road-Map. That is why Sustainable Aviation is calling for:

- **An Office for Sustainable Aviation Fuel or similar body** - Given the significant near-term opportunities offered by sustainable aviation fuels as both a measure to cut aviation carbon emissions and deliver economic benefits to UK industry, we need a dedicated Office for Sustainable Aviation Fuels (OSAF) or similar cross-departmental body with appropriate governance structure, membership and resources - would be vital to providing the essential cross-government co-ordination and visible support necessary to progress the development and commercial deployment of SAF. This could be based on the successful Office for Low Emission Vehicles (OLEV) or the public-private partnership success of the Aerospace Technology Institute (ATI). This will provide the essential cross-government co-ordination necessary to progress the development and commercial deployment of sustainable aviation fuels.
- **Investment to deliver a commercial plant** – £500m of matched public/private funding over five years (totaling £1bn) would support flagship first-of-a-kind commercial plant across the UK utilising wastes and residues to manufacture sustainable aviation fuels, as well as a UK centre of excellence for sustainable aviation fuel development. This funding will also support additional fuels development and testing to utilise the UK's considerable fuels testing expertise to expedite the approvals process for new aviation fuel technologies, helping to attract investment and anchor new fuels technology providers in the UK.

  Sustainable aviation fuels fall outside the remit of the Aerospace Growth Partnership (AGP) and ATI, and other dedicated funding streams that exist for electrification and hybrid aircraft. We need UK Government to take a similar strategic approach to sustainable aviation fuel as investor confidence is critical to what remains a nascent industry.
- **Recycled Carbon Fuels incorporated into the RTFO** - Applying the Renewable Transport Fuels Obligation (RTFO) to sustainable, waste-based feedstocks could give a major boost to sustainable aviation fuel development, and recycled carbon fuels should now be included to remove barriers to these ground-breaking technologies. There are a number of areas where the RTFO could be strengthened and provide more certainty for investors – notably regarding revisions to the development fuels sub-target as fuel volumes increase over the coming decade.
- **Applying a multiplier to SAF to encourage production/ investment** – Presently aviation fuels receive the same policy incentives as those provided to road fuels. As road fuels are a lower quality and require slightly less processing to produce, unless aviation fuels are prioritised in policy frameworks, producers are highly likely to continue to focus on road transport. Applying at least a multiplier of 1.2x for developmental sustainable aviation fuels would provide a signal to fuel producers to invest in aviation fuel production instead of using the same feedstock to produce road fuels, which currently provide more return for investors. This is in line with the Renewable Energy Directive II (RED II), which will be supporting fuels providers in the EU, and the UK outside of the EU needs to remain competitive.

We are at a critical juncture. The next decade must be a decade of significant progress if aviation is to be able to play its full part in a net zero future for the UK. Sustainable aviation fuels will need to play a key role in aviation's decarbonisation journey, but today this opportunity is still falling between the cracks: we have excellent research capabilities in UK universities and aerospace, but have limited facilities to test and approve new fuels and a patchwork of support for commercialisation. With Government support, this can change and we can deliver a world-class sustainable aviation fuels industry, from the development of fuels to their commercial use in aircraft.

INTRODUCTION

1.1. Addressing the sustainability challenge in aviation

Aviation plays a vital role in society. Not only does it bring economic benefits - aviation supports trade, investment and employment – it also enables millions of families to holiday each year and others to stay in touch with friends and family around the world. According to IATA, the combined activities of airlines, airports, ground services and aerospace contribute £66bn Gross Value Added (GVA) to the UK while supporting more than a million jobs.[1] Aviation enables other sectors to flourish, by facilitating exports and imports – 40% of UK trade by value is flown – as well as foreign direct investment. A good example is the tourism industry, where a further £26bn GVA and 490,000 jobs are possible thanks to aviation bringing around three-quarters of all visitors to the UK.

Understandably given the benefits aviation brings, demand for connectivity is growing. The Department for Transport forecasts 435m passengers travelling through UK airports by 2050, nearly 50% more than in 2018. The crucial challenge for the UK as a whole and aviation specifically is how we meet that growing demand while reducing emissions as part of the UK's commitment to a net zero economy by 2050.

Founded in 2005, Sustainable Aviation (SA) brings together UK airlines, airports, aerospace manufacturers and air navigation service providers to tackle the challenge of ensuring a sustainable future for our industry. SA is committed to working collaboratively to accelerate the development and commercialisation of advanced sustainable fuels in the UK.

Following the Committee on Climate Change's report on Net Zero, SA has reviewed its CO_2 Road-Map to reflect the latest research on climate change and how aviation can mitigate this. This includes a Net Zero scenario, outlining why SA believes that net zero is within reach for UK aviation while meeting growing demand. To achieve this ambitious aim, the aviation industry and Government need to work closely together to deliver each of the elements simultaneously, from delivering further improvements in engine and airframe design, completing UK airspace modernisation and introducing - at-scale - sustainable aviation fuels.

As aviation is a global industry, the UK needs to continue ts international leadership on climate and aviation to ensure aviation emissions are tackled globally, to avoid the real risk that steps taken in one country or region result in emissions being displaced to other regions or countries, rather than reduced overall.

1.2. The role of sustainable aviation fuels

Sustainable aviation fuels[2] are vital if aviation is going to be able to reach net zero by 2050. Research on new innovative aircraft propulsion systems, such as electric hybrid systems, full electric propulsion systems, hydrogen fuels and the use of solar power, is ongoing. While all these have the potential over the longer term to reduce and possibly eliminate the need for liquid hydrocarbon aviation fuels, these are not likely to reach commercial production within ten to twenty years and then most likely for short-haul and regional travel. On long-haul flights, the timescale to introduce these technologies is likely to be even longer and closer to 2050 as, for example, current battery technology is not advanced enough to power a long-haul aircraft. This means sustainable aviation fuels that replace fossil-based fuels are vital to reducing emissions until the new propulsion systems are ready. This was echoed at the Paris Air Show, where a number of aerospace manufacturers put their support for the development of sustainable aviation fuels as an essential component of the energy transition on record.[3]

1.3. The Sustainable Aviation Fuels Road-Map

This Sustainable Aviation Fuels Road-Map reflects on the pace of technological change since the 2014 edition and sets out how sustainable aviation fuels could contribute to UK aviation realising net zero by 2050 and is published alongside the updated CO_2 Road-Map.

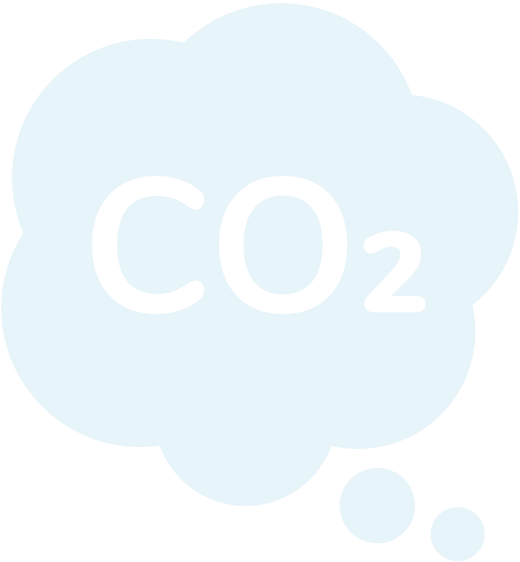
Developing this Road-Map presented a challenge; it is inherently difficult to forecast the size and shape of a new supply market. In the case of sustainable fuels, the industry is very much in its infancy. ICAO has studied a range of scenarios on the global potential of sustainable aviation fuels and this illustrated that take up varies widely based on the level of policy support helping to drive down cost and support new technology pathways.[4]

To provide expert analysis we asked E4tech to build on the analysis they undertook in 2014 and to reassess the potential role of sustainable aviation fuels in decarbonising UK aviation. Inevitably the technical potential for this new industry will be realised only if governments support the development of sustainable fuel supply chains.

That is why this Road-Map offers proposals on the roles that industry and Government can play to realise the opportunity we outline in the report. SA believes that the UK can be a global leader in growing the sustainable aviation fuels market. This arises from our strategic advantages in aerospace, biotechnology, fuels testing and approvals, and refining. The aerospace industry already has experience of successful collaborative initiatives working with government to grow and promote high-value technologies, and we can build something similar in the sustainable aviation fuels market.

The specific objectives of this Road-Map are:

1. To identify and forecast global and UK potential sustainable fuel production volumes out to 2050 and to relate these to the assumptions made in the 2016 SA CO_2 Road-Map;
2. To show the extent that UK aviation alternative fuels can contribute to the decarbonisation of the UK economy and enhance UK fuel security;
3. To demonstrate a viable market potential for advanced sustainable fuels to producers, refiners, investors and other stakeholders;
4. To highlight the potential for this new industry in terms of job creation, growth and improved fuel security in the UK;
5. To outline how industry and government can work together to develop a sustainable fuels industry in the UK for aviation and to help grow the UK's export potential.



SUSTAINABLE AVIATION FUELS

SUSTAINABLE AVIATION FUELS

At a glance

- Sustainable aviation fuels have come a long way since the 2014 Sustainable Fuels Road-Map but the market remains at a nascent stage of development
- To maximise the potential of sustainable aviation fuels, strict sustainability criteria need to be followed
- SA has chosen to focus on those fuels that are produced from wastes and residues, such as household waste or waste gases from industrial processes

2.1. Sustainability of sustainable aviation fuels

Sustainable aviation fuels are produced by taking a feedstock and converting it via industrial processes into a fuel. A range of different potential feedstocks have been identified. Existing limited supplies of SAF are currently processing waste oils, fats and greases and there are other advanced feedstocks such as algae/other non-food feedstock under development. Other projects under development are based on waste sources such as municipal solid waste, used cooking oil and waste industrial gases.

More sophisticated processing technologies necessary for the manufacturing of aviation fuels will widen the number of available feedstock types, and many of these are low-grade, low-value materials. Sustainable Aviation (SA) members are committed to the development of sustainable aviation fuels that offer at least 60% reduced life-cycle greenhouse gas (GHG) emissions over fossil fuels. SA members are actively supportive of the Roundtable on Sustainable Biomaterials (RSB), widely recognised as the most robust global sustainability standard.[5] The RSB is an international, multi-stakeholder standard organisation that has developed a feedstock and technology-neutral global standard for sustainability.[6]

Sustainable fuels:

- Are produced from biomass or recycled carbon;
- Meet stringent sustainability standards with respect to land, water, and energy use;
- Avoid Direct and Indirect Land Use Change (ILUC) impacts, for example tropical deforestation;
- Do not displace or compete with food crops;
- Provide a positive socio-economic impact;
- Exhibit minimal impact on biodiversity and conservation values;
- Have been assessed and certified by an appropriate sustainability standard.

For the purpose of this Road-Map, SA has chosen to focus on those fuels that are produced from wastes and residues, such as household waste or waste gases from industrial processes, in line with the UK's strategic priorities on sustainable fuels. While the ICAO Council has approved the inclusion of a new category of CORSIA-eligible fuels, these Low Carbon Aviation Fuels are fossil fuels that can demonstrate a lifecycle greenhouse gas saving greater than 10% compared to the fossil fuel baseline. SA does not consider these fuels fall under the definition of sustainable fuels described above and this fuel category is not included in this analysis.

Sometimes fuels are referred to in terms of the generation of the technology with which they are associated (1st, 2nd, 3rd, etc.) or 'Advanced' compared to early types of feedstock and processes, as a shorthand way of distinguishing sustainable from non-sustainable fuels. Such classifications can sometimes be overly simplistic and do not provide a consistent indication of sustainability. The aviation industry has been very focused on understanding best practice in this area and SA members believe that a fuel's sustainability should be measured against whether it can meet a robust independent standard which is independently audited.

2.2. Sustainable aviation fuels types

The 2014 Sustainable Fuels Road-Map set out a number of possible fuels based on their feedstock and the technological process used for refining them into sustainable aviation fuels. Much progress has been made on this front, summarised in **Table 1** below, and a number of fuel pathways have emerged as promising candidates for use in aviation.

Of the companies which were active in sustainable aviation fuel in 2014, the majority are still actively involved in the industry and a number of companies have entered the sector, growing the industry overall. (More detail can be found in **Appendix 1, A1.1**).

Table 1: Summary of technology progress since the 2014 roadmap

Production route	Plant in 2014	Plant in 2018
Alcohol-to-Jet	**1.** None	**2.** Several at pilot scale[7] **3.** Ekobenz[8] plant in commissioning (23 kt/year) **4.** Several other companies including Lanzatech and Gevo planning commercial-scale plant[9]
Gasification + FT	**5.** 1 plant operational (TRI plant processing black liquor ~20 kt/year) **6.** 1 plant planned (UPM, since cancelled)	**7.** TRI black liquor gasifier shut down **8.** Fulcrum[10] and Red Rock[11] have plant under construction (combined 75 kt/year capacity)
Pyrolysis	**9.** None focusing on aviation fuels	**10.** Still no pyrolysis plant upgrading to jet **11.** Ensyn/Envergent have ability to produce 'green diesel'[12], but no plant focussing on this **12.** IH^2 pilot plant in India[13]
Sugars to hydrocarbons	**13.** Amyris had operating commercial-scale aerobic fermentation plant (33 kt/year)	**15.** Amyris plant has since been sold to DSM[14]; Construction of two other aerobic fermentation plant is ongoing but these are not focused on aviation fuel.[15]
Oil-based processes	**15.** Many plant globally **16.** 2.5 mt/year of HEFA capacity worldwide, and 1.3 mt more planned	**17.** Over 4.5 mt capacity in dedicated hydro-treating plant **18.** Over 2 mt co-processing at refineries
Power-to-liquids: Fischer-Tropsch	**19.** None	**20.** Sunfire planning a demonstration facility in Norway (8 kt/year)[16]
Other thermochemical routes[17]	**21.** Aqueous phase reforming at pilot scale	**22.** Steeper Energy constructing demonstration HTL facility (1.2 kt/year)[18] **23.** Aqueous phase reforming still at pilot scale

In addition to these processes and fuels, progress has been made in researching further sustainable aviation fuel types and feedstock. For a fuel to be eligible for use in aviation, it has to be approved under the ASTM D1655 jet fuel specification. A number of fuels have either completed this approval process since the 2014 Sustainable Fuels Road Map (**Table 2**) or are currently still going through (**Table 3**). Based on the current status of their application, the fuels listed in **Table 3** are anticipated to achieve approval between 2019 and 2021.

Table 2: Fuels qualified for use in aviation (as of July 2019)

Fuel Name	Date certified	Maximum blend level
Fischer-Tropsch - Synthetic paraffinic kerosene (FT-SPK)	2009	50%
Hydroprocessed Esters & Fatty Acids (HEFA) - Synthetic paraffinic kerosene (SPK)	2011	50%
Synthetic Iso-Paraffinic fuels (SIP)	2014	10%
Fischer-Tropsch - Synthetic paraffinic kerosene with added aromatics (FT-SPK/A)	2015	50%
Alcohol-to-jet	2016 (updated 2018 to include more feedstocks and higher blend %)	50%
Co-processing of up to 5 vol% fats and oils in a refinery to produce kerosene	2018	5% (refinery input)[19]

Table 3: Fuels currently in D4054 qualification process[20]

ASTM Progress	Pathway	Feedstock	Task Force Lead
Phase 2 Testing	Hydro-deoxygenation Synthetic Kerosene (HDO-SK) Catalytic Hydrothermolysis Synthetic Kerosene (CH-SK)	Sugars and cellulosics Renewable fats oils and greases FOG	Virent ARA
Phase 1 OEM Review	High Freeze Point Hydroprocessed Esters and Fatty Acids Synthetic Kerosene (HFP HEFA-SK)	Renewable fats oils and greases	Boeing
Phase 1 Research Report	Hydro-deoxygenation Synthetic Aromatic Kerosene (HDO-SAK)	Sugars and cellulosics	Virent
Phase 1 Testing	Alcohol-to-Jet Synthetic Kerosene with Aromatics (ATJ-SKA) Integrated Hydropyrolysis and Hydroconversion (IH^2) Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)	Sugars and lignocellulosics Multiple Hydrocarbon-rich algae oil	Byogy, Swedish Biofuels Shell IHI

The full approvals process under ASTM D1655 is a lengthy one and it is currently not possible to complete the full approvals journey in the UK. To encourage sustainable aviation fuels innovation, ASTM has recently approved a streamlined, 'fast-track' approval process, which should assist producers in more quickly gaining ASTM qualification for their fuel, although they would be limited in terms of blend percentage. Most of this testing is currently offered in the UK but investment in SAF testing is needed to put the UK on a level footing with the testing facilities in the USA. This investment is not a substantial one and would help to establish the UK's position as a place to develop SAF projects from the lab, through to commercial scale production.

2.3. Production and usage of sustainable aviation fuels to date

In the years following the first Sustainable Fuels Road-Map (2014), significant technical progress has been made towards the commercialisation of sustainable alternatives to fossil fuels. These fuels are often referred to as “drop-in” fuels as they have a similar chemical composition to fossil fuels and can be blended with existing fuels. Internationally, the current limit has been set at a maximum 50% drop-in fuels per litre or gallon of fuel used in an aircraft. At this blending limit, no modifications are needed to existing aircraft and engines or to airport infrastructure.

Case Study: Airbus

With the UK being the centre of excellence for Fuel Systems, the primary focus is certification of new fuels and future fuel opportunities. Collaborations with UK universities ensure the quality and safety of fuels to be used in aircraft are maintained. New fuels projects to investigate materials impact such as Jetscreen and emissions characterisation are managed from the UK. Further collaborations are happening but as yet these are not in the public domain. Airbus has a global strategy for a global solution, which is focused around three central principles:

1. To support certification and qualification of new sustainable fuel pathways, to ensure compatibility with Airbus product policy
2. To support the aviation market as well as innovation and local partnerships all around the world
3. To support policy and standard making bodies, to promote sustainable fuels for aviation and align with Airbus product policy

More than 200,000 regular commercial flights and revenue flights have been undertaken with “drop-in” fuels ffrom an array of different feedstocks, including municipal waste and waste gases from heavy industry, algae, and sustainable crops – those grown on non-agricultural land having no Indirect Land Use Change (ILUC) impacts – and crop residues. Six different fuel production and conversion processes have been developed in parallel and approved by the ASTM International Fuels Standards Committee under its D7566 standard.[21]

The market remains, however, at a nascent stage of development and these fuels are produced in small volumes at relatively high cost and therefore are not yet commercially competitive. The ultimate goal is to develop commercial, sustainable, “drop-in” fuel solutions to form an increasingly significant proportion of the fuel supplied at UK airports.

At the time of the 2014 Sustainable Fuels Road-Map, global sustainable aviation fuel production capacity was dominated by plant using hydrogenated vegetable oil (HVO) as their feedstock, which can produce Hydrogenated Esters and Fatty Acids (HEFA), which can then be refined into aviation fuel. While other technologies are increasing their capacity share (Figure 1), HEFA capacity continues to dominate, with capacity of dedicated hydro-processing and co-processing now over 6,500 kt/year. HEFA capacity is not shown on **Figure 1** as it is an order of magnitude higher than the other technologies.

However, as can be seen from the graph below, whilst capacity has been increasing, actual production of sustainable aviation fuels is still low. Despite the high global hydrotreating capacity, very little of the fuel production from these facilities is destined for the aviation sector. For example, for direct sugars to hydrocarbons (Figure 1) the operational capacity and the majority of the planned capacity is being constructed by Amyris and is not destined for the aviation fuel market.

Plant capacities from current database (WIP) (excl. shut and decommissioned)

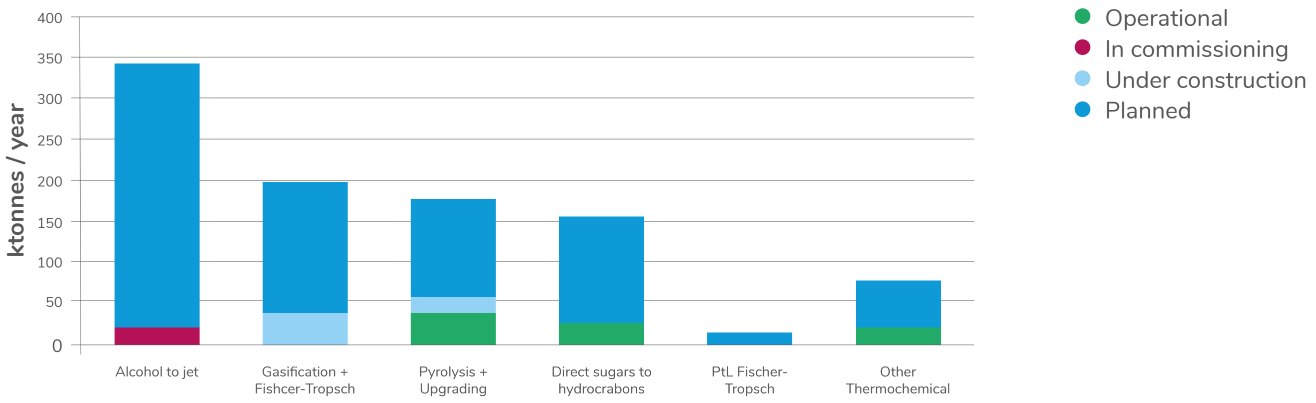


Figure 1 - Sustainable aviation fuel production capacity (excluding oil-based routes) as of Feb 2019[22]

2.3. Production and usage of sustainable aviation fuels to date (continued)

A challenge for the take-up of sustainable aviation fuels production is that many fuel refining plants that produce sustainable aviation fuels can equally produce diesel, and in some cases can switch between the two fuels over a timescale of just days whilst maintaining high yields. This is because there is substantial overlap between the kerosene hydrocarbon fraction, (typically C9 to C15) and the diesel fraction (typically C9 to C23). Given the stricter specification for jet fuel compared to diesel, it is usually more expensive to produce a sustainable aviation fuel. Furthermore, in the majority of countries the infrastructure for transporting and blending biodiesel is more established than for SAF. If sustainable aviation fuel is only incentivised at the same level as sustainable road transport fuels, there is a risk that the majority of the sustainable fuel will continue to go into the road transport sector. To drive greater volumes of fuel into the aviation sector, policies are needed to send a signal to encourage producers to supply SAF rather than diesel for the volumes outlined in this Road-Map to be realised.

The European Union (EU) has attempted to address this challenge of supporting sustainable fuel uptake particularly in the aviation sector through the revised Renewable Energy Directive (RED II). This applies a 1.2 times multiplier to SAF production consumption in the aviation sector compared to fuels destined for the road transport sector. This multiplier is a fundamental step ahead in acknowledging the structural challenge of adopting sustainable fuels in the aviation sector. However, some industry representatives believe that this incentive is not enough to close the gap between sustainable aviation fuel and fossil kerosene prices. We believe that the RTFO should apply a multiplier of at least 1.2x to ensure investment in SAF is prioritised as we must gain experience in the production and use of larger volumes of SAF in the years to come if we are to have effective decarbonisation options for aviation over the longer term.

The lack of production is also related to the currently limited demand for sustainable aviation fuels. Demand is predominantly driven by initiatives from airlines or airports. Known ‘off-take agreements’ or fuel orders between producers and purchasers (Table 4) predict a sustainable aviation fuel demand within the next 3 years of 650 kt/year, less than 0.5% of current global fossil aviation fuel use. If agreements are included where the supply volumes are uncertain, such as that between Fulcrum and United Airlines, the expected demand could reach 1 mt/year. This analysis is based on publicly available data and the actual volume of offtake in place is likely to be much greater than this.

Table 4: Off-take agreements between aviation sustainable fuel producers and suppliers

Producer(s)	Purchaser(s)	Offtake yearly production		Start Year	Length (years)
		Million gallons	Mt		
Air Total	Airbus/China Airlines	5 A350-900 deliveries at 10% blend		2017	-
AltAir	United Airlines	5	0.015	2016	3
	Gulfstream/World Fuel	-	-	-	3
	SkyNRG/KLM	30% blend target		2016	3
AltAir/Neste	KLM/SAS/Lufthansa/AirBP	0.33	0.001	-	3
Amyris/Total	Airbus/Cathay Pacific	48 A350-900 deliveries at 10% blend		2016	-
Fulcrum	Cathay Pacific	35	0.106	-	10
	United Airlines	90-180	0.274-0.547	-	10
	Air BP	50	0.152	-	10
Gevo	Lufthansa	8	0.024	-	5
RedRock	Southwest	3	0.024	-	-
	FedEx	3	0.009	-	7
SG Preston	Jet Blue	10	0.030	2019	10
	Qantas	8	0.024	2020	10
Total		**212 to 302**	**0.645 to 0.918**		

Source: ICAO, 2018, Sustainable Aviation Fuels Guide (“-“ means: no data available)

2.3. Production and usage of sustainable aviation fuels to date (continued)

Due to the requirements for refuelling infrastructure and fuel transport, such industry agreements are often supported by airports. A wide range of airports have supplied aircraft with alternative aviation fuels, including as far afield as Dehradun in India and Shanghai and Beijing in China. Since 2014, over 13 airports worldwide have integrated supply of sustainable aviation fuels into their regular operations (**Table 5**).

A growing number of other airports, e.g. San Francisco, have plans to integrate sustainable aviation fuel into their regular fuel supply. This represents a substantial development in sustainable aviation fuel logistics. Norway has gone the furthest and was the first country to start a regular supply of biofuel from Oslo airport in 2015. This developed through a long-term research plan involving multiple stakeholders from industry and academia. It now distributes sustainable aviation fuel to all airlines with flights departing from Oslo.[23]

Table 5: Airports refuelling regular flights with sustainable aviation fuel

Airport	Country	Refuelling with sustainable aviation fuel since
Karlstad	Sweden	2015
Oslo	Norway	2015
Los Angeles International	USA	2016
Stockholm Arlanda	Sweden	2017
Bergen	Norway	2017
Stockholm Bromma	Sweden	2017
Are Ostersund	Sweden	2017
Goteborg Landvetter	Sweden	2017
Halmstad	Sweden	2017
Chicago O'Hare International	USA	2017
Brisbane	Australia	2018
Visby	Sweden	2018
San Francisco	USA	2018
Luleå	Sweden	2019

In the absence of an obligation, take up of sustainable aviation fuel must still be driven by the aviation industry itself. In the UK there are several strong partnerships between the aviation industry and sustainable aviation fuel producers: Air BP have a strategic partnership with Fulcrum,[24] Shell and British Airways have a partnership with Velocys, and Virgin Atlantic have a partnership with Lanzatech. Both Velocys and Lanzatech are planning to build the first commercial sustainable aviation fuel plant in the UK with the support of the Department for Transport's Future Fuels for Flight and Freight competition, demonstrating the importance of strong government support in the UK via the RTFO and industry partnerships.

Case Study: British Airways and International Airlines Group

In 2019, International Airlines Group (IAG) committed to achieving net zero emissions by 2050 with Flightpath Net Zero.

IAG has committed $400m to the development of new sustainable fuel supply chains. British Airways' (BA) flagship project as part of this is to construct an advanced fuels facility that will annually convert around 500,000 tonnes of household and office waste left over after recycling into a number of sustainable low-carbon fuels – including aviation fuel. The project, Altalto, is a collaborative project between BA, Velocys and Shell. The new plant will be sited at Immingham in north-east Lincolnshire on what is currently vacant land surrounded by existing industrial buildings.

This fuel produced will deliver to a 70% greenhouse gas reduction for each tonne of fossil jet fuel that it displaces, 90% reduction in particulate matter, and 100% reduction in sulphur dioxide. The development will also help establish North East Lincolnshire as an international hub in what is expected to be a global market for sustainable aviation fuels.

At present, the aviation sector is eligible to participate in these mechanisms but unlike the roads sector is not obliged to, e.g. through a blending mandate or obligation to make certain GHG reductions. This is due to the global nature of the aviation sector, where action at ICAO level has been preferred. The introduction of national or regional blending mandates may lead to increasing fuel burn if they are not designed carefully to avoid unintended consequences. This is due to the highly competitive nature of the airline industry and the high cost of fuel for airlines. The result is airlines will strive to avoid the higher fuel costs imposed by carrying extra fuel from outside a particular country or region before flying to it. This also risks increasing emissions from the aircraft due to the extra fuel adding to the weight of the aircraft. The only two countries that have implemented blend mandates are Indonesia and Norway[25], although it is believed that Indonesia's targets, which originally mandated a 2% biofuel blend in 2016, 3% blend in 2020 and 5% blend in 2025, are postponed.

2.3. Production and usage of sustainable aviation fuels to date (continued)

There are, however, an increasing number of national frameworks and initiatives set up to support the deployment of sustainable aviation fuel that stop short of imposing an obligation, such as those illustrated in Table 6. For instance, in 2012, Australia set up a coalition of aviation industry stakeholders to develop a national sustainable aviation fuel supply chain. Today, the Australian Initiative for Sustainable Aviation Fuels aims to reach 50% of aviation fuel consumption supplied by biofuels by 2050. Sweden has even stronger commitment. The roadmap “Fossil Free Sweden” aims to achieve fossil-free domestic aviation by 2030 and entirely decarbonising all outbound flights by 2045. However, most of the targets laid out in these initiatives are aspirational and are not backed up by strong policy mechanisms such as strong support schemes.

Table 6: National and regional initiatives support sustainable aviation fuel uptake

State/Region	Organisation/Initiative	Target	Target Type	Target Year
Indonesia	Indonesian Government	2% blend	Mandate	2018
USA	US Federal Aviation Administration	1 bn US gal (5% demand)	Government target	2018
Norway	Norwegian Government	0.5% blend	Mandate	2020
Europe	European Commission (Biofuels Flightpath)	2 Mt (3-4% demand)	Aspirational	2020
Scandinavia	Nordic Initiative for Sustainable Aviation (following EU)	3-4% blend	Aspirational	2020
Spain	Government initiative	2% blend	Mandate (not yet agreed)	2025
Germany	Aviation Initiative for Renewable Energy in Germany	10% blend	Aspirational	2025
Israel	Fuel Choice Initiative (Programme of the Government of Israel)	20% blend	Aspirational	2025

In the short-term, demand will therefore likely continue to be driven by industry initiatives, augmented increasingly by national-level support schemes, and motivated by the long-term requirements for CORSIA compliance from 2021.

Case Study: CORSIA

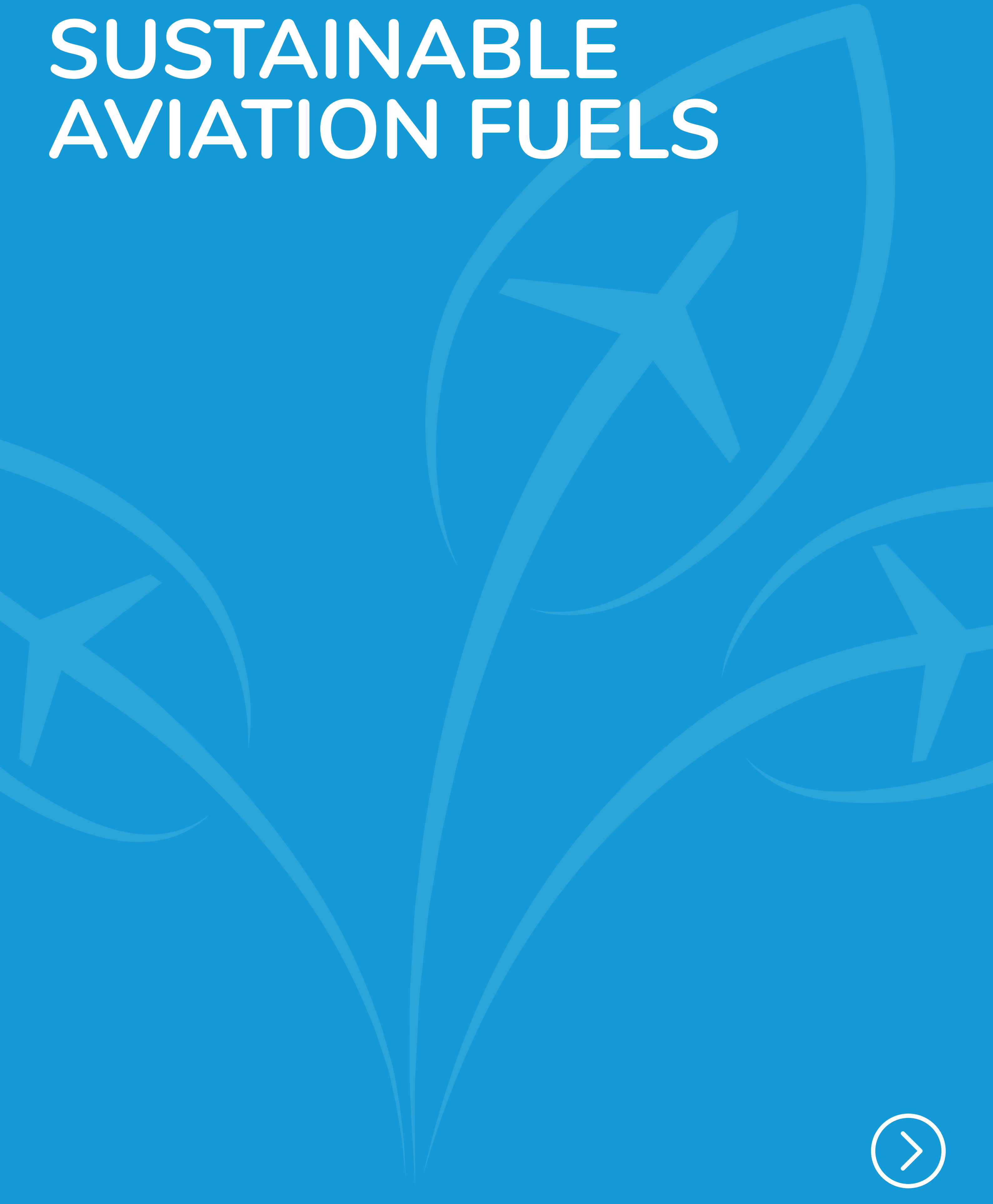
The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) was adopted in 2016 by ICAO and aims to stabilise net CO_2 emissions from international civil aviation at 2020 levels. Given that ICAO, and by extension CORSIA, covers the majority of international air traffic in the world, this is a key long-term driver for SAF demand in international aviation (domestic aviation is not included in CORSIA).

Participation in CORSIA will begin through a pilot phase (2021 – 2023) and first phase (2024 to 2026) on a voluntary basis. The second phase (2027-2035) will apply to all states that have an individual share of international aviation activities above 0.5%.

Airlines can comply with CORSIA through a number of measures: reducing fuel burn, e.g. through more efficient aircraft and operations; ensuring that the fuel they do burn has lower CO_2 emissions, e.g. through supplying sustainable aviation fuel; and through a market-based offsetting mechanism.

Supply of sustainable aviation fuels is therefore a key part of how airlines could meet their obligations under the CORSIA agreement. As the aviation sector is anticipated to grow at a rate of 3.5% per year, the requirement for carbon neutral growth from 2020 onwards will becoming increasingly challenging, and could lead to the demand for increasing volumes of sustainable aviation fuel to complement other emissions reduction measures.

THE FUTURE FOR SUSTAINABLE AVIATION FUELS



THE FUTURE FOR SUSTAINABLE AVIATION FUELS

At a glance

- Demand for sustainable aviation is expected to grow, but production needs to ramp up to meet this demand
- E4tech analysis for Sustainable Aviation shows that there is significant potential for sustainable aviation fuels production in the UK
- Policy signals are needed to ensure more fuel is prioritised for aviation if we are to scale up production and gain experience of flying using SAF over the coming decades
- If realised, this production will not only support jobs and economic growth in the UK but also provide an opportunity for exporting UK skills, IP and expertise

3.1. Future demand for sustainable aviation fuels

Currently, there are different views on the potential for sustainable aviation fuels globally. In the International Energy Agency's (IEA) Beyond 2°C Scenario (B2DS)[26], which aims to achieve net-zero emissions by 2060 and to stay at net zero or below thereafter, global sustainable aviation fuels demand in 2060 reaches 150 Mt/y (**Figure 2**). This corresponds to 70% of the total aviation fuel demand. Interestingly, the projected volume of fuel in the IEA scenario is lower than that targeted by ICAO, but the share of sustainable aviation fuels of the total global aviation fuel burn is higher. This is because the IEA B2DS scenario foresees a dramatic reduction of overall energy consumption in the aviation sector through the substantial reduction of aircraft fuel consumption and the decrease of aviation activity through modal shift in favour of high-speed rail.

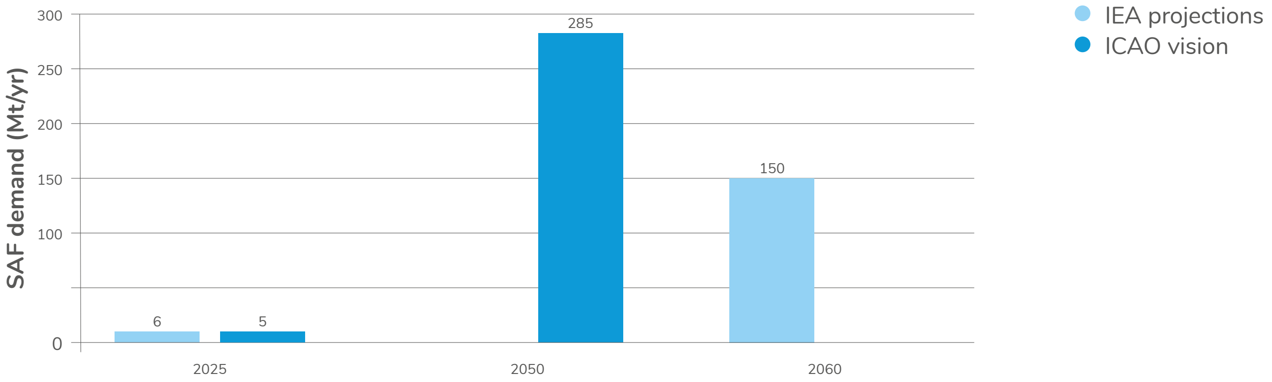


Figure 2 - Global sustainable aviation fuel demand projections for 2025, 2050 and 2060 (B2DS)[27,28,29]

3.2. Future supply of sustainable aviation fuels

Whilst the broad demand-based scenarios by ICAO and IEA are helpful, the Sustainable Aviation Fuels Road-Map considers a number of factors driving investment and estimates potential production based on technology improvement progress and existing planned investment. The analysis conducted by E4tech for Sustainable Aviation estimated the technical ability of the industry to scale-up, based on the current number of technology developers, scale of existing and planned plant, and plausible build-rates in the sustainable aviation fuels industry.

In creating this projection, E4tech made a number of assumptions. For example, a number of activities in the UK may influence future policy around sustainable fuels in aviation, namely the Committee on Climate Change's bioenergy review and the Department for Transport's consultation on Aviation Strategy. This Road-Map modelled the impact of:

- a supportive policy environment;
- success rates of ongoing technological innovation;
- the likelihood that companies currently working on sustainable aviation fuel production will continue to do so; and
- technology providers license the technology once they get to maturity

3.2. Future supply of sustainable aviation fuels (continued)

For the purposes of this assessment, which reflects the **potential production** of sustainable aviation fuel, all fuel types outlined in **Tables 2** and **3** are included, regardless of whether they are currently certified or are in the certification process.

The methodology adopted for this study is a ‘bottom-up’ methodology. In order to estimate the future potential deployment of sustainable aviation fuel production the current deployment of sustainable aviation fuel technologies is assessed, and how that could plausibly develop under a number of scenarios. Annex 1 outlines this in further detail. Given the large degree of uncertainty, two scenarios reflecting slow and fast growth of the industry have been developed to project the potential production volume. The slow and fast growth scenarios differ in terms of the initiation rate, the launch-point and the success rate.

As described above, there is a large overlap between the diesel and kerosene fuel specification. In most cases, commercial factors would influence the choice for fuel producers as to whether to produce diesel or kerosene. This has therefore been reflected in an ‘aviation-optimised’ scenario, which maximises the production of the kerosene fraction, and a ‘road-optimised’ scenario, which maximises the production of diesel. These scenarios reflect economic limitations on fuel-refining plant operation, rather than the absolute highest or lowest kerosene production. These two factors combine to give four scenarios (**Table 7**).

Table 7: Summary of scenarios considered

		Product State	
		Road Optmized	Aviation Optmized
Supply Scale-up	Low	Slow Growth (Road-optimized)	Slow Growth (Aviation-optimized)
	High	Fast Growth (Road-optimized)	Fast Growth (Aviation-optimized)

3.3. Global and UK sustainable aviation fuel supply modelled to 2035

E4tech estimated that the global sustainable jet fuel supply potential to 2035 in an optimised scenario could reach between 14.5 and 30.9 million tonnes per year, corresponding to between 4% and 8% of global kerosene use in 2035.[30] This would represent an increase of between 12% and 25% compared to 2017 global biofuel production.[31]

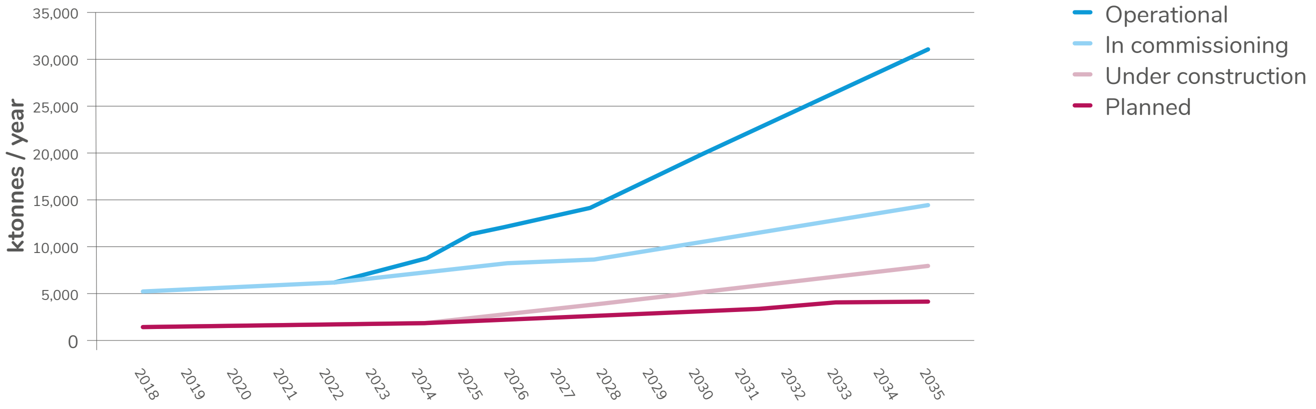


Figure 3 - Global sustainable jet fuel supply potential

As this deployment builds from the current known fuel-refining plants and producers in each technology, the majority of the capacity in 2035 is still assumed to be hydro-treatment capacity for HEFA production. The second largest production method is alcohol-to-jet, with roughly 20% of the total sustainable aviation fuel production capacity. Gasification + Fischer-Tropsch (FT) and pyrolysis routes could also have a meaningful contribution to total sustainable aviation fuel volumes. However, direct sugars to hydrocarbons, power-to-liquids and other thermochemical production methods are predicted to remain fairly small. The breakdown of these global production volumes by the different sustainable aviation fuel production technologies is illustrated in **Table 8**, and the development over time is provided in **Figure 2**.

3.3. Global and UK sustainable aviation fuel supply modelled to 2035 (continued)

Table 8: Sustainable aviation fuel production technologies

	2035 global sustainable aviation fuel production capacity (kt/y)	
Route	**Slow Growth, Aviation Optimised**	**Fast Growth, Aviation Optimised**
Hydrotreated oils/fats	9,577	17,642
Alcohol to jet	2,443	6,884
Gasification + FT	727	1,839
Pyrolysis	728	1,765
Other thermochemical	371	950
Sugars to hydrocarbons	268	815
PtL: FT	255	875

Case Study: Virgin Atlantic

In 2008, Virgin Atlantic was the first airline to conduct a ‘biofuel’ test flight on a commercial aircraft. Then, in October 2011, following a detailed market review, Virgin announced their partnership with LanzaTech – with the aim of securing advanced, waste-based affordable jet fuels with the highest possible sustainability standards.

LanzaTech’s approach recycles waste carbon-rich gases to produce ethanol, from which jet fuel can be made. Their technology captures waste CO gases from heavy industrial facilities (like steel mills and refineries) before it is flared into the atmosphere as greenhouse gas CO_2. LanzaTech’s jet fuel has no land, food or water competition issues and at least 70% reduction in Life Cycle Analysis (LCA) carbon emissions compared with fossil jet fuel.

In October 2018, Virgin Atlantic flew the world’s first flight from Orlando to London Gatwick , using fuel made from this ground-breaking approach. However, in the UK, this technology is locked out of the Renewable Transport Fuels Obligation (RTFO). Should this technology be included in the RTFO, Virgin believes that the world’s first full-scale plant of this type could be running as soon as the early 2020s.

E4Tech’s analysis highlighted that access to feedstock is not a major constraint in the period to 2035. The exception to this is waste fats, oils and greases as illustrated below in **Figure 4**. Further detail on this analysis can be found in **Appendix 1**, section **A1.3.3**.

While there is currently no sustainable aviation fuel produced in the UK, and the first production is assumed to begin in the early 2020s when fuel-refining plants currently being planned by Lanzatech and Velocys come online. From there onwards, if UK production were to grow in line with global production, UK-produced sustainable aviation fuel produced could provide between 3.3% and 7.8% of the UK’s 2035 kerosene demand in the aviation optimised scenario.[32] It would also be possible for the UK to access higher levels of sustainable aviation fuel by importing from other regions.

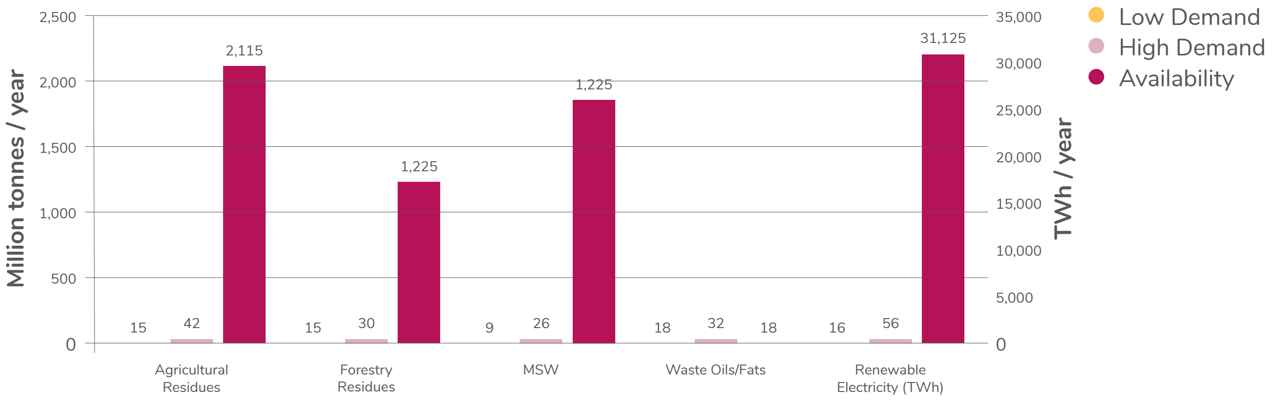


Figure 4 - Global 2035 feedstock demand compared to availability of sustainable feedstock

3.3. Global and UK sustainable aviation fuel supply modelled to 2035 (continued)

A comparison is made in **Figure 5** with the fuel volume that is required by the DfT Development Fuel target. This target includes both aviation and road transport fuel and does not require fuel to be actually produced in the UK. This analysis illustrates that at the start of this period the development fuel target is relatively ambitious compared to the level of sustainable aviation fuel which could be produced in the UK. However, beyond 2032 there is scope to increase the development fuels target, particularly given that development fuels in the road transport sector will also be contributing to this target.

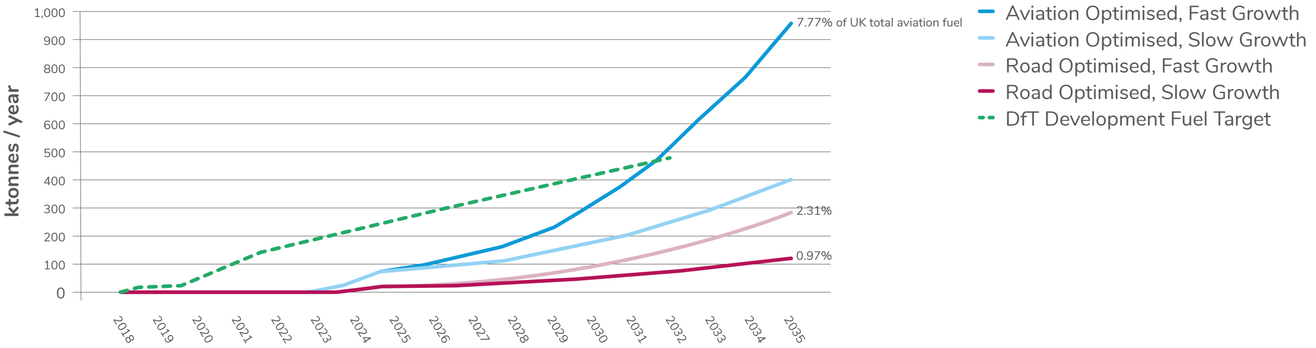


Figure 5 - UK sustainable jet fuel supply potential (excluding HEFA), and comparison with DfT development fuels target

This ramp-up in UK sustainable aviation fuel production assumes that the two planned sustainable aviation fuel refining plants in the UK successfully come online in the early 2020s, and that additional UK plants are planned to come online soon after those. The typical size of a commercial-scale sustainable aviation fuel refining plant is variable depending on the technology. Considering the nameplate capacities adopted in this study, the deployment illustrated above would correspond to between 5 and 14 plants in 2035 in the slow and fast scenarios respectively[33]. In the fast scenario, this corresponds to a new plant every 1.3 years and around £4bn of total investment.[34]

The previous fuels roadmap published by SA UK in 2014[35] suggested that in a high scenario the UK could produce around 600 kt/year of sustainable aviation fuel in 2030, if deployment began immediately. As there is still currently no production of sustainable aviation fuels in the UK, it is now unlikely that 600 kt/year of sustainable aviation fuels can be produced in the UK until around 2033 (**Figure 5**), and further delays to the fuel-refining plant deployment timelines which underpin this study would limit the sustainable aviation fuel production capacity which can be achieved by 2035.

However, it is possible that there could be synergies for alcohol-to-jet plant with existing UK ethanol production, of which there is currently capacity for 700 kt/year.

No HEFA plant are assumed in the UK (**see Appendix 1**), however import of feedstock or diversion of waste fats and oils from some of the UK's existing 580 kt/year of fatty acid methyl esters (FAME) production capacity could facilitate HEFA production in the UK. Development of novel oil crops could also support the business case for HEFA production in the UK.

3.4. Impact on UK greenhouse gas emissions of sustainable fuel production to 2035

The modelled ramp-up of sustainable aviation fuel production in the UK could give greenhouse gas (GHG) emissions savings of **1.2 million tonnes CO_2eq**. (aviation-optimised, slow-growth scenario) to **2.8 million tonnes CO_2eq**. (aviation-optimised, fast-growth scenario) in 2035 compared to a business-as-usual scenario where no sustainable aviation fuel is produced.

To estimate this, it is important to bear in mind that the GHG emissions of each sustainable aviation fuel production pathway can vary substantially, depending for example on the type of feedstock used, how that feedstock is collected or cultivated, and how much optimisation of the process has taken place. For the purposes of this study, published GHG emissions were used, based on a review of IRENA (2016)[36], de Jong (2017)[37] and the European Commission's 2018 REDII[38].

3.4. Impact on UK greenhouse gas emissions of sustainable fuel production to 2035 (continued)

The values used for this analysis, and key assumptions, are summarised in Appendix 1. For the purposes of this study none of the routes are assumed to capture the carbon released in fuel production, but integration of carbon-capture & storage into the sustainable aviation fuel production process could enable even greater GHG savings to be made.[39] The GHG emissions for sustainable aviation fuels have been compared to the fossil fuel comparator 94 gCO_2eq/MJ as set out in the RED II.[40]

3.5. UK supply of sustainable aviation fuels to 2050

The ramp-up of sustainable aviation fuels will not stop in 2035. Modelling exact impacts beyond 2035 is challenging, as the uncertainties become more significant. However, using the E4tech model, under the aviation-optimised scenarios, UK sustainable aviation fuel production is assumed to rise by on average 34% per year under the low scenario and 44% per year under the high scenario from 2025 to 2035. These growth rates are high, although annual capacity additions are moderate, reflecting that this builds from a situation where no sustainable aviation fuel is produced in the UK currently.

In 2050, if 30% of the UK demand for kerosene is to be met by domestically produced sustainable aviation fuel, c. 4.5mt/year of sustainable aviation fuel production would be required.[41] This corresponds to an annual growth rate from 2035 of 11% (under the high sustainable aviation fuel production scenario) to 18% (under the low sustainable aviation fuel production scenario). These annual growth rates are not dissimilar to historic growth rates in global biofuels production. For example, between 2001 and 2011 biofuel production grew from 16 billion litres to 100 billion litres, corresponding to an average annual growth rate of 20%.[42] Beyond 2035, Sustainable Aviation has taken the view that the present net zero policy position of the UK government will increase the likelihood that CCS technology will be integrated with fuel production. This means that the average greenhouse gas reductions realised by emerging fuels pathways will increase and we envisage that by 2050, the average greenhouse gas saving of SAF versus fossil fuel will equal 100%. Velocys has already announced an integrated CCS agreement is in place for their project in Mississippi.[43]

We predict a range of technologies will be deployed globally but with respect to the UK we see waste derived fuels as the primary opportunity in the short-medium term. In the medium term, we expect co-processing of suitable sustainable biocrudes will increase the volumes of SAF entering supply chains, e.g. through the introduction of co-processed pyrolysis oils or sustainably produced low ILUC crops. In the longer term as more novel feedstock (such as power to liquids using waste CO_2 or direct air capture and algae) are developed and move to larger scale production, we expect this opportunity to expand - see Table 9 below.. Sustainable Aviation plans to update this Road-Map on a regular basis to account for the new sustainable fuels pathways that are constantly evolving.

Table 9: Potential fuel supply pathways for production from 2020-2050

Timeframe	Technology pathway	Feedstock	UK production potential
To 2020	Biomass to liquid	Mixed MSW	High
To 2020	HEFA	Waste oils*	Low
To 2020	Alcohol To Jet	Waste gases	High
To 2020	Green diesel	Waste oils*	Low
2020 - 2030	Alcohol To Jet	Lignocellulosic	Med
2020 - 2030	Pyrolysis oils	Mixed MSW	High
2020 - 2030	Farnesene	Sugar cane/LC residue	Low
2020 - 2030	Co-processing	Wastes oils*/ pyrolysis	Med
2020 - 2030	SIP	Sugars/LC materials	Med
2030 - 2040	Novel Hydro routes	Waste oils*	Low/Med
2030 - 2050	HEFA	Algae	Unknown
2030 - 2050	Biotech conversion	Waste gases	Unknown

3.6. Limiting factors on reaching production potential

In the modelling assumptions, it is the potential production of sustainable aviation fuels technology deployment, rather than the availability of feedstock, that is considered to be the limiting factor. Nevertheless, the availability of sufficient quantities of sustainably produced or collected feedstock is crucial to the scale-up of the industry. The full analysis of availability can be found in **Appendix 1**, but a summary of the main findings is below.

For routes using ligno-cellulosic feedstocks, the global sustainable fuels production in 2035 under the high scenario would require less than 2% of the global supply of agricultural residues, forestry residues and MSW.[44] Whilst it is widely acknowledged that there remain challenges in mobilising feedstocks even if they are available, this suggests that for ligno-cellulosic feedstocks, access to sustainable wastes and residues will not be a limiting factor to 2035.

To produce the 2035 volume of power-to-liquids (PtL) fuels would require substantial amounts of renewable electricity, which is also likely to be in demand from other sectors. If new PtL facilities are combined with new renewable electricity generation facilities, then the supply of renewable electricity could keep pace with this additional demand from the aviation sector. The key challenge in terms of feedstock availability is access to sustainable fats and oils. The global deployment of HEFA modelled in this work would exceed globally available waste oils and fats even in the low scenario. Achieving levels of production required would require substantial new volumes of oil crops or novel oil crops.

In the UK, the high and low scenarios modelled require between 7% and 16% of total sustainably available agricultural residues, forestry residues and MSW.[45] This is a higher proportion of available feedstock than the global deployment requires but is still within what could be accessible in the UK. The use of waste fossil feedstocks such as industrial gases from steel mills or refineries could further increase the total available feedstock in the UK.

3.7. The value of sustainable aviation fuels production to the UK

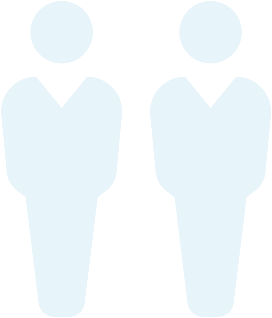
Historically the UK has had strengths in key industries essential to the success of a new sustainable aviation fuels sector. When this is coupled with the UK's ownership of the global jet fuel standard 91-091 (through the Ministry of Defence), there is a particularly unique concentration of fuels expertise in the UK. This was highlighted through the success of the Special Interest Group hosted by the Knowledge Transfer Network, which attracted many members and was able to build some useful coalitions in a very short time period.

The Sustainable Aviation Fuel Special Interest Group (SAF SIG)

This two-year programme (2017-2019) was sponsored by Innovate UK, Sustainable Aviation and Department for Transport. The SAF SIG team published a series of resources: a landscape map; Cleared for offtake – a guide for producers on what airlines are looking for in a sustainable fuel; ASTM D4054 step-by-step guide to jet fuel approval, and; Research and Development priorities to support a UK sustainable aviation fuel industry. The SIG delivered a networking event attended by 130 delegates, 10 webinars, a mission to USA plus a competition to give away an auxiliary power unit and provide two SMEs with fuel testing support. Across the whole supply chain, the SAF SIG team supported 107 companies, built a SAF network of 406 individuals, made 82 introductions, brokered 9 collaborations and enabled four NDAs to be signed with a UK airline.

https://ktn-uk.co.uk/interests/sustainable-aviation-fuel

This collective expertise also means the UK has the building blocks in place to gain substantial value from the domestic production of sustainable aviation fuels and could also capture a percentage of the market for sustainable aviation fuel produced outside the UK. As part of its modelling of the potential for sustainable fuels production in the UK, E4tech also modelled the potential economic opportunity this would bring to the UK. Development of a domestic industry for the production of sustainable fuels could generate a **Gross Value Added (GVA) to the UK of between £310m-£742m in 2035**.



Such a UK industry could support between 2,200 and 5,200 UK jobs.

Additionally, if domestically produced sustainable aviation fuel were to replace imported kerosene (the UK currently imports more than 70% of its aviation fuel), this could also have a positive impact on the UK's balance of payments and security of supply. If 950 kt/year of kerosene, equivalent to the high sustainable aviation fuel production scenario, is produced domestically instead of being imported to the UK, this represents a **positive impact of £550m on the UK balance of payments**.

3.7. The value of sustainable aviation fuels production to the UK (continued)

It is also likely that the UK could capture value from the production of sustainable aviation fuel elsewhere in the world, for example through the supply of technology components and engineering services related to the design and development of conversion technology components and plant.

These opportunities are exportable, protectable through intellectual property (IP) rights and well-aligned with the UK's commercial strengths. Moreover, early movement in this field is likely to support the development of IP from which value can arise in the future. With Velocys and Lanzatech both planning their first commercial sustainable aviation fuel production plant in the UK, this opportunity is clear. **The value to the UK from global sustainable fuel production could be £915m-£1,952m/year in 2035, supporting between 6,400 and 13,600 jobs.**

The potential value of a UK sustainable fuels industry is based on a methodology developed in the context of the UK Department of Energy and Climate Change's (since merged into the Department of Business, Energy & Industrial Strategy) Technology Innovation Needs Assessment. This calculates the fuel revenue equal to the value of fossil kerosene plus the buy-out price (i.e. upper limit) of two development Renewable Transport Fuel Certificates (RTFCs)[46] and an average gross value added (GVA) per worker in the non-manufacturing production sector of £144,000.[47]

Table 10: Estimated GVA from sustainable aviation fuel production in 2035, in the aviation optimised scenario (2018 pounds)[48]

	Slow Growth	High Growth
UK GVA from UK fuel production (£/year)	310m	742m
UK GVA from non-UK fuel production (£/year)	915m	1,952m
Total UK GVA (£/year)	1,225m	2,695m

3.8. A vision for a UK sustainable aviation fuels industry

Bringing all of the above together, Sustainable Aviation has set out a vision for UK sustainable aviation production in the UK. The updated Road-Map reflects a greater level of global sustainable aviation fuel activity since the previous analysis and the greater support for sustainable aviation fuels in the UK fuels policy to 2032. With the application of enhanced policy support and some financing support for initial commercial plants, Sustainable Aviation believes that the UK would be able to realise the high trajectory outlined in **Figure 6**.

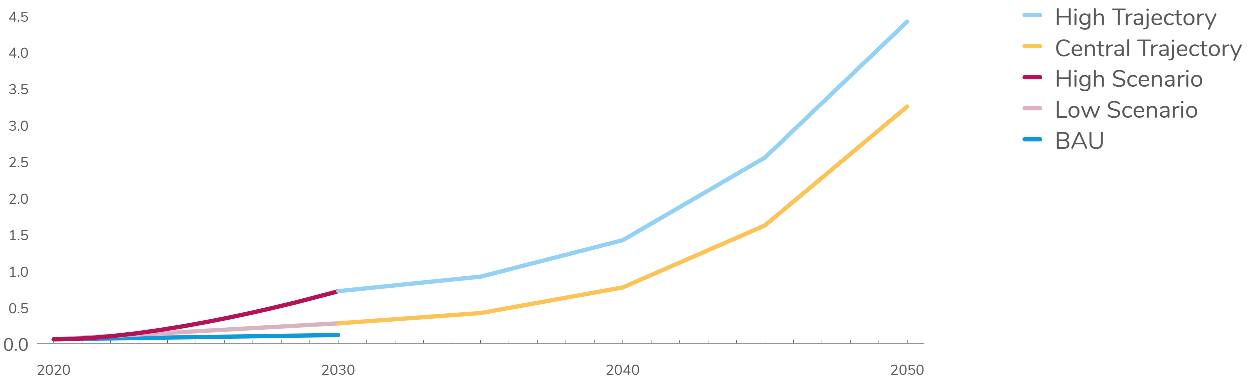


Figure 6 - UK Sustainable Aviation fuels - projected volumes to 2050

Sustainable Aviation's early estimates assumed a very gradual steady increase in the use of sustainable fuels to 2050. However, the outcome of this study illustrates that early volumes will be fairly modest to 2030 with a more rapid ramp up of production beyond this date, which will be taken into account in the update to Sustainable Aviation's CO_2 Road-Map in 2020.

TURNING POTENTIAL INTO REALITY

TURNING POTENTIAL INTO REALITY

At a glance

- Sustainable Aviation Fuels production in the UK needs policy support, investment and partnership between Government and industry to capitalise on the opportunities ahead

4.1. Delivering on the Road-Map

With the need to rapidly decarbonise over the period to 2050, it is essential to ensure the initial commercial sustainable aviation fuel plants come on-line in the next few years, if there is any chance of scaling up this technology in the decades to come. Much depends on how emerging technology deployment is supported.

However, barriers to investment and commercialisation still exist. There is a substantial gap between the cost of fossil fuel kerosene and sustainable aviation fuel, which the Renewable Transport Fuel Obligation has started to help bridge. ICAO's Committee on Aviation Environmental Protection has signalled the need for large capital investments in sustainable aviation fuel production infrastructure, and substantial policy support.

For example, today sustainable aviation fuel falls outside the remit of the Aerospace Growth Partnership (AGP) and ATI, and other dedicated funding that exists for electrification and hybrid aircraft. We need UK Government to take a similar strategic approach for sustainable aviation fuels as investor confidence is critical to what remains a nascent industry.

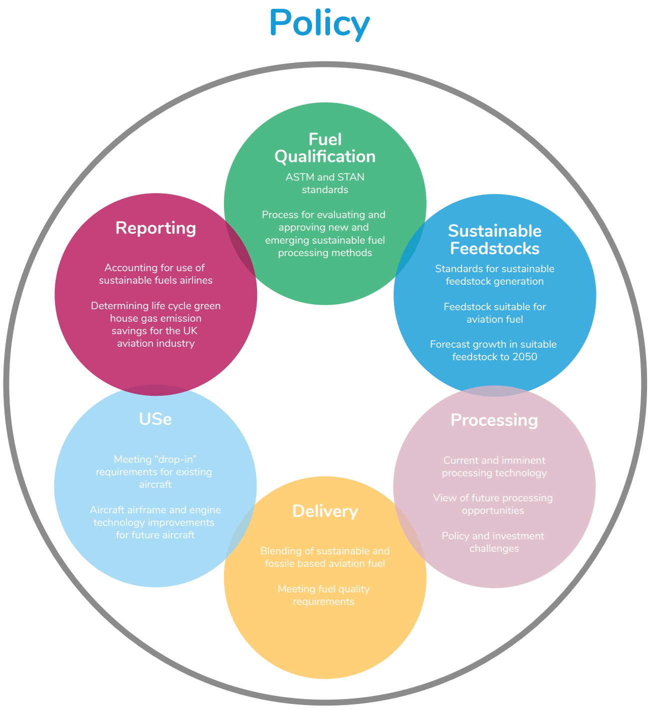


Figure 7 - Elements required to deliver sustainable fuels

As **Figure 7** below shows, developing sustainable aviation fuels is a long journey that involves a number of processes, companies and organisations to come together. Given this, the Department for Transport (DfT) and the Knowledge Transfer Network (KTN) sponsored a two-year Special Interest Group (SIG). This work helped to convene a broad set of stakeholders including SMEs, academia, oil companies, technology providers, government, aerospace and aviation stakeholders. There are now over 400 individual members in the group with a number of the connections made during the SIG continuing to evolve.

4.2. What do we want and why is more support needed?

To ensure UK opportunities are fully realised the sector has four core asks of Government:

- **OSAF** - Given the significant near-term opportunities offered by sustainable aviation fuels (SAF) as both a measure to cut aviation carbon emissions and deliver economic benefits to UK industry, we need a dedicated Office for Sustainable Aviation Fuels (OSAF) (OSAF) or similar cross-departmental body with appropriate governance structure, membership and resources - would be vital to providing the essential cross-government co-ordination and visible support necessary to progress the development and commercial deployment of SAF. This could be based on the successful Office for Low Emission Vehicles (OLEV) or the public-private partnership success of the Aerospace Technology Institute (ATI) – to provide the essential cross-government co-ordination necessary to progress the development and commercial deployment of SAF. If a dedicated "Office" is not possible, a similar cross-departmental body with appropriate governance structure, membership and resources should be established.

  This would build on the opportunities outlined in this report and the work of the KTN's Sustainable Aviation Fuels SIG. This Office would deliver a UK strategy to turn the potential of sustainable aviation fuels into a reality in the UK.

- **Investment to deliver plant** – Matched public/private funding of £500m over 5 years (totaling £1bn) would support flagship first-of-a-kind commercial plants across the UK utilising wastes and residues to manufacture SAF, as well as a UK centre of excellence for SAF development. This funding should also support additional fuels development and testing to utilise the UK's considerable fuels testing expertise to expedite the approvals process for new aviation fuel technologies, helping to attract investment and anchor new fuels technology providers in the UK.

4.2. What do we want and why is more support needed? (continued)

- **Investment to deliver plant (continued)** – This funding would help unlock the aforementioned economic potential of SAF to the UK, including a Gross Added Value to the UK economy of £742 million by 2035, 5,200 UK jobs, £1,952 million export value (over 8 times the 2014 prediction) and a £550m value to the UK's balance of payments from indigenous UK production.

- Government support would help to 'de-risk' public and private investments in SAF and help the sector in the UK to reach a critical mass. Support is further needed to help move some of these technologies from R&D and fuels testing, through development to full commercial-scale plants (of which none presently exist in the UK).

  Additional funding would allow the UK to create a comprehensive aviation fuels strategy, allowing the UK to capitalise on its leadership in global aerospace and aviation and seize the opportunities presented by the emerging sustainable fuel market to reduce emissions, create jobs and bolster investments in science and technology.

  Presently the UK imports over 70% of its jet fuel and this volume continues to increase annually. New sustainable fuel production would also increase the UK's fuel supply chain resilience and open up a whole new market for UK companies.

- **Recycled Carbon Fuels incorporated into the RTFO** - Applying the Renewable Transport Fuels Obligation (RTFO) to sustainable, waste-based feedstocks gave a major boost to SAF development, and recycled carbon fuels should now be included to remove barriers to these ground-breaking technologies.

- **Apply a multiplier** for SAF developmental fuels to provide a signal to fuel producers to invest in aviation fuel production instead of using the same feedstock to produce road fuels, which currently provide more return for investors. This is in line with the Renewable Energy Directive II, which will be supporting fuels-providers in the EU and the UK needs to remain competitive post-Brexit on SAF. However we believe that the UK should consider applying a higher value than the 1.2 currently indicated in the RED II, as a 20% margin is unlikely to drive material investment in SAF production.

4.3. Why an office for sustainable aviation fuels?

We believe that the creation of an Office for Sustainable Aviation Fuels (OSAF) – or similar cross-departmental body with appropriate governance structure, membership and resources - would be vital to providing the essential cross-government co-ordination and visible support necessary to progress the development and commercial deployment of SAF. The draft Terms of Reference, below, gives an indication of where each department would bring relevant expertise and leadership.

Whilst it is important that all the decarbonisation elements are joined up (e.g. electrification and SAF), we believe that sustainable fuels represent a unique and immediate set of challenges that would benefit directly from a dedicated focus. Other low-carbon propulsion of aircraft, such as hydrogen or electric propulsion, are already covered in the Aerospace Growth Partnership and the Aerospace Technology Institute.

While there are certain technical adaptations that can be made to engines and aircraft flying on SAF, the **main development opportunity lies in the fact SAF can be used on existing aircraft and engines**, and thus SAF fall outside the remit of the aerospace industry and firmly in the realm of fuel providers and airlines. That is why Sustainable Aviation believes that OSAF would fill a crucial void in the existing policy landscape.

- **Successful precedents:** We recognise the role that **OLEV** played as a dedicated team working across government (based in the Department for Transport but also including staff from then-departments BIS and DECC, now BEIS) as a one-stop shop for interaction between Government, industry and other stakeholders to support the early market for ultra-low emission vehicles (ULEV). This office provided over £900 million to "position the UK at the global forefront of ULEV development, manufacture and use". OLEV co-ordinated ULEV R&D and supply chain activity across Government and with industry to maximise economic benefits for the UK.

  We believe that given the scale of the challenge in delivering cleaner aviation specifically, and the significant near-term opportunities offered by sustainable aviation fuels as both a measure to cut aviation carbon emissions and deliver economic benefits to UK industry, a dedicated Office or similar cross-government focused team for an equivalent cross-government strategic SAF initiative should be established.

  In the US the **Commercial Aviation Alternative Fuels Initiative (CAAFI)** coalition focuses the efforts of the US government working with the US commercial aviation sector to engage the emerging alternative fuels industry. One of its focus areas is business, to facilitate the deployment of alternative jet fuels in the marketplace, connecting fuel producers and fuel users, evaluating the business case for use of alternative jet fuels, and identifying opportunities for deployment.

  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.

4.3. Why an office for sustainable aviation fuels? (continued)

- **Successful precedents (continued)** - CAAFI serves a primary role to facilitate the exchange of information about, and coordination of, private-sector and governmental initiatives supporting the development and commercialization of "drop-in" alternative aviation fuels.

  CAAFI says that 'The types and volumes of alternative fuels reaching the marketplace will depend on many factors, including the extent of governmental support (R&D and policy)'.

- **Cross-government co-ordination[49]:** An office or similar cross-departmental structure would help to provide the essential cross-government co-ordination necessary (i.e. across DfT, MoD, BEIS, Defra and HM Treasury) to progress the development and commercial deployment of SAF - supporting moving these technologies from R&D and fuels testing, through development to full commercial-scale plants - and would signal the Government's clear commitment to working with the sector to prioritise delivery of the sustainable aviation fuels Road-Map.

  Similarly, UK government has established the cross-departmental **Joint Air Quality Unit** and the **Centre for Connected and Autonomous Vehicles**, further examples of where the benefits of a joint-working have been identified in pursuit of a common goal.

- **Signalling:** We believe that this level of cross-government recognition and funding should also be afforded to SAF development as a priority and is also why we envisage an 'OSAF' playing a critical convening role, bringing together industry and government departments, and critically signalling to investors that the UK was serious about developing a domestic SAF capability.

  On 22 July 2019 **BEIS** unveiled an £80 million investment to help develop the next generation of electric vehicles and new hybrid aircraft. The Business Secretary cited this welcome announcement as helping to 'create the next generation of net zero technologies that will transform entire industries', including aviation. However, this is the kind of investment and focus that SAF requires as the more immediate, near-term opportunity to decarbonise aviation.

We set out a draft Terms of reference for a cross-departmental office. Such a terms of reference could be finalised by way of a cross-government and industry working group.

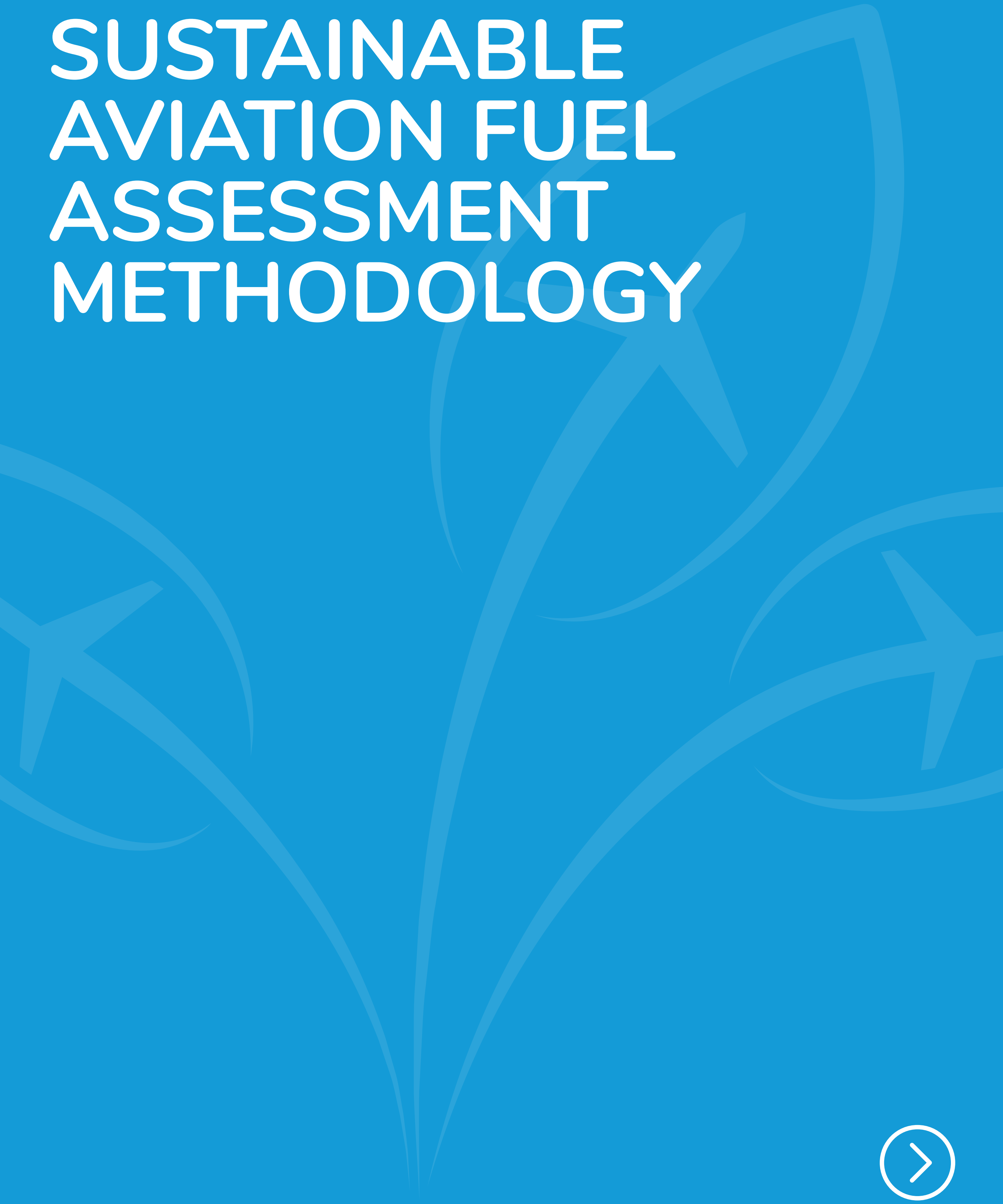
4.4. Cross-government Office for Sustainable Aviation Fuels – Draft terms of reference

Objective: To ensure the UK becomes a global leader in sustainable aviation fuels

Remit:

- Bring together relevant Government departments (**DfT, BEIS, HM Treasury, MoD, Defra, Innovate UK, UKTI**) to ensure a joined-up Government approach
- Act as a convener, bringing together industry with government departments
- Create a UK network of fuels testing facilities, following the example of the US Clearinghouse to accelerate new fuels development (**MoD and BEIS**)
- Encourage R&D in future sustainable aviation fuels, working with UK aerospace and academia to take them to commercial production (**BEIS and Defra**)
- Drive the commercial deployment of sustainable fuels, including by administering a £500m fund to support "first of a kind" fuel plants (**DfT, HMT and BEIS**)
- Support fuel providers and airports to ensure jet fuel facilities are sustainable aviation fuel ready and to remove barriers to the take-up of sustainable aviation fuels (**DfT and BEIS**)
- Promote the UK internationally as the best place to invest in sustainable fuels (**BEIS and DIT**)
- Support manufacturers to ensure aircraft and engines are adapted to a sustainable aviation fuels future (**BEIS**)
- Ensure the RTFO adapts to the changing sustainable fuels landscape and work with industry to develop a post-RTFO commercialisation strategy (**DfT and HMT**)
- Identify opportunities to support the UK's Clean Growth agenda: with the aim of supporting the industrial strategy by repurposing first-generation refining capacity and redundant fossil refining capacity (**DfT and BEIS**)

APPENDIX 1: SUSTAINABLE AVIATION FUEL ASSESSMENT METHODOLOGY



APPENDIX 1: SUSTAINABLE AVIATION FUEL ASSESSMENT METHODOLOGY

A1.1. Approach

E4Tech, on behalf of Sustainable Aviation, undertook a study into the potential for sustainable aviation fuels, globally and specifically in the UK. This Appendix outlines the approach taken. E4tech have previously validated many of the assumptions in this model with fuel producers, and in addition they reached out to developers of Alcohol to jet, Fischer-Tropsch, HEFA, and HTL technology to validate specifically the kerosene production slate assumed in this model.

Two important assumptions underlie the study: a) a supportive policy environment and b) technology success, with all companies currently working on sustainable aviation fuel production assumed to continue to do so, and to license the technology once they get to sufficient scale.

Companies still actively involved in technology for sustainable aviation fuel production		Companies no longer active in technology for sustainable aviation fuel production	New companies entered sustainable aviation fuel industry
Swedish Biofuels	Terrabon (Bankrupt)	Byogy	SG Preston
Lanzatech	Solena (Bankrupt)	Ekobenz	Velocys
UOP	Solazymes (Nutrition focus, and bankrupt)	Gevo	Fulcrum
Licella	LS9 (Acquired by REG)	REPSOL	Envergent
Emerald Biofuels	KiOR (Bankrupt)	CEPSA	Steeper Energy
Darling Int. and Valero	Blue Sun (Bankrupt)	Preem	Proton Power
BTG	Biochemtex/BetaRenewable	Petrixo	Shell/CRI
Anellotech	(acquired by Versalis)	Galp	Genifuel Corporation
Amyris (focus on chemicals)	Virent (acquired by Tesoro)	Armstrong Energy	Expander Energy
TRI	Forest BTL (Unclear)	Sunfire	Cielo
		INERATEC	
		Green Fuel Nordic	

A1.2. Fuels in scope

A1.2.1 Available conversion technologies

The following aviation fuel production routes are currently certified under ASTM D7566-16:

- **Fischer-Tropsch** - Synthetic paraffinic kerosene (FT-SPK)
- **Fischer-Tropsch** - Synthetic paraffinic kerosene with added aromatics (FT-SPK/A)
- **Hydroprocessed Esters & Fatty Acids (HEFA)** - Synthetic paraffinic kerosene (SPK)
- **Co-processed esters and fatty acids**
- **Synthetic Iso-Paraffinic fuels (SIP)**
- **Alcohol to jet**

A1.2.1 Available conversion technologies (continued)

SIP, HEFA and FT fuels are certified for use in aviation, with SIP and HEFA deployed at commercial-scale today (but mainly for the road transport fuels market). A larger number of processes are at the demonstration stage; both in terms of demonstrating production at scale and also the suitability of the fuels for aviation.

A1.2.1.1 HEFA

HEFA is produced by the conversion of vegetable oils or waste oils and fats. It can be used as a "drop-in" blending components for the production of diesel and aviation fuels. The hydrotreatment process consists of: thermal decomposition; hydrogenation and isomerization reaction to produce diesel; and an additional selective cracking process to produce aviation fuel.

Full-scale commercial plants are operating using vegetable oils, tallow and used cooking oil:

- Neste Oil operates two 190,000 tonne per annum plants in Finland and two 800,000 tonnes per annum plants in Singapore and Rotterdam, producing diesel fuel
- Dynamic Fuels operate a commercial plant in the US, which has supplied aviation fuels for test flights via SkyNRG
- World Energy in California operates the only plant that is producing sustainable aviation fuel from waste oils, greases and fats on a regular basis

Experience of operating full commercial-scale plants could allow a rapid capacity ramp-up, however the availability of sustainable feedstocks may constrain future deployment due to concerns over the direct and indirect impacts of using virgin plant oils for fuel production. HEFA may be produced from microalgae, and this has received much interest from the aviation sector as it may overcome issues related to land use change. But, the production of microalgae oils for fuel production is not yet demonstrated at commercial scale.

At present, the capacity and economic margins to produce diesel are greater than for fossil fuel; reducing the incentive to supply the aviation sector. As a result, existing HEFA capacity produces predominantly diesel fuels, with a small fraction suitable for aviation. It is estimated that approximately 10% of current output could be destined to aviation fuel. It is however, technically feasible to configure plants to produce 60% aviation fuels.

The use of Green Diesel (i.e. the diesel fraction of the HEFA process) as a blending component in aviation fuels is currently being assessed for approval by ASTM. Such approval would simplify the process for the production of aviation fuels via hydrotreatment and could lead to an immediate increase in the production capacity for sustainable fuels. However, the aviation industry will continue to compete with the road transport sector for this resource.

A1.2.1.2 Fischer-Tropsch

Fischer-Tropsch (FT) fuels are produced via a set of chemical reactions that convert syngas—a gaseous mixture of carbon monoxide (CO) and hydrogen (H2) – into liquid hydrocarbons, including synthetic paraffinic kerosene (SPK). Solid feedstocks, such as biomass, are first gasified to produce syngas, followed by the catalytic FT conversion of the syngas to liquids. FT fuels may be produced from a range of feedstocks, such as coal, natural gas, biomass and/or waste. However, only FT fuels produced from certain biomass or waste will meet the sustainability criteria set out by SA.

The FT process is currently applied at commercial scale by Sasol, Petro SA, Shell and Oryx using fossil feedstocks. Biomass or waste-based FT processes (BTL) are at the pilot and demonstration stages, with first commercial scale plants in development including the Fulcrum Sierra project in the USA.

There is also interest in alternative sources of syngas. For example, the reverse combustion of CO_2, and electrolysis of water, being developed by the Sandia National Laboratories and by the Solar-Jet FP7 project led by ETH Zurich. These processes are at an early stage development and have not yet been integrated with downstream FT conversion. Sunfire is planning to build an 8kt demonstration unit in the Norway to produce sustainable aviation fuels.

A1.2.1.3 Synthesized Iso-Paraffinic (SIP) routes

The direct conversion of sugars to hydrocarbons may be achieved via biological or thermochemical processes. Today only the Amyris Total process has been approved. This process modifies yeast cells to ferment sugars to hydrocarbons that can be used directly as a fuel component. The process produces C15 hydrocarbon farnesene produced which is used in a number of chemical and material applications, including ground transport fuels and use as an aviation fuel blending component up to a maximum of 10% with fossil fuel.

Several other routes are in earlier stages of development. Some technologies only currently produce a chemical precursor, which requires further upgrading/refining before use in aviation fuel. Other integrated processes are operating at small scale and are engaged in the fuel accreditation process.

A1.2.1.3 Synthesized Iso-Paraffinic (SIP) routes (continued)

Some example processes under development include:

- The use of biological catalysts to ferment sugars to hydrocarbons that may be hydrogenated to produce fuel blending components. For example, LS9 produce fatty acid methyl esters (FAME) and fatty acid ethyl esters (FAEE) that may be converted to aviation fuel blending components via hydrotreatment

- The use of aqueous phase reforming to convert sugars to hydrogen and a mixture of chemical intermediates (e.g. alcohols, ketones, acids, and furans), which are converted to fuel blending components by conventional condensation and hydrotreatment processes. As developed by Virent

A1.2.1.4 Alcohol-to-jet (ATJ) routes

The alcohol-to-jet (ATJ) route involves the catalytic conversion of methanol, ethanol or butanol into kerosene. The typical conversion route is first dehydration of the alcohol(s) to alkenes (olefins), followed by oligomerization into longer chain hydrocarbons and hydrogenation, with final rectification/distillation into gasoline, aviation fuel and diesel fractions. Catalytic processes are being developed that yield high fractions of aviation fuel (50%) as opposed to gasoline (15%) and diesel (35%).

Catalytically converting alcohols to higher hydrocarbon fractions suitable for transport applications is an established technology, e.g. Mobil's Methanol-to-Gasoline process. However, the conversion of ethanol and iso-butanol is currently at the demonstration stage. A demonstration plant is planned with funding from the European Commission's Seventh Framework Programme, and the accreditation of aviation fuels produced from iso-butanol and ethanol is underway.

Ethanol or iso-butanol intermediates may be produced via the fermentation of biomass, carbon monoxide rich waste gases (e.g. steel mill waste gas), or syngas from biomass gasification.

A1.2.2 Future sustainable aviation fuel production processes

New processes are being developed which are currently at laboratory and development stage. These are not the focus of this roadmap in terms of the potential for deployment to 2035, but their successful development could result in these processes contributing significant volumes of sustainable fuel to the aviation industry between 2035 and 2050. For the purposes of this assessment, which reflects the **potential production** of sustainable aviation fuel, the needs of these processes in terms of technical milestones, appropriate funding, and commercialisation strategy should not be overlooked.

Therefore, the fuel production technologies are grouped into the following fuel categories for the purposes of this study:

- Alcohol to jet (including ethanol, isobutanol and n-butanol to jet)
- Gasification + FT
- Pyrolysis (including the IH^2 process)
- Direct sugars to hydrocarbons (Aerobic fermentation)
- Hydrotreated oils and fats (including both standalone hydrotreatment and co-processing in a refinery)
- Power-to-liquids (Fischer-Tropsch)
- Other thermo-chemical (hydrothermal liquefaction and aqueous phase reforming)

In theory, sustainable aviation fuels could be produced via methanol, for example using either a variation of the Exxon Methanol to Gasoline (MTG) process, or methanol to olefins + olefins to gasoline and distillate (MOGD) process. However, no companies are currently developing this technology for the purpose of producing aviation fuel. Therefore, whilst there are promising routes for the production of methanol from both biomass and renewable electricity, it is unlikely that sustainable aviation fuel produced from methanol will contribute meaningfully to aviation fuel supply in 2035.

A further potential fuel type is co-processing of crude pyrolysis oil and FT waxes in refineries with crude oil. These could facilitate the upgrading process required to produce high-quality sustainable aviation fuels from these products. However, currently the production of sustainable aviation fuels via Fischer-Tropsch or pyrolysis is not constrained by the ability to upgrade the products, so co-processing was not considered as a separate sub-category.

A1.3. Method

A1.3.1 Global Ramp-up

The methodology adopted for this study is a 'bottom-up' methodology, in order to estimate the potential deployment of sustainable aviation fuel production technologies today based on their current deployment, and how that could plausibly develop under a number of scenarios. Extensive information on companies currently developing sustainable aviation fuel production technology and the plants they operate or have planned formed the basis of the model development.

A1.3.1 Global Ramp-up (continued)

The likely future deployment of each route is then assessed based on the following key factors that influence how far and how fast a pathway can progress:

- **Project timeline:** how long it takes to build each plant
- **Lifetime:** How many years each plant operates for
- **Plant capacity:** How large each plant is
- **Utilisation rate:** How many hours per year a plant operates for
- **Number of developers:** independently starting projects
- **Initiation rate:** How many commercial projects can be started each year, e.g. via technology licences
- **Launch points:** How soon after a previous project starts is it is feasible for the next project to start
- **Success rate:** How many of these plants and developers might fail/be unsuccessful?

A1.3.1.1 Project timelines

The development timeline defines how long it would take from project inception to a fully operational plant. This includes Project development & financing (PD), Construction (CO), Commissioning & ramp-up (CM) phases. For each technology type (biological, thermochemical and chemical) and for each stage of plant scale-up (pilot, demonstration, 1st commercial, 2nd commercial and Nth commercial) an average development timeline is applied, as illustrated in **Figure A1**.

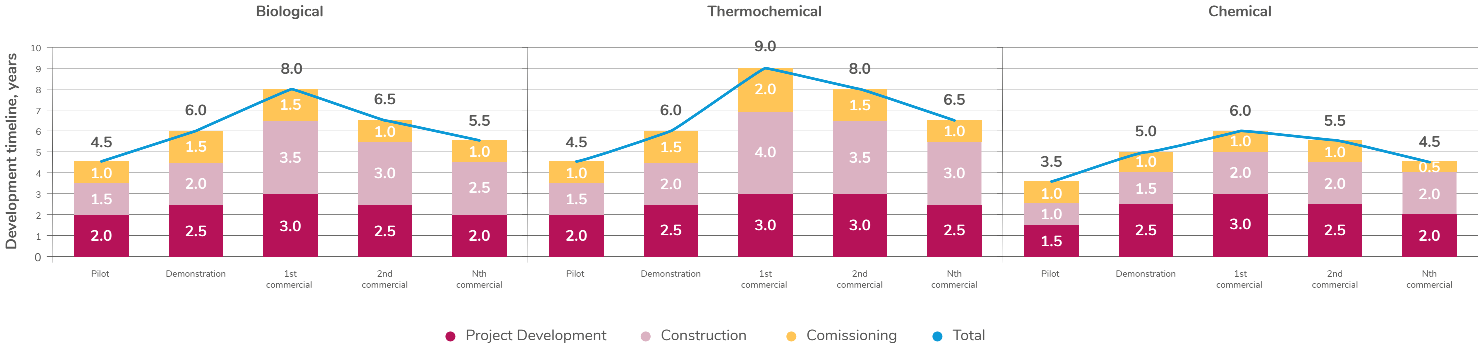


Figure A1.1 - Illustrative development timeline assumptions

Small pilot and demo plants are relatively quick to design, built and commission, whereas 1st commercial plants typically take the longest number of years. 2nd and subsequent (Nth) commercial plants were assumed to be quicker, due to developer learning and replication of technical plans, contracts etc.

Thermochemical routes (those using gasification, pyrolysis, APR, HTL) are the most capital intensive, and will typically have longer timelines. Chemical routes (Alcohol catalysis) are the least capital intensive with shorter timelines. Biological routes (DSHC) generally lie somewhere in between.

A1.3.1.2 Lifetime of plants

The following assumptions were made concerning plant lifetimes:

- **Pilot plant =** 3 years
- **Demonstration plant =** 5 years
- **Commercial plant =** 28 years

By taking this approach, any pilot and demo plants built early in the time period do not contribute to the total production capacities at the end of the period. The short lifetime of pilot and demonstration plants reflects the fact that they are often loss-making facilities, and generally developers choose to operate these plants for only long enough to gain valuable test data and experience, in order to finance future plants. Given the pilot and demo capacities are very small compared to the commercial facilities, then choosing longer or shorter lifetimes has limited impact on the ramp-up results.

A1.3.1.3 Generic plant output

The 1st commercial and 2nd commercial plant sizes were based on the size of plants already constructed or planned by companies. For Nth commercial plants, it was assumed that each technology route converged to using an average output fuel capacity per year figure for all the Nth commercial plants within that route.

The assumptions around the capacity of Nth commercial plants are provided in Table A1.1. These are not assumed to vary by scenario, given the economically viable plant scales are not particularly dependent on the wider industry development – rather they depend on capital costs, operating costs and efficiencies, trading off against feedstock prices and local availability near plants (or imports). Within the considered timespan, there will not be multiple rounds of Nth commercial plants built, so these assumptions will apply to all modelled Nth commercial plants.

Table A1.1: Nameplate capacities of commercial plants

Conversion pathway	kt/yr	Pj/vr
Alcohol catalysis	143	6.3
APR with catalytic upgrading	103	4.5
Aerobic fermentation	43	1.9
Gasification with Fischer-Tropsch	88	3.9
Fast pyrolysis with catalytic upgrading	65	2.9
HTL with catalytic upgrading	56	2.5
Hydroprocessing of oils/fats	350	15.4
Power to Liquid: Fischer-Tropsch	87	3.8

A1.3.1.4 Utilisation rate of plants

All plants across all pathways were assumed to run at 90% utilisation once successfully constructed and commissioned, so actual annual fuel production is slightly below the nameplate capacities.

A1.3.1.5 Number of developers

The number of developers is a key determinant of future deployment of that technology, as each developer is expected to take their technology to commercial scale (subject to any failure rates), and start initiating new commercial projects (either under an owner operator or licensing model).

Table A1.2 outlines the number of technology developers in each conversion pathway. These were not assumed to vary by scenario or over time, as this number is an actual, current number of developers within each pathway. This continues the database working principle that only includes developers which have at least a pilot plant. Lab-scale facilities – often in research institute - are excluded.

Table A1.2: Number of technology developers

Conversion pathway	
Alcohol catalysis	6
APR with catalytic upgrading	1
Aerobic fermentation	3
Gasification with Fischer-Tropsch	7
Fast pyrolysis with catalytic upgrading	10
HTL with catalytic upgrading	7
Hydroprocessing of oils/fats	16
Power to Liquid: Fischer-Tropsch	3

A1.3.1.6 Initiation rate

The initiation rate is the number of Nth commercial projects that start construction per year (globally), per developer. The main drivers underpinning the initiation rate are the attractiveness of licensing the technology, which depends on economics, constraints (such as feedstocks), and the capacity of each Nth commercial plant. The initiation rates assumed are summarised in **Table A1.4**.

Table A1.4: Number of Nth commercial projects started each year, by each developer

Conversion pathway	Slow Growth	Fast Growth
Alcohol catalysis	1	2
APR with catalytic upgrading	1	2
Aerobic fermentation	1	2
Gasification with Fischer-Tropsch	1	2
Fast pyrolysis with catalytic upgrading	1	2
HTL with catalytic upgrading	1	2
Hydroprocessing of oils/fats	0.25	0.5
Power to Liquid: Fischer-Tropsch	1	2

A1.3.1.7 Launch points

The launch points define when the next technology stage (project) is most likely to start. These were assumed to vary according to the technology stage, and between scenarios, but not vary significantly between technologies, reflecting the fact that investors are likely to require a similar number of years of operational evidence before taking larger investment decisions, independent of the specific technology.

Table A1.5: Launch point assumptions for each technology stage

Stage	Rules	Slow Growth	Fast Growth
Pilot	Only actual or announced pilot plants will be featured	-	-
Demo	Any actual or announced demo projects will be featured. If no plans, demo project development assumed to begin # (see right) years after the start of pilot operations	1	0.5
1st commercial	Any actual or announced projects will be featured If no plans, 1st commercial plant construction assumed to begin **# (see right)** years after the start of demonstration operations. Investors often require ~10,000hrs of operational data before investing in a 1st commercial plant	3	2
2nd commercial	Any actual or announced projects will be featured If no plans, 2nd commercial plant construction assumed to begin **# (see right)** years after the start of 1st commercial plant operations	3	2
Nth commercial	Nth commercial construction begins **# (see right)** years after the start of 2nd commercial plant construction. Several plants can be initiated simultaneously (see initiation rate slide), with the same number of new plants initiated the next year, and the next year, etc.	2	1.5

APPENDIX 1: SUSTAINABLE AVIATION FUEL ASSESSMENT METHODOLOGY

A1.3.1.8 Success rate

Projects and developers may not be successful, so a % success rate was used to define the expectation of any particular project being successful from inception to operation **(Figure A1.2 and Figure A1.3)**.

		Compounded success rate if a developer already has an operating plant at X technology stage today				
Future technology stage	**Individual plant success rate**	**Pilot**	**Demo**	**1st com**	**2nd com**	**Nth com**
Pilot	50%	100%	100%	100%	100%	100%
Demonstration	60%	60%	100%	100%	100%	100%
1st commercial	70%	42%	70%	100%	100%	100%
2nd commercial	80%	34%	56%	80%	100%	100%
Nth commercial	90%	30%	50%	72%	90%	100%

Figure A1.2 Success rate assumptions by technology state, in the Slow Growth

		Compounded success rate if a developer already has an operating plant at X technology stage today				
Future technology stage	**Individual plant success rate**	**Pilot**	**Demo**	**1st com**	**2nd com**	**Nth com**
Pilot	75%	100%	100%	100%	100%	100%
Demonstration	80%	80%	100%	100%	100%	100%
1st commercial	85%	68%	85%	100%	100%	100%
2nd commercial	90%	61%	77%	90%	100%	100%
Nth commercial	95%	58%	73%	86%	95%	100%

Figure A1.3 Success rate assumptions by technology state, in the Fast Growth

The compounded success rates on the right-hand side of the tables reflect that if a developer currently has e.g. an operating demo plant, then the likelihood of success of a future 2nd commercial plant also depends on the success of an intermediate 1st commercial plant. These compounded success rate %s were used to calculate the likely average fuel production by multiplication by the individual plant production outputs.

A1.3.2 UK ramp-up

The projection of the UK sustainable aviation fuel capacity was obtained taking into account the current planned capacity in the country, and assuming that a fraction of the total future plants could be built in the UK. This fraction corresponds to the estimated UK share of the global aviation fuel market. In mathematical terms the UK sustainable aviation fuel production potential is given by:

$$\text{UKfuture} = \text{UKplanned} + \{(\text{Globalfuture} - \text{UKplanned})^{kt} \text{ X Market Share UK}\}\ [\_\_\_]\text{yr}$$

A1.3.2 UK ramp-up (continued)

In the absence of specific prospective market data, a reasonable proxy for the future market size is country population. Therefore, the UK market share was assumed to be equal to the ratio between the UK population and the sum of Europe and North America population (EU-28, USA, Canada, Mexico).

$$\text{Market Share UK} = \frac{\text{UK population}}{\text{EU}_{28} + \text{USA} + \text{Canada} + \text{Mexico}} = 6.6\%$$

Nonetheless, the UK does not produce sustainable aviation fuel currently and the first plant is expected to come online around 2021. Therefore, the UK sustainable aviation fuel production over the period to 2021 was based on known planned plants, assuming that they all succeed. From 2021 an annual increase in UK percentage of global production was applied until reaching the calculated value in 2035 of 6.6%.

Additionally, it is unlikely that a new HEFA plant would be located in the UK due to resource constraints and lack of support from the RTFO. Hence, the HEFA capacity was excluded from the calculation of UK future market share in 2035.

A1.3.3 Product slate

Given the large degree of uncertainty in how these factors will evolve and vary to 2035, two scenarios reflecting slow and fast growth of the industry are developed to project the potential production volume. The slow and fast growth scenarios differ in terms of the initiation rate, the launch-point and the success rate.

All of the technology routes considered can produce a number of different fuel types: there is a large overlap between the diesel and kerosene fuel specification, so the majority of the fuel production technologies within scope could produce both diesel and kerosene, as well as other fuel types. In this study two cases are considered: where the percentage of jet output is maximised, and where the percentage of other fuels is maximised. The percentage of jet fuel (as a percentage of total fuel output from the plant) in each of these two scenarios is shown in Table A1.6.

Table A1.6 High and low kerosene slate

Route	Jet % when pathway optimised to produce other fuels	Jet % when pathway optimised to produce jet
Alcohol catalysis	25%	90%
APR with catalytic upgrading	20%	60%
Aerobic fermentation	0%	100%
Gasification with Fischer-Tropsch	20%	50%
Fast pyrolysis with catalytic upgrading	20%	60%
HTL with catalytic upgrading	20%	60%
Hydroprocessing of oils/fats	14%	70%
RFNBO: FT catalysis	20%	50%

A1.3.3 Product slate (continued)

In most cases commercial factors would influence the choice of fuel producers as to whether to produce diesel or kerosene. These scenarios reflect economic limitations on plant operation, rather than the absolute highest or lowest kerosene production. These two factors combine to give 4 scenarios, as illustrated in **Table A1.7**.

Table A1.7: Summary of scenarios considered

		Product State	
		Road Optmized	Aviation Optmized
Supply Scale-up	Low	Slow Growth (Road-optimized)	Slow Growth (Aviation-optimized)
	High	Fast Growth (Road-optimized)	Fast Growth (Aviation-optimized)

A1.3.4 Level of feedstock demand from modelled deployment

The feedstock demand from the modelled sustainable aviation fuel production are compared to the availability of sustainable feedstock. The global and UK figures for feedstock availability are based on a model developed by Ricardo for BEIS to assess the bioenergy resource potential ("UK and Global Bioenergy Resource Model", 2017). These figures correspond to estimates of total available feedstock, not limited by economic viability of collecting and using it. However, sustainability criteria are applied to exclude feedstocks which are associated with GHG emissions above relevant sustainability standards. The figure for MSW includes both biogenic and non-biogenic MSW.

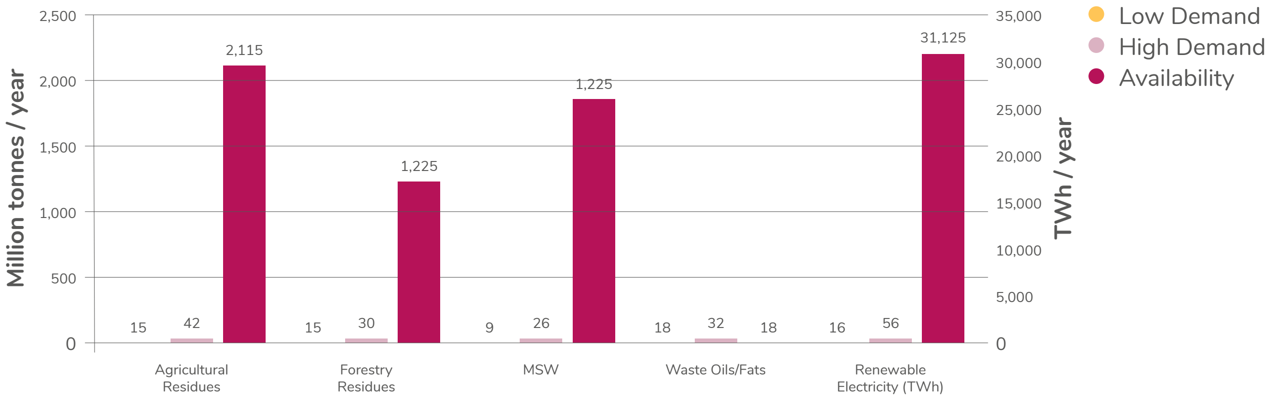


Figure A1.4 - Global 2035 feedstock demand compared to availability of sustainable feedstock

A1.3.4 Level of feedstock demand from modelled deployment (continued)

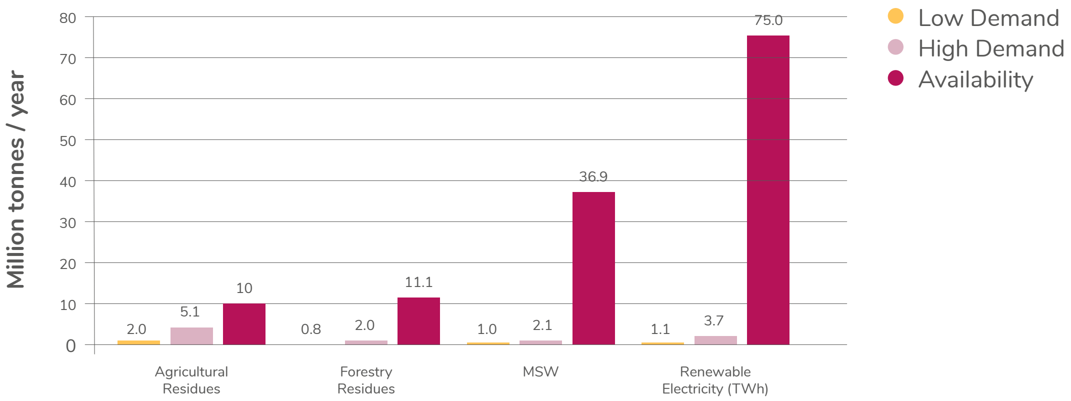


Figure A1.5 - UK 2035 feedstock demand compared to availability of sustainable feedstock

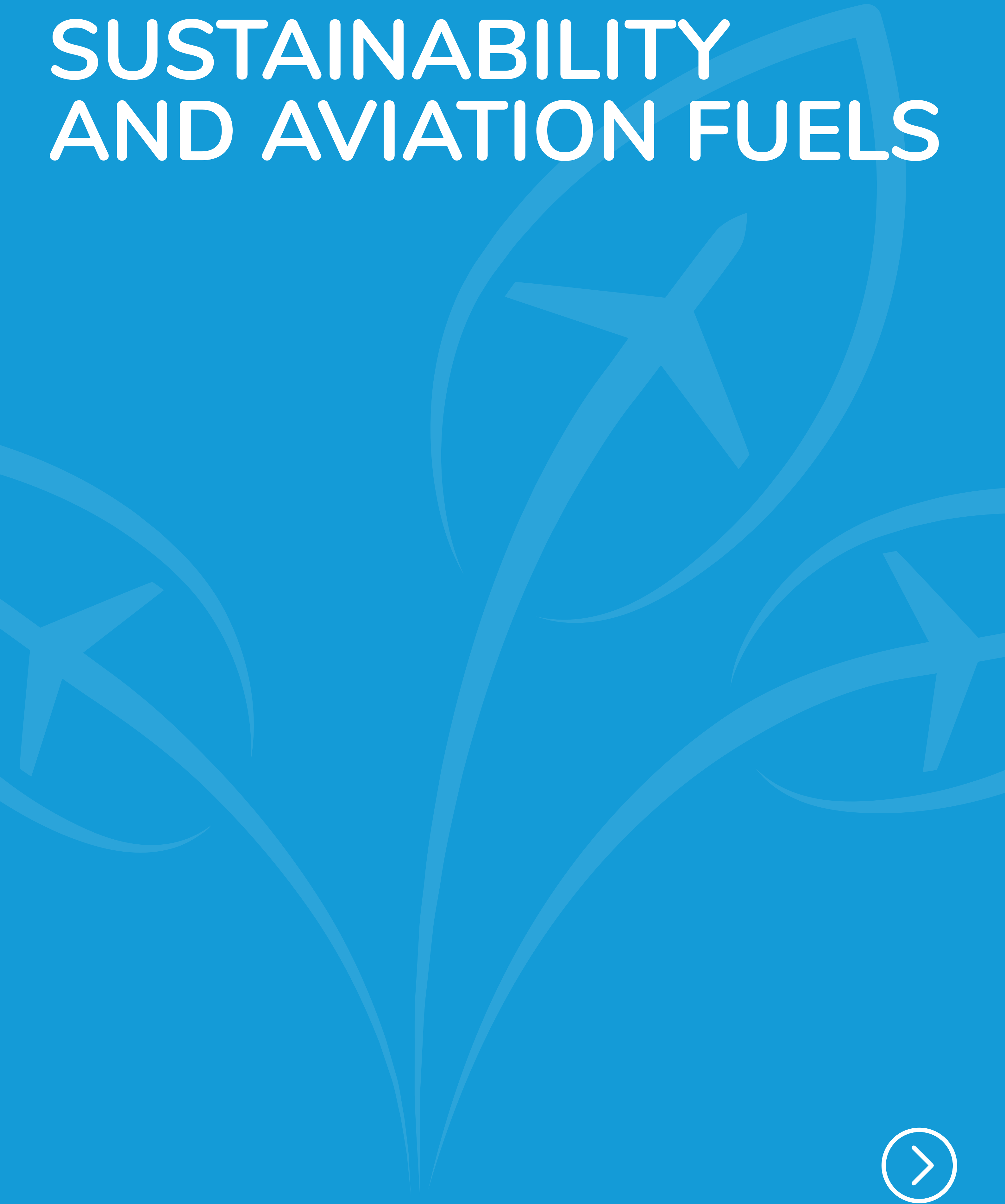
A1.3.5 Sustainable aviation fuel GHG emissions profiles modelled by E4Tech

Table A1.8 Average GHG emission values used to calculate overall GHG emissions of anticipated fuel volumes

Route	GHG emissions ($gCO_2eq./MJ$)	Reference for GHG emissions intensity	Specific feedstock / other assumptions in figure used
Alcohol catalysis	35.0	de Jong et al (2017)[50]	AtJ using ethanol produced from corn stover
Other thermochemical (APR and HTL)	20.0	Average of APR GHG intensity (22 $gCO_2eq./MJ$) from IRENA (2016)[51] and HTL (18 $gCO_2eq./MJ$) from De Jong et al. (2017)	APR figure based on sugars from agricultural residues; HTL from forestry residues with in-situ hydrogen generation
Gasification with Fischer-Tropsch	13.7	European Commission (2018) RED II[52]	Typical value for FT diesel produced from waste wood
Fast pyrolysis with catalytic upgrading	22.0	De Jong et al. (2017)	Pyrolysis of forestry residues, assuming in-situ hydrogen production
Aerobic fermentation	25.0	Industry source, adjusted for 2G sugars from farmed wood	Adjusted to be applicable to 2G sugars from farmed wood
Hydroprocessing of oils and fats	14.0	European Commission (2018) RED II	Average of typical values for hydrotreated oil from waste cooking oil and animal fats from rendering
RFNBO:FT catalysis	19.5	Schmidt et al. (2018)[53]	Based on the use of wind / PV in Germany today, including construction of power plants and production facility.*

*Typically for GHG assessments of biofuels, the emissions from equipment and infrastructure is not taken into account, but in the case of PtL fuels, particularly when renewable electricity is used, these 'infrastructure' emissions can comprise the majority of the fuel GHG emissions. Therefore, the figure used in **Table A1.8** does include emissions from the construction of power plants and the production.

APPENDIX 2: SUSTAINABILITY AND AVIATION FUELS



APPENDIX 2: SUSTAINABILITY AND AVIATION FUELS

At a glance

- SA supports advanced fuels production and any policy mechanisms to ensure that ILUC risk is addressed and mitigated
- The UK Government and aviation industry have a role to ensure that global aviation policy frameworks address the issue of sustainability and that sustainability criteria is incorporated into global climate change policy for aviation

Sustainable Aviation members take the sustainability of alternative fuels very seriously. In addition to the sustainability criteria outlined in **Section 2.1** of the main report, there are a number of other factors that are taken into consideration.

A2.1 Feedstock availability and sustainability

Aviation fuels are produced by taking a feedstock and converting it via industrial processes into a fuel. A range of different potential feedstocks have been identified. Some are based on oil crops such as algae and other non-food feedstock while others are based on waste sources such as municipal solid waste, used cooking oil and waste industrial gases. More sophisticated processing technologies necessary for the manufacturing of aviation fuels will widen the number of available feedstock types, and many of these are low grade, low value materials.

The European Climate Framework and the International Council on Clean Transportation published a report on the availability of cellulosic wastes and residues in the EU[54], supported by SA members which identified a potential of 900 million tonnes of available waste material in the EU. Of this it is estimated that 220-230 million tonnes can sustainably be recovered for energy production. The conversion of this into sustainable fuels could generate 36.7 million tonnes of biofuel for all transport modes.[55] Total fuel use by EU aviation in year X was Y

Some SA members were part of the ICAO international Alternative Fuels Task Force (AFTF), which is a constituent part of the Committee on Aviation Environmental Protection (CAEP) that developed the CORSIA regulations. The AFTF developed harmonised life cycle assessment methodologies, a set of sustainability criteria and eligibility criteria for sustainability certification systems.

The ICAO CORSIA work on sustainability is still ongoing. Present requirements focus only on greenhouse gas emissions and carbon stock and, while a positive first step, are not sufficient to ensure that fuels reach the higher sustainability goals of the SA group. The most complete framework for achieving these goals is outlined in the Roundtable on Sustainable Biomaterials (RSB) standard which provides a full set of criteria to ensure that fuels are truly sustainable. There have been a number of reports over recent years outlining both feedstock availability and the significant potential for the development of conversion technologies in the UK.[56,57]

A2.3 Indirect impacts

In addition to the direct impacts that can generally be measured and attributed to a fuel production method, we recognise that there is concern that the use of land can have negative unintended consequences on the environment. Indirect Land Use Change (ILUC), whereby the production of newly demanded products on existing cropland displaces other agricultural activity to other high carbon stock land (e.g. tropical forest) is a significant concern.

The possible extent of negative ILUC and the resulting GHG emissions that may occur as a result of additional demands for a variety of crops in different regions is not fully understood. Considerable work has been done to identify policies and practices that mitigate the risk of causing negative ILUC[58] and has led to the creation of the RSB Low ILUC module for sustainability certification[59]. More recently, policy mechanisms dealing specifically with ILUC have been approved and are entering use: namely the EU Renewable Energy Directive II (RED II) Delegated act on high and low Indirect Land Use Change[60] and ICAO's CORSIA approach for ILUC modelling and low ILUC practices.

A2.3 Indirect impacts (continued)

SA members have been heavily engaged with NGOs and policymakers to ensure that the sustainable fuels they are seeking to develop do not lead to negative ILUC impacts. One major way of mitigating the risk of ILUC is through the use of feedstock based on waste materials and residues for these sustainable fuels. In order to fully understand the impacts of the use of these feedstocks, it may be important to assess displacement emissions when using waste or residual material to avoid the risk of indirect emissions when material streams are diverted from existing uses. RSB has developed and is piloting a methodology for displacement emissions[61]. Other ways in which the risk of ILUC impacts can be mitigated are:

- Producing feedstock on unused land – that is land that is not currently used to provide provisioning services
- Increasing feedstock availability for sustainable fuels without increasing the pressure on land use through increased yield or land productivity
- Feedstock production on underused land - land that falls between the above two categories
- Increased feedstock availability through reduction in post-harvest waste
- Integrating food and fuel production in ways that lead to higher overall land productivity
- Using feedstocks that require little land such as algae

SA welcomes the UK Government's recent work on advanced fuels production and support the move to ensure that ILUC risk is identified and accounted for. SA members have been focused on understanding best practice in this area and are working with the International Civil Aviation Organisation, (ICAO) and the International Air Transport Association, (IATA), EcoFys and NGOs to develop globally harmonised sustainability criteria. As the UK was at the forefront of standards development in the EU, SA believe that this is an area where the aviation sector and Government should work together to ensure that sustainability of fuels production globally is prioritised in the development of a global climate change policy for aviation.

A2.4 Sustainability standards

Sustainability standards have been developed to provide reassurance that supply chains are robust and provide genuine environmental and climate benefits. Increasingly they also address socio-economic aspects of fuel production. Some of these standards are national or regional standards that are embodied in legislation. Others are voluntary standards developed by NGOs.

A2.4.1 Government sustainability standards

The EU has a target of obtaining 14% of its transport fuel from renewable sources by 2030. The Renewable Energy Directive (RED) specifies a number of sustainability criteria that fuel must meet in order to be accounted towards the target.

- Minimum level of GHG emission saving of 50% compared to fossil fuels for plants that began operation before October 2015, rising to 60% for plants operating from 1 October 2015, and 65% from 1 January 2021 for bio-based fuels
- Minimum level of GHG emission saving of 70% compared to fossil fuels for plants beginning operations after 1 January 2021 for renewable fuels from non-biological origin
- Areas of high carbon stock (wetland, forest and peatland), should not be used for fuel production
- Land with high biodiversity should not be used for biofuels production

The EU is also implementing changes to existing legislation to address concerns about ILUC impacts via the EU Renewable Energy Directive II (RED II) delegated act on high and low Indirect Land Use Change. The EU RED and RED II are transposed into national legislation by Member States.

In the UK the RED is implemented through the Renewable Transport Fuel Obligation (RTFO). Although it is unclear to what extent the RTFO will be aligned with RED II in future, present UK policy extends to 2032.

Under the RTFO, those supplying biofuel must meet specified sustainability criteria in order for their fuels to be recognised as being entitled to the benefit of Renewable Transport Fuel Certificates (RTFCs). Obliged fuel suppliers are required to redeem a number of RTFCs in proportion to the volume of unsustainable fuel (e.g. fossil fuels) they supply. RTFCs may be earned by any company supplying sustainable fuels. They may be bought or sold on an open market, Obligated suppliers also have the option to 'buy out' their obligation, paying a fixed fee per litre of sustainable fuel that would otherwise have to have been supplied to earn RTFCs. Fuels from wastes and residues (and lingo-cellulosic and non-food cellulosic feedstocks) are "double counted". These fuels receive twice as many RTFCs per litre. Sustainability data supplied for all fuels must be independently verified by a qualified third party.

In 2019, the government also UK government also included a new fuel category: development fuels. These are fuels derived from wastes and residues and manufactured using novel technologies. Aviation fuels fall within this category and to encourage investment in new technologies, eligible fuels can earn a higher level of incentives.

A2.4.2 Voluntary standards

A number of different voluntary standards exist that relate to biofuels. The most robust of these have been developed through multi-stakeholder frameworks and follow the ISEAL Principles. The ISEAL Alliance is a non-governmental organisation whose mission is to promote best practice in standards organisations and certification systems. Membership is open to all multi-stakeholder sustainability standards and accreditation bodies that demonstrate their ability to meet the ISEAL Codes of Good Practice and accompanying requirements, and commit to learning and improving.

The SA Community is actively supportive of the RSB Standard – broadly considered to be the best-in-class sustainability certification for fuels produced from biomass and recycled carbon. It is a fully qualified biofuels standard of the ISEAL Alliance and takes a robust approach to environmental and social sustainability, as well as requiring significant (50% minimum) greenhouse gas emission reductions. The RSB is well-placed to support the SA community innovate sustainable solutions having continuously evolved to match emerging technologies and issues.

The RSB is an international, multi-stakeholder standard organisation that has developed a feedstock and technology-neutral global standard for sustainability. The RSB produced the world's first Low ILUC certification module in 2015, developed and launched a standard for Advanced Fuels (made from waste and residual biogenic sources, as well as recycled carbon) in 2017 which is fully in-line with CORSIA reporting requirements. Additionally, RSB has taken the lead in developing and piloting an approach for Displacement Emissions that might be caused by the redirection of feedstock pathways requiring new feedstocks for the original use.

Another voluntary standard relevant to sustainable fuels is that developed by Bonsucro - a not-for-profit initiative dedicated to reducing the environmental and social impacts of sugar cane production. Bonsucro is also a member of the ISEAL Alliance.

The EU has formally recognised a number of voluntary standards approved to demonstrate compliance with the EU RED sustainability requirements. These include the RSB standard.

A2.5 Aviation and sustainable fuels

A global airline-led initiative called the Sustainable Aviation Fuel Users Group (SAFUG) was formed in September 2008 with support and advice from leading environmental organizations such as the Natural Resources Defence Council and the RSB to help accelerate the development and commercialization of sustainable fuels in aviation. Airlines that wish to become members have to sign a pledge at CEO level which commits the airlines to consider specific sustainability criteria when sourcing 'sustainable' fuels. The Group now has more than 30 member airlines which represent approximately 33% of annual global commercial aviation fuel demand. SAFUG's membership includes a number of members of Sustainable Aviation.

Sustainable Aviation is committed to strong sustainability principles, consistent with those of SAFUG. As such it has committed to only support sustainable fuels that, in addition to the Renewable Energy Directive criteria, also meet at least the following sustainability requirements[62]:

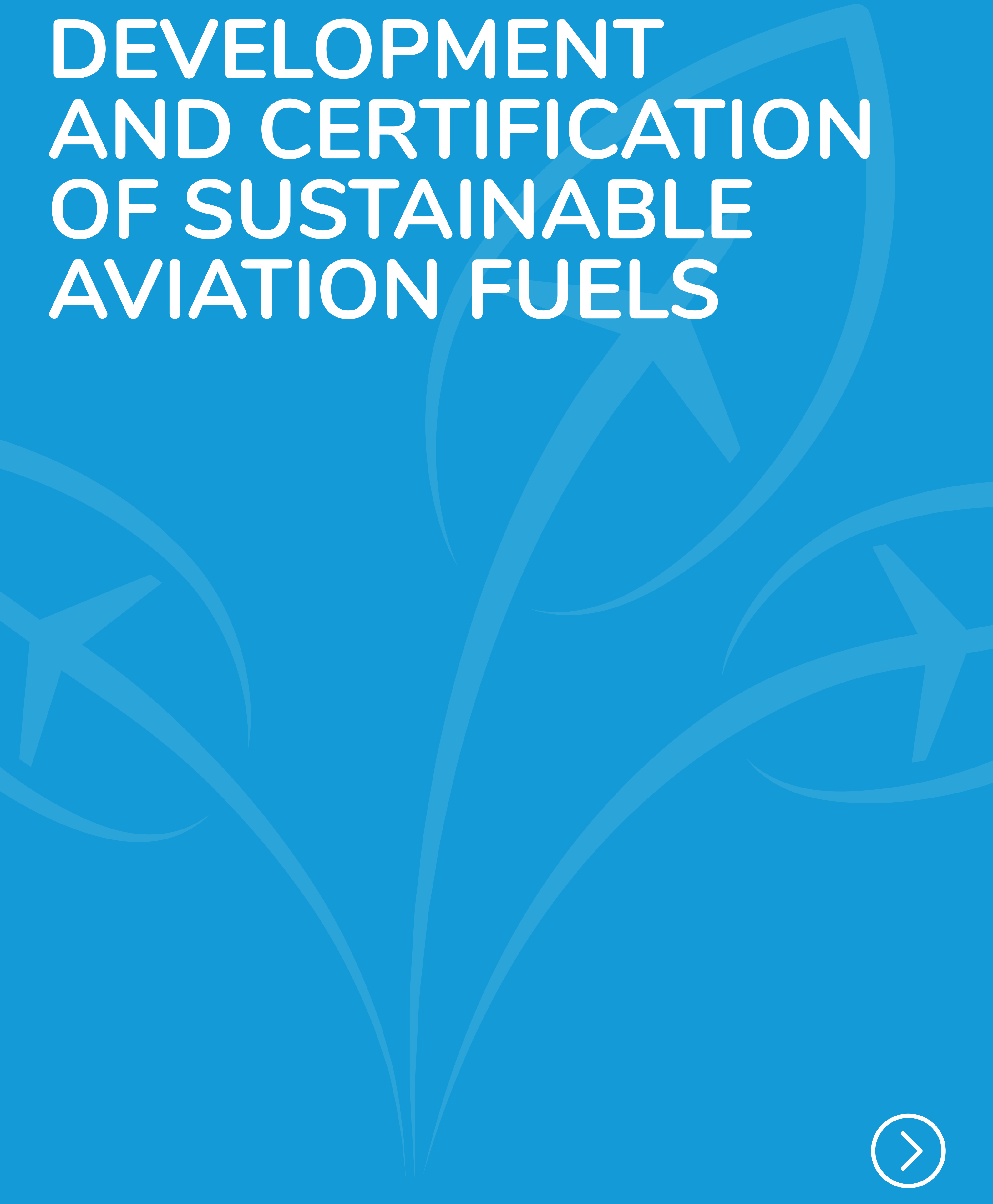
1. Any aviation fuel should be developed in a manner that is non-competitive with food and where biodiversity impacts are minimized;
2. The cultivation of any land should not jeopardize drinking water supplies or have a negative impact on an area already identified as suffering from high water stress;
3. High conservation value areas and native eco-system should not be cleared and cultivated for aviation fuel production– directly or indirectly;
4. Total life cycle GHG emissions should be significantly reduced compared to those associated with fossil sources (at least 60% emission saving);
5. In developing economies, development projects should include provisions for outcomes that improve socioeconomic conditions for small-scale farmers who rely on agriculture to feed them and their families, and that do not require the involuntary displacement of local populations.

SA also believes that over time the average greenhouse gas savings attributed to fuels produced will improve and that the average greenhouse gas savings will increase as more carbon capture technology becomes integrated into sustainable aviation fuel production plants. Members of SA are pursuing a number of sustainable fuel projects, details of which can be found in **Appendix 3**.

A2.6 Next steps for sustainable aviation fuels

As the sustainable fuels industry is beginning to develop a growing number of companies are gaining formal sustainability certification for the production of their fuel. A body of knowledge on best practice in terms of producing feedstocks and converting these into fuel will also develop. Both of these are expected to increase customer, investor and stakeholder confidence that future fuels are genuinely sustainable. In conclusion, SA members are fully committed to only deploying alternative fuels that meet the highest sustainability standards.

APPENDIX 3: DEVELOPMENT AND CERTIFICATION OF SUSTAINABLE AVIATION FUELS



APPENDIX 3: DEVELOPMENT AND CERTIFICATION OF SUSTAINABLE AVIATION FUELS

At a glance

- There are six production pathways (including a fast-track approval approach) that have obtained aviation fuel specification approval as acceptable processes to produce fuels that can be blended with fossil fuels. Other production pathways are also being assessed for potential use in aviation
- The UK also certifies aviation fuels through the Ministry of Defence. It has an important role in maintaining the long-term technical authority and ownership of these standards to sustain, improve and modify the specification to enable sustainable fuel use in Europe
- Presently aviation fuels are rarely integrated into new advanced fuels research programmes and this needs to be addressed. There may be opportunities to improve the capacity and capability to test new fuels at lower cost
- Integrating the UK's efforts to develop new advanced fuels would deliver synergies across sectors. Bilateral agreements between governments and industry also have the potential to improve efficiency of advanced fuels developments
- We recommend that a Code of Practice be established to ensure that new fuel suppliers are able to meet the stringent quality and safety standards associated with the production and handling of certified aviation fuel
- Access to distribution systems will need to be permitted in future as a greater supply of synthetic fuels enters UK pipelines, storage and handling systems. There are still barriers to overcome in this area
- The zero rating of fuels under the EU Emissions Trading Scheme (ETS) provides a modest incentive for aviation fuels (whereby eligible credits are valued at approximately €70/tonne of fuel.) Guidance allowing purchase-based accounting is welcome and mirrors the purchase-based accounting method used for the CORSIA. We believe this is a pragmatic approach to accounting for third party purchases of biofuels

A3.1 Drop-in fuels

The reason for the use of drop-in fuels is to ensure the safe operation of flights, for which specific limits are placed on fuel properties and requirements for fuel quality. Fuels made from new production pathways have additional requirements, e.g. blending ratios with fossil fuel, to ensure that the resultant fuel properties are consistent with the historical experience of existing aviation fuels. This allows them to be used in existing aircraft without modification.

Any new sustainable fuel has to be certified as being equivalent to either DEF STAN 91-091 JET A1 or ASTM D1655 JET A/A1 in order to qualify for use in the existing aircraft fleet. Complete re-certification of the aircraft would be required to use any other form of aviation fuel or fuel blend outside these limits. That is why approval of new fuels has focussed on replicating the properties of fossil fuel and testing has mostly been designed to demonstrate "no harm" to airframe or engine systems.

A primary reason for the blending requirement is because sustainable aviation fuels do not contain aromatic hydrocarbons. Aromatic hydrocarbons ensure the safe performance of the entire aircraft and engine fuel system, and also ensure fluid property requirements are met. An example of that is the effect on the fuel quantity gauging indication (FQI) systems that has to be considered. Aircraft FQI systems depend on inherent properties (e.g. viscosity) and relationships found in fossil fuel. If fuels do not exhibit similar properties to fossil fuels, the fuel indication provided to the flight crew could be inaccurate. Fuels also have to ensure the correct fuel flow to the engines in all operating conditions. Therefore, the properties must be consistent with existing aircraft performance requirements.

There is also a range of additional issues which need to be safely managed before using new sustainable fuels for fuel systems, including lubricity levels due to the lack of sulphur in sustainable fuels and the impact of the lack of aromatic compounds on the seals.

Limits vary depending on the production process and vary from 10% to a maximum of 50% blend. For the technical reasons outlined above, a blend needs to have an aromatics content of at least 8.4%. Since FT, HEFA and SIP based fuels have no aromatics content, the fossil fuel needs to have an aromatics content of at least 16.8% to permit 50% blending for HEFA and FT fuels. In practice, much of the fossil fuel produced in Europe has an aromatics content below that figure.

APPENDIX 3: DEVELOPMENT AND CERTIFICATION OF SUSTAINABLE AVIATION FUELS

A3.1 Drop-in fuels (continued)

Given the small volumes of sustainable fuel currently being produced, this blending limit does not constitute a near-term barrier to scaling-up the use of this fuel. The eventual aim is to develop 100% sustainable "drop-in" fuels which do not require blending with fossil fuel. This may be achieved through introduction of synthetically produced aromatic compounds – which can be produced sustainably or by completely removing the need for aromatics content in fuel through redesigning aircraft fuel systems and engines. Demonstration flights using 100% fuel have been completed, demonstrating the potential for these greater blends in the future.

Engine and airframe manufacturers are working to understand the impact on engines and airframes of sustainable fuels where the fuel composition and/or properties deviate from conventional fossil fuel, and to determine to what degree specifications for these fuels can be acceptably extended to facilitate the increased use of sustainable fuels. On-going work focuses on:

- Increasing proportions of already approved HEFA and FT fuels beyond 50% blend mix with fossil fuel
- Exploring and approving new feedstock's and processes
- More radical changes to engines/airframe that might be possible with the introduction of an optimised synthetic fuel
- Producing synthetic aromatic compounds which can be blended with sustainable fuel, or be co-produced as part of a new fuel process

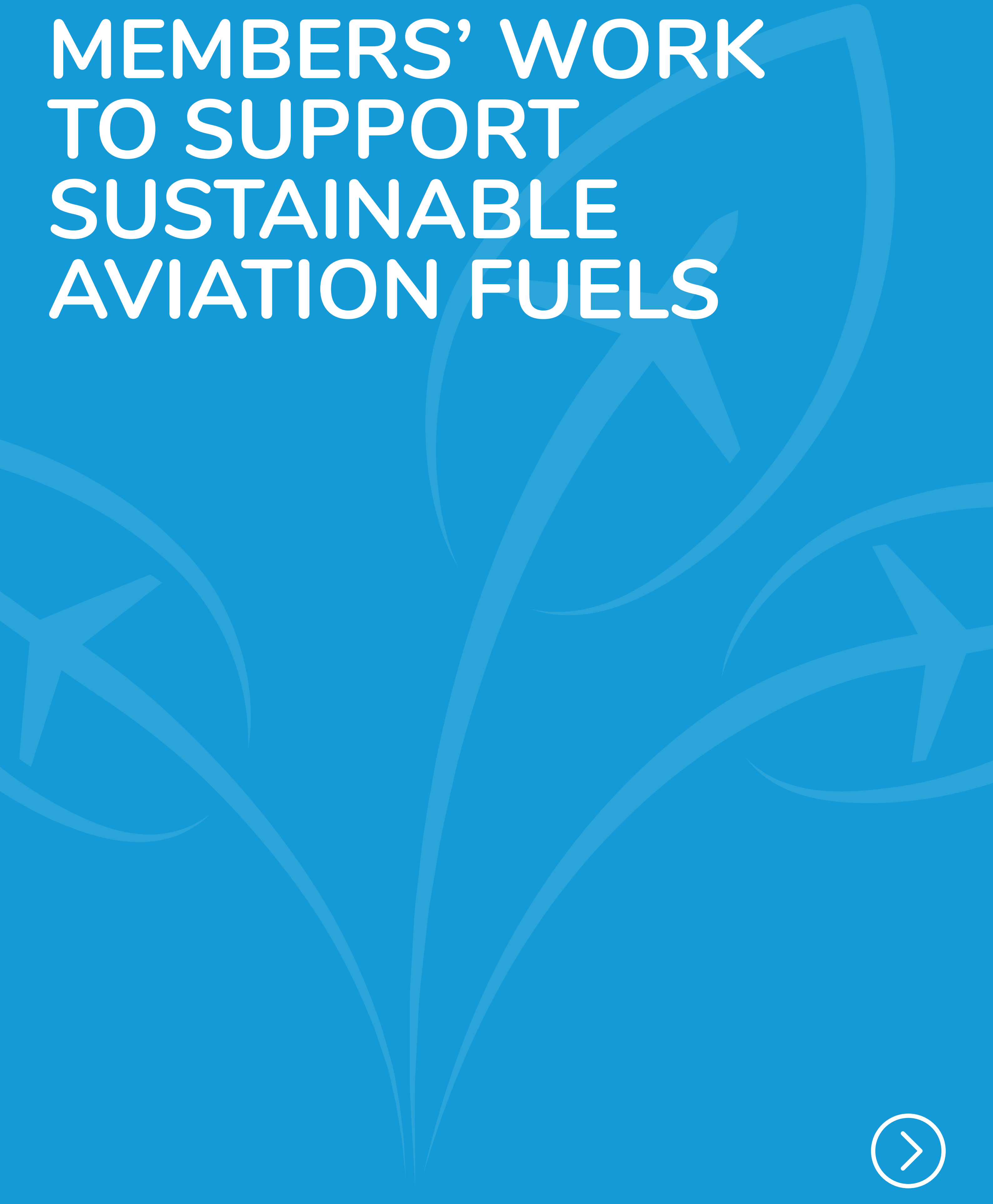
SA members have worked on a number of these other technology pathways. For example, Rolls-Royce and British Airways have collaborated as part of the FAA funded CLEEN programme, to test a number of new fuels containing synthetic aromatic compounds. The objective is to understand the suitability and functional performance of these fuels. Some of them have different mixes of hydrocarbons to fossil fuel or other aviation fuels already certified. As these fuels and aromatic components are still at a low Fuels Readiness Level (FRL)[63], a significant amount of testing is required by all stakeholders in the ASTM process prior to these fuels being approved for commercial use.

Many of the technologies under development are able to use waste materials, waste gases or agricultural residues and many are feedstock flexible. The potential environmental and energy security benefits of this work are considerable.

A3.2 Conclusions

- For the medium term, drop-in sustainable fuels must be the priority for current and planned sustainable fuels
- There are some challenges associated with introducing sustainable fuels into the existing fuel delivery infrastructure
- Current ways to account for the use of sustainable fuels present some challenges and SA has made specific recommendations to Government in this area to enable future growth in use of sustainable fuels

APPENDIX 4: SA MEMBERS’ WORK TO SUPPORT SUSTAINABLE AVIATION FUELS



APPENDIX 4: SA MEMBERS' WORK TO SUPPORT SUSTAINABLE AVIATION FUELS

Sustainable Aviation (SA) members are at the forefront of developing sustainable aviation fuels. This chapter sets out some case studies of that work by British Airways (IAG), Virgin Atlantic, Airbus and Boeing.

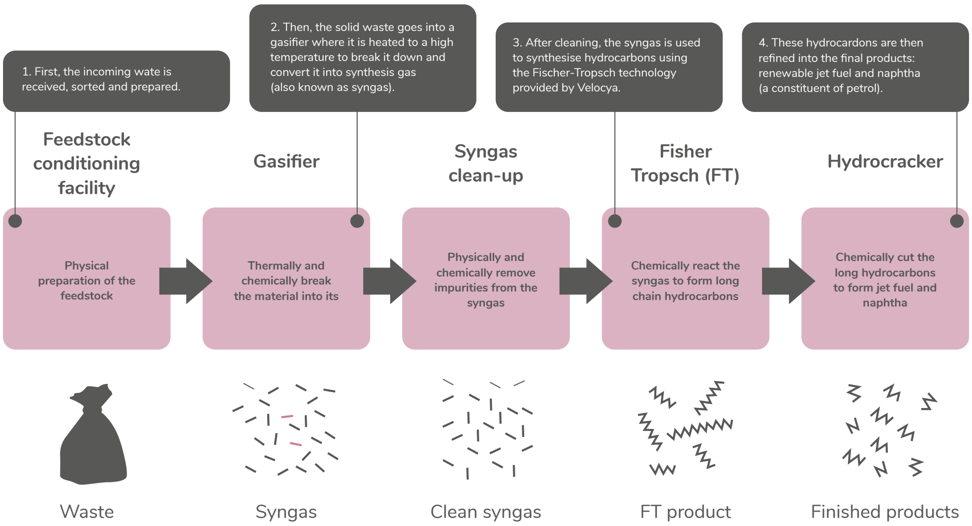
A4.1 British Airways and International Airlines Group

In 2019, International Airlines Group (IAG) committed to achieving net zero emissions by 2050 with Flightpath Net Zero. IAG is first airline group worldwide to commit to such a target and ensure gradual steps are taken until 2050. For example, by 2030 they have a target to reduce net CO_2 emissions by 20% and by 2025 there is a target for 10% reduction per passenger kilometre. The Flightpath Net Zero initiative is aligned with the United Nations' objective to limit global warming to 1.5 degrees and contributes to the UK government's goal of a net zero carbon economy by 2050. Coinciding with this initiative, IAG airline British Airways will carbon offset emissions for all its UK domestic flights, making them net zero carbon from 2020.

IAG has committed $400m to the development of new sustainable fuel supply chains. British Airways' (BA) flagship project as part of this is to construct an advanced fuels facility that will annually convert around 500,000 tonnes of household and office waste left over after recycling into a number of sustainable low-carbon fuels – including aviation fuel. This waste would otherwise be destined for landfill and incineration. The project, Altalto[64], is a collaborative project between BA, Velocys and Shell. The new plant will be sited at Immingham in north-east Lincolnshire on what is currently vacant land surrounded by existing industrial buildings.

The fuel production process is fundamentally different to incineration: instead of being burnt (with energy recovery in the form of electricity), the carbon in the waste is converted into a fuel for use in aircraft or vehicles. While converting waste to electricity can be valuable, there are many low-carbon methods to make electricity other than waste-to-energy. Given that it is difficult to produce sustainable jet fuel and that using waste is one of the very few economic ways of doing so, it is therefore a far better use of household waste than incineration.

The process consists of several stages



The annual production of fuels from the facility results in a net reduction of CO_2 of over 80,000 tonnes per year, equivalent to taking over 50,000 cars off the road. Furthermore, by avoiding 500,000 tonnes per year of non-recyclable waste going to landfill is equivalent to taking more than another 50,000 cards off the road. This fuel produced equates to a 70% greenhouse gas reduction for each tonne of fossil jet fuel that it displaces, 90% reduction in particulate matter, and 100% reduction in sulphur dioxide.

APPENDIX 4: SA MEMBERS' WORK TO SUPPORT SUSTAINABLE AVIATION FUELS

A4.1 British Airways and International Airlines Group (continued)

Alongside the noted environmental benefits, the development will bring significant social benefits and will also help establish North East Lincolnshire as an international hub in what is expected to be a global market for sustainable aviation fuels. The technology is carbon-capture-ready meaning that when suitable policies are introduced to support CCS, the project can readily be adapted with the potential to create negative emission greenhouse gas savings.

A4.2 Virgin Atlantic

In 2008, Virgin Atlantic was the first airline to conduct a 'biofuel' test flight on a commercial aircraft – a ground-breaking move that challenged the belief it was not possible to fly commercial aircraft on a biofuel blend. Then, in October 2011, following a detailed market review, Virgin announced their partnership with LanzaTech – with the aim of securing advanced, waste-based affordable jet fuels with the highest possible sustainability standards.

LanzaTech's approach recycles waste carbon-rich gases (and other over-abundant waste streams) to produce ethanol, from which a range of low-carbon products, including jet fuel, can be made. Their primary technology captures waste CO gases from heavy industrial facilities (like steel mills and refineries) before it is flared into the atmosphere as greenhouse gas CO_2 (or used much less efficiently for ground heat or power, where there are better, carbon-free, renewable options). LanzaTech's jet fuel has no land, food or water competition issues and at least 70% reduction in Life Cycle Analysis (LCA) carbon emissions compared with incumbent fossil jet fuel.

LanzaTech estimates that its process could apply to 65% of the world's steel mills, offering scope to provide up to 19% of the world's current aviation fuel demand. The process is also expected to improve local air quality in the vicinity of steel plants by reducing emissions of nitrogen oxide and other particulate emissions.

Since partnering with Virgin Atlantic in 2011, LanzaTech has gone from pilot to demonstration to commercial-scale ethanol production and has secured funding for five commercial ethanol plants, in China, Belgium, US, India and South Africa. First commercial ethanol production started in China in May 2018.

Waste ethanol-derived alcohol to-jet (ATJ) is now being scaled too: the first significant batch was produced in 2016 (1,500 USG); US Department of Energy funding was awarded in 2016 to design US demonstration plant; and in 2018, UK Department for Transport funding was secured to scope out UK sites for the world's first commercial jet fuel plant.

In April 2018, ASTM International added ethanol as an approved feedstock for alcohol-to-jet synthetic paraffinic kerosene (SPK) which means that it can now be used on commercial flights. As a result, in October 2018 Virgin Atlantic flew the world's first flight from Orlando to London Gatwick[65], using fuel made from this ground-breaking carbon capture and utilisation (CCU) approach, clearly demonstrating this pioneering waste-based fuel is now ready to commercialise.

However, in the UK, this technology is locked out of the Renewable Transport Fuels Obligation (RTFO) because of the origin of waste carbon molecules (fossil carbon molecules coming from the chemical reagent used to make steel). Such exclusion also applies to other critical advanced approaches like those using excess plastic waste (after all reductions and recycling has taken place) and air capture CO_2 fuels. Should this technology be included in the RTFO, the world's first full-scale CCU-to-jet plant could be running as soon as the early 2020s, with others following soon after, enabling production of 100 million gallons per year (enough to fly all Virgin Atlantic's UK outbound 2018 flights as a 50:50 mix).

Virgin Atlantic is keen to drive this and other advanced fuel developments to help kick start a whole new sustainable aviation fuel market: to provide UK airlines with affordable fuels with carbon savings upwards of 70%, that can be bought and flown routinely – helping to turn the aviation carbon challenge into a huge clean growth opportunity for the UK.[66]

A4.3 Airbus

Airbus has a global strategy for a global solution[67], which is focused around three central principles:

1. To support certification and qualification of new sustainable fuel pathways, to ensure compatibility with Airbus product policy
    - Support qualification campaigns, support and promote fuel certification within International aviation bodies
    - Anticipate new evolutions of fuels within future designs
    - Ensure new fuels satisfy all quality and safety standards
2. To support the aviation market as well as innovation and local partnerships all around the world
3. To support policy and standard making bodies, to promote sustainable fuels for aviation and align with Airbus product policy

A4.3 Airbus (continued)

Airbus's strategy is managed around the world through partnerships and research projects:

China

In 2012, Airbus launched its collaboration with Tsinghua University in China to complete a sustainability analysis of Chinese feedstocks and to evaluate how best to support the development of a Chinese value chain to speed up the commercialization of sustainable fuels. With the Final Assembly Line (FAL) at Tianjin there is future opportunity for delivery flights on sustainable fuels.

Canada

A Perfect Flight was completed by Airbus and Air Canada, bringing together all best practices including operational, maintenance, air traffic management and the use of sustainable aviation fuels to achieve an over 40% reduction in CO_2 emissions on a commercial flight from Toronto to Mexico City.

Following the successful partnership with Air Canada, Airbus launched an initiative with BioFuelNet Canada and Air Canada to assess solutions in Canada for the production of sustainable fuels for the Canadian aviation market. At Mirabel in Canada Airbus manufactures the A220 and has the potential for delivery flights on sustainable fuels in the future.

Europe

EU

At European Union level, Airbus is works closely with the European Commission. The ITAKA (Initiative Towards sustAinable Kerosene for Aviation) project aimed to contribute to the short-term (2015) EU Flightpath. The overarching objectives were to drive the development of EU policies which resulted in the review and updating of the Renewable Energy Directive (RED).

France

Airbus collaborated with Air France, Total and CFM to perform a demonstration flight (French initiative "Joining our Energies") at Le Bourget Air Show using an Airbus A321 with fuel-efficient Sharklets and Sustainable A-1 sustainable SIP aviation fuel from Total/ Amyris produced through an innovative conversion of sugar (Farnasane).).

Airbus was the first manufacture to offer sustainable aviation fuels for every delivery flight of new aircraft. This started from the Toulouse base with successful deliveries of A321, A330 & A350 to a variety of customers. This includes China Southern Airlines, Cathay Pacific, Japan Airlines, Delta Airlines, Air France & ATR with the latest being Air France's first A350.

Airbus is a key signatory to Demeter which is an industry and government collaboration for the promotion, development and implementation of sustainable transport solutions, including aviation fuels.

Germany

In collaboration with AIREG, Airbus is working to develop and industrialise fuel made from renewable electricity and direct captured carbon, known as Power-to-Liquids. Airbus has an Algae research facility in Ottobrunn, in collaboration with the German government. With the Final Assembly Line at Hamburg there is future opportunity for delivery flights on sustainable fuels.

Airbus is continuing to investigate opportunities to use sustainable aviation fuels and two potential areas have been identified: flight test operations and Beluga flights. Initial sustainability and life-cycle analysis are being undertaken with a view to future flights.

United Kingdom

With the UK being the centre of excellence for Fuel Systems, the primary focus is certification of new fuels and future fuel opportunities. Collaborations with UK universities ensure the quality and safety of fuels to be used in aircraft are maintained. New fuels projects to investigate materials impact such as Jetscreen and emissions characterisation are managed from the UK. Further collaborations are happening but as yet these are not in the public domain.

Airbus believes a key element of the development of sustainable fuels for aviation is political support and frameworks to ensure optimization, financial investment and development of sustainable fuels in an economically, socially and environmentally sustainable manner while improving the readiness of existing technology and infrastructures.

Malaysia

Airbus established a Malaysian Centre of Excellence to assess local solutions for sustainable biomass production in Malaysia. The aim is to determine the most suitable feedstocks to ensure that any future aviation fuel production in the region is based only on sustainable solutions.

APPENDIX 4: SA MEMBERS' WORK TO SUPPORT SUSTAINABLE AVIATION FUELS

A4.3 Airbus (continued)

Russia

Further collaborations launched included a cooperation agreement between Airbus and Rostec group in Russia to launch a large-scale analysis of Russian feedstock and to evaluate how to speed up the development and commercialisation of sustainable aviation fuels in the region.

United States

From the Mobile Final Assembly Line, Airbus have successfully delivered A320neo aircraft to Delta Airlines using sustainable aviation fuels with future deliveries in 2020.[68]

A4.4 Boeing

Boeing's sustainable fuel activities

As part of Boeing's commitment to protect the environment and support the long-term sustainable growth of the aerospace industry, they are leading industry efforts worldwide to develop and commercialize sustainable aviation fuels, which emits 50 to 80 percent less CO_2 on a life-cycle basis than fossil fuel.

The primary benefit of using biofuel in a commercial jetliner is its ability to reduce greenhouse gases throughout the entire life cycle of the fuel—from the growth cycle of the fuel source, when the natural process of photosynthesis absorbs CO_2 from the air, to its use in an engine, when it improves the environmental performance of commercial aviation and aircraft that are flying today.

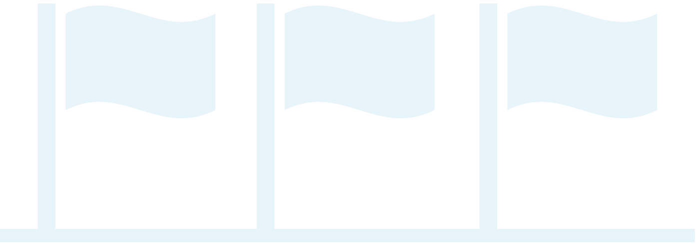
Boeing works aggressively with customers, research institutions, governments, and other stakeholders to identify and develop sustainable feedstocks and approve new fuel pathways that will expand aviation biofuel supplies globally and regionally. Boeing have active biofuel development projects on six continents, including in the United States, Europe, China, Japan, Middle East, Southeast Asia, Brazil, Mexico, Southern Africa, and Australia.

Boeing's near-term goal is to contribute to accelerate initial production and use of sustainable aviation fuels by 2025 to meet 2% of the total amount of global aviation fuel demand, and they believe this goal can be met. On the long-term, their intent is to enable sufficient rate of production growth or total supply availability to enable sustainable aviation fuels to meet industry goals. In 2018, 5.5bn litres of sustainable aviation fuels were commercialised in forward purchase agreements by airlines.

In 2011, Boeing led the aviation community's efforts to include a blend of up to 50% of sustainable fuel produced through the HEFA (hydro-processed fatty acid esters and free fatty acid) process in international aviation fuel specifications ASTM D7566 and UK MoD DEF STAN 91-091. This approval was based on several years of research and testing conducted by Boeing, their customers and others throughout the aerospace industry. Since then, airlines around the world have flown more than 180.000 regularly scheduled commercial flights using a blend of fossil and sustainable fuels.

Boeing was the first to propose the direct, "drop-in" use of green diesel – a renewable diesel fuel used mainly today for truck transport – as a price-competitive sustainable aviation fuel. Green diesel or High Freeze Point Hydroprocessed Esters and Fatty Acids Synthetic Kerosene (HFP HEFA-SK) made sustainably from plant oils and waste animal fat, has production capacity of 800m gallons in the US, Europe and Asia that could supply 1% of global aviation fuel demand. Green diesel's price, including incentives from the US and other governments, is about the same (approximately US$3/gallon) as fossil fuel. Boeing is working with the US Federal Aviation Administration (FAA), engine companies, green diesel companies and other stakeholders on testing and approvals to bring this new source of sustainable fuel to fruition.

Boeing was a co-founder in 2008 of the Sustainable Aviation Fuel Users Group (SAFUG), a group of leading global airlines, industry leaders, environmental organizations and fuel technology leaders. SAFUG, which accounts for more than 32 percent of annual commercial aviation fuel use, is committed to develop sustainable fuel, without adverse impact to greenhouse gas emissions, local food security, soil, water and air. Through SAFUG, aviation became the first global transportation sector to voluntarily promote acceptance of sustainability practices into its fuel supply chain.



APPENDIX 4: SA MEMBERS' WORK TO SUPPORT SUSTAINABLE AVIATION FUELS

A4.4 Boeing (continued)

Boeing works closely with airlines, research institutions, governments and others to develop regional sustainable aviation fuel supply chains using a variety of sustainable feedstocks. Some of their efforts include:

Brazil

Boeing co-sponsored the Roadmap for Sustainable Aviation Biofuels in Brazil published in 2013. They established the Joint Research Centre for Sustainable Aviation Fuels with Embraer in 2014 to fund research and collaborate with industry partners, such as Gol Airlines. The research funding is aimed at gaps and opportunities described in the Roadmap as well as feasibility assessments for promising supply chains in different regions in Brazil. In 2018 and 2019, Boeing announced over US$1m investment in Brazil's efforts to establish a sustainable aviation fuels industry in a collaboration with Roundtable on Sustainable Biomaterials (RSB) and World Wild Fund for Nature (WWF). The investment will focus on initiatives that maximise social, economic and environmental benefits to local communities engaged in the development of feedstock that can be used to produce sustainable aviation fuels.[69]

China

Boeing collaborates with the Commercial Aircraft Corp. of China to research ways to efficiently turn waste cooking oil, often called "gutter oil," into sustainable fuel.

Ethiopia and South Africa

In addition to the project in Brazil, Boeing will work with RSB and WWF in similar project in Ethiopia and South Africa – countries identified to be of key importance given their rapidly growing commercial aviation sectors and potential to produce significant volumes of feedstocks.

South-east Asia

Boeing collaborates with the RSB to assess opportunities and challenges for smallholder farms to produce sustainable fuel feedstocks. Regional sustainable fuel efforts supported by Boeing utilise principles established by the RSB to evaluate issues such as greenhouse gas emissions, local food security, conservation, soil, water, air, and technology, inputs and waste management.

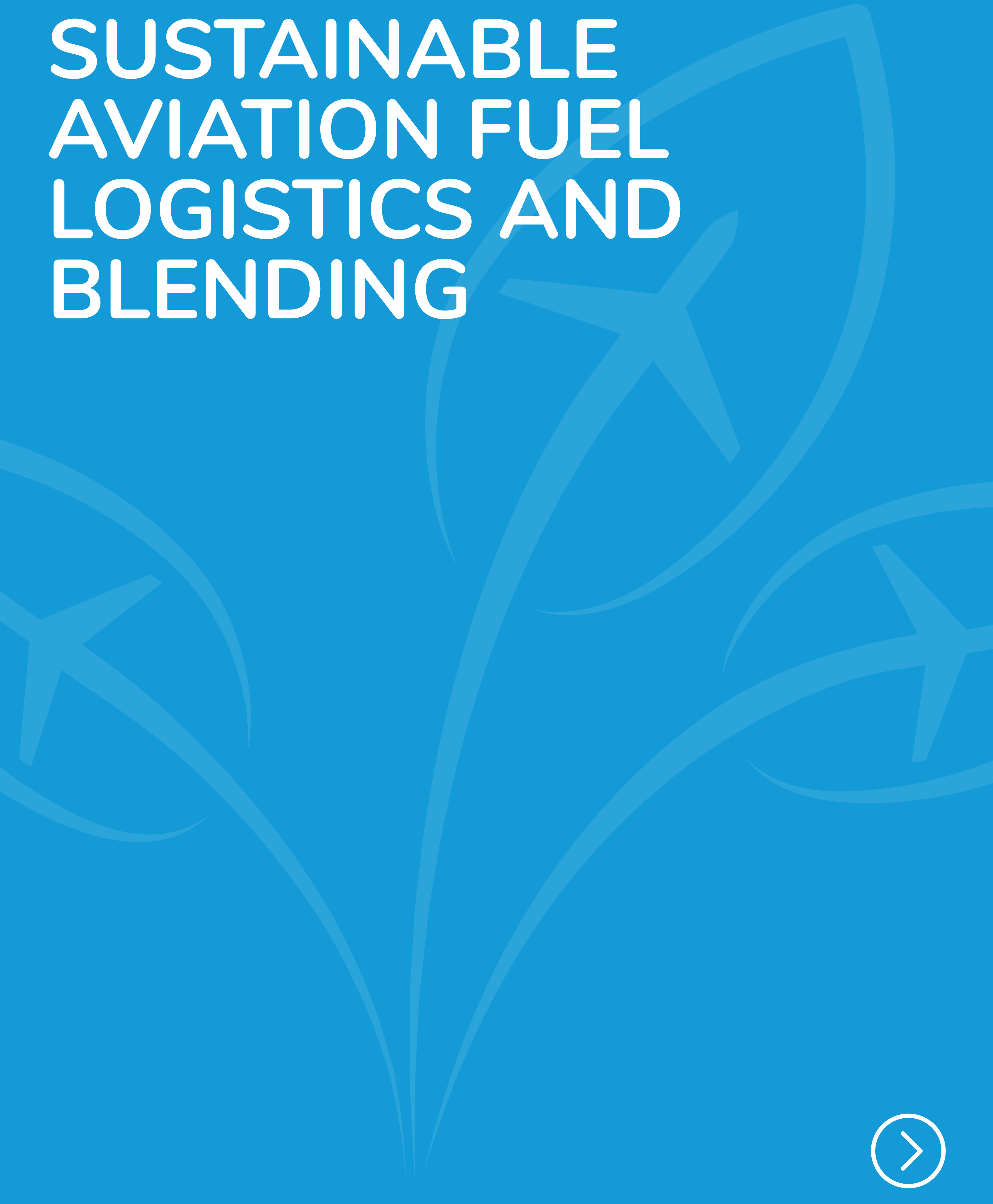
United Arab Emirates

Establishment of the Sustainable Bioenergy Research Consortium (SBRC) to prove the concept of a comprehensive value chain centred on Seawater Energy and Agriculture System (SEAS). The SEAS is the world's first desert ecosystem designed to produce fuel and food in saltwater. Fish and shrimp raised at the facility provide nutrients for the plants as well as contribute to the UAE's food production. On 15 January 2019, a Boeing 787-9 Dreamliner flight crowned a three-year research project with sustainable aviation fuels derived from oil in Salicornia plants, which were grown on the two-hectare SEAS farm in Masdar City.[70]

United States

In 2019, Boeing started to offer airlines and operators the option of powering their new commercial jet with sustainable aviation fuels for the flight home. The programme is designed to further spur the use of sustainable aviation fuels produced by World Energy at its refinery in Paramount, Calif., the world's first facility designed to commercially produce renewable jet fuel. Made from agriculture waste, the fuel is certified for commercial use and can be blended with traditional jet fuel without modifications to airplanes, engines or fuelling infrastructure. The option will be available for customers accepting new airplanes at Boeing's delivery centres in Seattle and Everett, Wash. The company also plans to use sustainable aviation fuels for certain flight tests at its Boeing Field facility, while working to offer the same option at its South Carolina Delivery Centre.

APPENDIX 5: SUSTAINABLE AVIATION FUEL LOGISTICS AND BLENDING



APPENDIX 5: SUSTAINABLE AVIATION FUEL LOGISTICS AND BLENDING

Supplying and using sustainable aviation fuels comes with a series of strict requirements and regulations. In transitioning from the existing well-established fossil fuel supply chain model to a sustainable fuel infrastructure, there will be new entrants at many of the stages: feedstock, bio-oil processing, refining, and even fuel blending partners; each may have less experience than those in the existing mature fuel supply chain. All involved need to work with the bodies listed below to ensure that procedures, standards and the parameters for fuel quality are defined, enforced and maintained:

- ASTM and DEF STAN;
- US Federal Aviation Authority (FAA) and the European Aviation Safety Agency (EASA)
- The Energy Institute (EI);
- International Air Transport Association (IATA);
- The Joint Inspection Group (JIG);
- Other relevant regulatory authorities.

In the USA, the CAAFI organisation has co-ordinated work to support the certification of sustainable fuels through a range of Department of Defence funding. This co-ordination has ensured that duplication of efforts to test new fuels have been minimised. The UK needs to provide more focus to support certification and to develop new pathways.

As with all fuel used by aircraft, sustainable aviation fuels need to meet international fuel standards, the US ASTM D1655 specification and the UK Ministry of Defence's DEF STAN 91-091. The fuel needs to be traceable and the quality assured at each step of the way. In addition to that, to prove the sustainability of the fuel, there is a further certification requirement, not least for the purposes of qualifying for emissions trading programmes, such as the EU Emissions Trading Scheme. This appendix sets out those requirements.

A5.1 Traceability and chain of custody of sustainable fuel

The requirements of DEF STAN 91-091 specification ensure fuel meets the required technical standards and that traceability of the fuel supply is present. These requirements will allow the chain of custody for sustainable fuels to be adapted in a simple manner from the general requirements that apply to all fossil fuels.

The fuel supply chain has established a Joint Inspection Group (JIG) which sets out a common set of fuel quality requirements based on the most stringent requirements of DEF STAN 91-091 and ASTM D1655. This is widely used as a common voluntary standard. As with DEF STAN 91-091, synthetic components are permitted, but "shall be reported as a percentage by volume of the total fuel in the batch". Additionally, there is an ICAO standard, ICAO997, which reflects global minimum standards.

A further requirement of DEF STAN 91-091 is that technical documents demonstrating fuel quality must accompany the product to its destination. Information relating to sustainable fuel purchases is provided to airlines by fuel producers, whose records are generally subject to audit under existing tax codes. The most common of these documents are:

- RCQ - Refinery Certificate of Quality
- COA - Certificate of Analysis
- RTC - Recertification Test Certificate

A5.1.1 Refinery Certificate of Quality

Existing purchase records and Refinery Certificates of Quality (RCQ) provide sufficient detail of batch contents to satisfy requirements on traceability and chain of custody. The RCQ is the definitive original document describing the quality of an aviation product. It contains the results of measurements, made by the product originator's laboratory, of all the properties listed in the latest issue of the relevant specification. It also provides information regarding the addition of additives, including both type and amount of any such additives. In addition, it includes details relating to the identity of the originating refinery and traceability of the product described. RCQs shall always be dated and signed by an authorised signatory.

A5.1.2 Certificate of Analysis

A Certificate of Analysis (COA) may be issued by independent inspectors and/or laboratories that are certified and accredited and contains the results of measurements made of all the properties included in the latest issue of the relevant specification. It cannot, however, include details of the additives added previously. It shall include details relating to the identity of the originating refiner and to the traceability of the product described. It shall be dated and signed by an authorised signatory. A COA shall not be treated as an RCQ.

A5.1.3 Recertification Test Certificate

The Recertification Test Certificate (RTC) demonstrates that recertification testing has been carried out to verify that the quality of the aviation fuel concerned has not changed and remains within the specification limits, for example, after transportation in ocean tankers or multiproduct pipelines, etc. Where aviation product is transferred to an installation under circumstances which could potentially result in contamination, then before further use or transfer, recertification is necessary. The RTC shall be dated and signed by an authorized representative of the laboratory carrying out the testing. The results of all recertification tests shall be checked to confirm that the specification limits are met, and no significant changes have occurred in any of the properties.

APPENDIX 5: SUSTAINABLE AVIATION FUEL LOGISTICS AND BLENDING

A5.1.4 Certificate of Sustainability

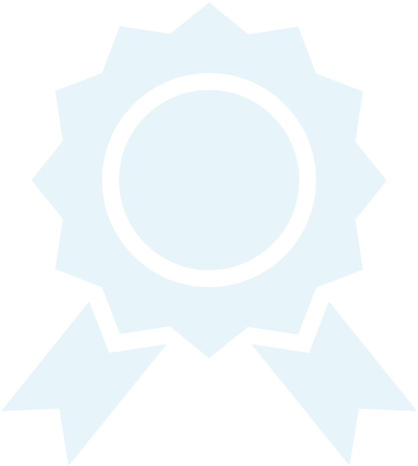
For sustainable fuel an additional Certificate of Sustainability (CoS) must be produced using an approved voluntary certification scheme. Batches of both fossil fuels and sustainable fuels, have documentation that describes their properties and accompany them to their final destination. A certificate of sustainability will be created by the certified biofuel producer, and alongside other documentation, passed along with the fuel as it is blended and transported. SA members are also members of the Sustainable Aviation Fuels Users Group (SAFUG) who are committed to strict sustainability standards such as the Roundtable on Sustainable Biomaterials; which considers social, environmental and economic impacts of fuels production. As sustainable fuels become a commoditised product, it will be necessary to design a new method for tracking fuel sustainability certificates on a global basis.

A5.1.5 Adaptations for sustainable fuels

With the exception of Certificates of Sustainability, which are not required for fossil fuel, the same certification documents apply to sustainable aviation fuel as to fossil fuel, with the following modifications:

- RCQ - sustainable fuel blend cannot be certified to ASTM D7566, ASTM D1655 or DEF STAN 91-091 until it has been blended with fossil fuel, the blend point is considered the point of batch origin, and an RCQ must be produced at this point. The RCQ is the only document that can guarantee the volume fraction of the bio-component (which, importantly, yields the mass when multiplied by the fuel density) without additional testing, and must accompany the product to point of final use. Additional sustainable fuel cannot be blended into the batch downstream to ensure that the agreed limit of (e.g. 10% or 50% v/v) is not exceeded.

The above information is necessary to apply for credit under emissions trading programs.



A5.2 Certification under ASTM and DEF STAN

The general procedure for certification under the international fuels standards DEF STAN 91-091 and ASTM D1655 is outlined below.

1. Neat synthetic component is produced to the requirements of Annex A1, A2 or A3 of Specification D7566
    - For the neat synthetic component prior to blending, test results demonstrating compliance with Annex A1 A2 or A3, and additives are listed on a separate Refinery Certificate of Quality (RCQ)
    - A certificate of sustainability (CoS), is produced for the batch, reflecting the feedstock used, geographical information, and other key product information. Note that it may be necessary for the feedstock to also carry sustainability certification
2. Neat synthetic component may be transported, and is eventually blended with fossil fuel, ensuring a homogeneous mix. The blending location is considered the point of manufacture of the blend
    - For HEFA and FT fuel the blends must contain no less than 50% by volume fossil fuel which is compliant with ASTM D1655 or DEF STAN 91-091 and of known synthetic fuel content. For SIP fuels the blends must contain no less than 90% fossil fuel which is compliant with ASTM D1655 or DEF STAN 91-091 and of known synthetic fuel content
    - If the fossil fuel already contains a portion of synthetic fuel this must be accounted for in any subsequent blending to ensure the blending ratio limit (e.g. 10% or 50% v/v) is not exceeded
    - Representative samples of the blend are tested against the primary specifications (as opposed to those in the Annex) of Specification D7566
    - Test results and additives are listed in a new RCQ
    - The RCQ must clearly display the volume percentage of each synthetic blending component along with its corresponding release Specification and Annex number, product originator and originator's RCQ number
    - RCQ should contain a statement referring to both D7566 and the agreed specification. For example: "It is certified that the samples have been tested using the Test Methods stated and the Batch represented by the samples conforms to ASTM D7566 and DEF STAN 91-091 latest editions". Or, "It is certified that the samples have been tested using the Test Methods stated and the Batch represented by the samples conforms to ASTM D7566 and ASTM D1655 latest editions"
    - A new CoS is produced for the blend, indicating the blend volume % of the synthetic component

A5.2 Certification under ASTM and DEF STAN (continued)

3. Blend is transferred to new owner along with original RCQ for the neat synthetic component (as discussed in chapter 5), RCQ for the blend, and CoS

4. Airline purchases some quantity of the synthetic fuel blend. The airline is provided with:
    - RCQ or COA of the blend, indicating percentage sustainable,
    - RCQ or COA of the neat bio-component,
    - CoS of the blend, and
    - Purchase records (bill of lading, purchase receipts, or other verifiable documentation detailing the quantities transferred)

A5.3 EU Emissions Trading System rules on aviation biofuel accounting

Under the EU's Emissions Trading System (ETS), flights within the EU are subject to emissions trading. As part of ETS, airlines can account for using sustainable aviation fuels under certain conditions, including traceability, outlined below.

1. The aircraft operator must ensure that:
    - A purchase records based system for determining sustainable feedstock is only applied where the aircraft operator can obtain reasonable assurance that the sustainable fuel purchased can be traced to its origin, thereby ensuring that sustainable fuels are not double counted in the EU ETS or any other renewable energy scheme. For this purpose, criteria for the transparency and verifiability as laid down below must be met
        - either by a sustainability scheme approved by the Commission under the RES Directive, or
        - ensured by appropriate national systems (like e.g. guarantee of origin registries), or
        - by other appropriate evidence provided by the fuel supplier(s) to the aircraft operator
    - All relevant purchase records are kept in a transparent and traceable system (database) for at least 10 years, and are made available to the EU ETS verifier, and upon request to the competent authority of the administering Member State
    - The aircraft operator sets up appropriate data flow and control procedures, which ensure that only quantities of sustainable fuels used for EU ETS flights are taken into account. For this purpose, the following shall be ensured:
    - Traceable and verifiable evidence is provided about physical sales of biofuels to third parties;
        - No double counting of biofuels shall occur. Where data gaps are found, the aircraft operator shall conservatively assume that the fuel correlating to the data gap is a fossil fuel
        - Only fuels meeting the relevant sustainability criteria are taken into account
    - The aircraft operator shall submit to the verifier together with the annual emissions report a corroborating calculation showing that the total quantity of sustainable fuels accounted for under the EU ETS for flights of the aircraft operator neither exceeds the total quantity of fuel uplifts at that aerodrome for flights covered by the EU ETS in the reporting year, nor the total quantity of sustainable fuel physically purchased minus the total quantity of sustainable fuel physically sold to third parties at this aerodrome by this aircraft operator

2. The use of laboratory analyses for determination of the sustainable biomass fraction of fuels uplifted shall be excluded where a purchase-based system for sustainable fuel determination is set up, in order to avoid double counting (as discussed in chapter 5)

APPENDIX 5: SUSTAINABLE AVIATION FUEL LOGISTICS AND BLENDING

A5.3 EU Emissions Trading System rules on aviation biofuel accounting (continued)

3. Where the aircraft operator relies on evidence from the fuel supplier(s) as mentioned under point 1.(a).iii, the aircraft operator shall request the fuel supplier to comply with the following criteria in order to allow for appropriate verification under the EU ETS:

    - Evidence on meeting the relevant sustainability criteria for each consignment of sustainable fuel must be made available by the fuel supplier to the EU ETS verifier and the competent authority upon request. Appropriate records must be kept for 10 years
    - Evidence must be provided that the total amount of sustainable fuel sold does not exceed the amount of sustainable fuel purchased and meeting the appropriate sustainability criteria. Appropriate records must be kept for 10 years
    - Where several fuel suppliers share facilities such as storage tanks for the sustainable fuel, those suppliers shall set up an appropriate system of joint record keeping
    - The system for accounting of biofuel shall be set up in a transparent way, ensuring that no double counting of sustainable fuel can occur
    - In order to minimise the administrative burden on all participants of such system, the supplier (or, where appropriate, the suppliers sharing the facilities) should ensure that the records are verified at least once per year by an accredited verifier, applying a reasonable level of assurance and a materiality threshold appropriate for the amount of sustainable fuels sold to EU ETS aircraft operators. If such verification is not performed, it is likely that the verifiers of the aircraft operators purchasing sustainable liquids each have to carry out their own verification. The result of the "centralised" verification (at the supplier) shall be communicated in written form to all aircraft operators having purchased sustainable fuels in year x, not later than 28 February of year x+1. Those communications shall be made available to the EU ETS verifier by the aircraft operator, and upon request to the competent authority of the administering Member State

A5.4 Blending/co-mingling of sustainable aviation fuels

Current fuel specifications require synthetic fuels to be blended before delivery into the fuel distribution system.[72] This imposes restrictions on supply logistics and these severely limit suppliers achieving product yield suitable for aviation fuel. They could lead to these products being used for less demanding applications.

There are, however, a growing number of airports that are now able to offer routine refuelling with a blend of sustainable fuel and there is a great potential for providing a comparatively simple, sustainable "drop-in" fuels logistics model. Supplies can be aggregated around airports to reduce fuel transportation and congestion whilst simultaneously improving air quality and reducing carbon emissions and costs.

Once blended fuels have been delivered, co-mingling occurs in pipelines, joint airport storage and distribution systems. This means the fuel actually used in an aircraft may have a lower or higher proportion of sustainable fuels than the airline purchased. What the airline purchased was a guarantee that the fuel used has been produced, rather than that it has been used fully by them.

GLOSSARY

GLOSSARY

Useful terms

Advanced fuel	Advanced fuels are produced by more complex processing technologies that are able to process wastes, residues and other feedstock types. These successors to first generation fuels usually yield higher greenhouse gas savings and often avoid the land use concerns associated with many first generation technologies and feedstocks
Aviation fuel	Aviation fuel in use in aviation is a kerosene-type fuel, commonly referred to as Jet A-1 or Jet A. Jet A-1 is suitable for most turbine engine aircraft. It has a flash point of 38oC and a freeze point maximum of -47 oC. Jet A is only available in North America and has a higher freeze point (-40 oC)
Biofuel	The term ‘biofuel’ is generally used to describe non-fossil fuels derived from biomass, but it’s important to note that the sustainability of some of these depends on their source and processing
“drop-in” fuels	A fuel that can be used with current technology and does not require modifications to Engines or fuel supply systems
Development fuels	A ‘Development Fuel’ is a high-blend renewable fuel produced from wastes, including bio-substitute natural gas, renewable hydrogen, renewable aviation fuels and any other fuel that can be blended above 25% and still meet relevant fuel standards
Fossil fuel	General term for buried combustible geological deposits of organic materials, formed from decayed plants and animals that have been converted to coal, natural gas or crude oil by exposure to heat and pressure in the Earth’s crust over hundreds of millions of years
Jet A1	See aviation fuel above
Sustainable Aviation Fuel	Fuels that provide high greenhouse gas lifecycle savings (>60%) when compared with their fossil equivalents and can be shown through the use of a robust certification scheme that they deliver genuine sustainability benefits
Sustainable fuel	Sustainable fuel’ can be derived from biomass, but could also be derived from other sustainable sources that have a lower overall carbon footprint than fossil- or some biomass-derived fuels – such as fuels made from bio or non-bio waste streams
Synthetic aromatic	A manufactured aromatic hydrocarbon product, i.e. one that contains alternating single and double bonds between carbons. The simplest form of which is known as a benzene ring with six carbon and six hydrogen atoms. Some aromatic compounds in jet fuel contain more complex fused benzene compounds
Synthetic fuel	A manufactured hydrocarbon product which is chemically similar to the fossil equivalent that can be substituted for or mixed with other aviation fuels. It may or may not be produced from sustainable feedstock.

GLOSSARY

Useful acronyms

ASTM	American Society for Testing and Material International
ATAG	Air Transport Action Group
ATJ	Alcohol to jet technology
BtL	Biomass to liquid technology
CAAFI	Commercial Aviation Alternative Fuels Initiative
CCC	UK Committee on Climate Change
CH	Catalytic Hydrothermolysis
CLEEN	US Federal Aviation Authority's CLEEN is the Continuous Lower Energy, Emissions and Noise Programme
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CtL	Coal to liquid technology
DEF STAN	UK Defence Standard
DOD	US Department of Defence
EASA	European Aviation Safety Agency
EI	Energy Institute (Petroleum Industry professional body)
EPFL	Ecole Polytechnique Fédérale de Lausanne
EU RED	EU Renewable Energy Directive
FAA	US Government's Federal Aviation Administration
FQI	Fuel Quantity Indication
FT	Fischer Tropsch (processing pathway for sustainable fuels)
GBP	Pound Sterling
GDP	Gross Domestic Product
GHG	Greenhouse gas
GtL	Gas to liquid technology
GVA	Gross value added
HDCJ	Hydro treated depolymerized cellulosic jet

GLOSSARY

Useful acronyms

HEFA	Hydrogenation of esters and fatty acids
IATA	International Air Transport Association
ILUC	Indirect Land Use Change
ISEAL Alliance	International Social and Environmental Accreditation and Labelling Alliance – the global association for sustainability standards
JIG	Joint Inspection Group (petroleum industry grouping of companies that jointly operate many international airport fuel facilities)
LCA	Life Cycle Analysis
MBMs	Market based measures
NATS	The UK's National Air Traffic Service
NNFCC	The National Non Food Crops Centre is a leading international consultancy with expertise on the conversion of biomass to bioenergy, biofuels and bio based products
RSB	Roundtable on Sustainable Biomaterials
SA	Sustainable Aviation
SAFSIG	Sustainable Aviation Fuels Special Interest Group
SAK	Synthetic Aromatic Kerosene
SIP	Synthesized Iso-Parafinic (fuel)
SK	Synthetic Kerosene
SPK	Synthetic Paraffinic Kerosene
UCO	Used Cooking Oil
WWF	World Wide Fund for Nature

FOOTNOTES

FOOTNOTES

1 International Air Transport Association, The Importance of Air Transport to United Kingdom (2019), <https://www.iata.org/publications/economics/Reports/voa country reports/2019/IATA_United_Kingdom_Report.pdf>

2 Sustainable aviation fuels must provide high greenhouse gas lifecycle savings (>60%) when compared with their fossil equivalents and show through the use of a robust certification scheme that they deliver genuine sustainability benefits.

3 A Statement by the Chief Technology Officers of seven of the world’s major aviation manufacturers (Paris: 2019), <https://www.globenewswire.com/news-release/2019/06/18/1870056/0/en/The-Sustainability-of-Aviation-A-Statement-by-the-Chief-Technology-Officers-of-seven-of-the-world-s-major-aviation-manufacturers.html> [accessed November 2019]

4 Aviation CO_2 emissions reductions from the use of alternative jet fuels (March 2018), Energy Policy Volume 114, Pages 342-354 https://www.sciencedirect.com/science/article/pii/S0301421517308224

5 International Coalition for Sustainable Aviation (ICSA) (September 2019) https://www.icao.int/Meetings/A40/Documents/WP/wp_561_en.pdf

6 Roundtable on Sustainable Biomaterials https://rsb.org/

7 Including Gevo plant in Texas, USA; and Lanzatech Freedom Pines plant in Georgia, USA (https://www.energy.gov/eere/bioenergy/articles/beto-funded-technology-produces-jet-fuel-virgin-atlantic)

8 Innovative Production of Synthetic Fuels, <http://ekobenz.com/production-plant> [accessed November 2019]

9 Including Lanzatech (https://www.process-worldwide.com/lanzatech-wins-bid-for-worlds-first-large-scale-atj-facility-a-731473/) and Swedish Biofuels (https://cordis.europa.eu/project/rcn/197830/factsheet/en)

10 http://fulcrum-bioenergy.com/facilities/

11 https://www.redrockbio.com/lakeview-site.html

12 https://www.greenaironline.com/news.php?viewStory=263

13 https://ec.europa.eu/energy/sites/ener/files/documents/29_laxmi_narasimhan-ih2_advocacy_lead.pdf

14 Brotas 1 plant. https://www.dsm.com/corporate/media/informationcenter-news/2017/11/51-17-dsm-expands-strategic-alliance-with-amyris-and-acquires-brazilian-production-facility-from-amyris.html

15 The Brotas 2 plant will produce speciality products, and Sao Martinho plant will focus on sweeteners (https://www.rubbernews.com/article/20180108/NEWS/180109953/dsm-expands-alliance-with-amyris)

16 https://bioenergyinternational.com/biofuels-oils/sunfire-build-8-000-tonne-per-annum-power-liquid-facility-norway

17 For the purposes of this study, ‘other thermochemical routes’ refers to aqueous phase reforming and hydrothermal liquefaction

18 https://www.statkraft.com/about-statkraft/Projects/norway/silva-green-fuel/

19 Limit is 5% by volume of refinery input, whereas for other biojet fuels the blend limit is in terms of biojet blending percentage in fossil kerosene

20 Fuel Qualification’, Commercial Aviation Alternative Fuels Initiative, <http://www.caafi.org/focus_areas/fuel_qualification.html> [accessed November 2019]

21 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons (ASTM D7566-19), (West Conshohocken, PA: ASTM International, 2019)

FOOTNOTES

22 Sustainable aviation fuel production capacity has been estimated from total plant production capacity, using the ‘aviation optimised’ product slates described in Chapter 3 if actual data was not available on plant aviation fuel output.

23 O.M. Larson, Aviation Biofuels at Oslo Airport (presentation given at ICAO seminar on alternative fuels) (2017) <https://www.icao.int/Meetings/altfuels17/Documents/Olav%20Mosvold%20Larsen%20-%20Avinor.pdf> [accessed November 2019]

24 Air BP and BP Ventures announce investment of $30 million in biojet producer Fulcrum (Emerald Media, 2016) <https://www.emeraldmedia.co.uk/5/news/1857/air-bp-and-bp-ventures-announce-investment-of-30-million-in-biojet-producer-fulcrum> [accessed November 2019]

25 Lefteris Karagiannopoulos and Terje Solsvik, Norway will make airlines use more environmentally friendly fuel from 2020 (Oslo: Reuters, 4 October 2018) <https://www.reuters.com/article/us-norway-biofuels/norway-will-make-airlines-use-more-environmentally-friendly-fuel-from-2020-idUSKCN1ME25U> [accessed November 2019

26 In the B2DS scenario “technology improvements and deployment are pushed to their maximum practicable limits across the energy system in order to achieve net-zero emissions by 2060 and to stay net zero or below thereafter, without requiring unforeseen technology breakthroughs or limiting economic growth”.

27 Market Report Series: Renewables 2018 (Paris: International Energy Agency, 2018)

28 Proposed ICAO vision on aviation alternative fuels (Montreal: International Civil Aviation Organization, 2017) [Adopted at the Conference on Aviation and Alternative Fuels held in Mexico City, 11-13 October 2017]

29 Energy Technology Perspectives 2017, (Paris: International Energy Agency, 2017)

30 Based on anticipated 2035 global jet fuel consumption of 382,700 ktonnes/year (ETP 2017, RTS scenario)

31 IEA (2019) Biofuels for Transport, Available from: https://www.iea.org/tcep/transport/biofuels/ Based on an estimated UK 2035 kerosene annual demand of 12,200 kt from DfT projections

32 For the “Other Thermochemical” route the average nameplate capacity between APR and HTL was assumed (80 kt/yr).

33 Based on approximate total investment cost of typical commercial-scale plant of £300m

34 Sustainable Fuels UK Road-Map (Sustainable Aviation, 2014)

35 missing footnote

36 Innovation outlook: Advanced liquid biofuels (International Renewable Energy Agency, 2016)

37 Sierk de Jong, et al., ‘Life-cycle analysis of greenhouse gas emissions from renewable jet fuel production’, Biotechnolo Biofuels 10(64) (2017)

38 Directive (EU) 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) [2018] OJ L328/82

39 Biomass in a low-carbon economy (London: Committee on Climate Change, 2018)

40 Directive (EU) 2018/2001

41 Sustainable aviation CO_2 Road-Map (Sustainable Aviation, 2016)

42 Sustainable Fuels UK Road-Map (Sustainable Aviation, 2014)

FOOTNOTES

[43] Velocys' Bayou Fuels project set to produce negative emission fuels after signing CCUS agreement with Oxy Low Carbon Ventures (Velocys, 2019) https://www.velocys.com/2019/10/10/negative-emission-fuel-agreement/

[44] MSW figures presented here refer to total volume of MSW, not just biogenic MSW, when in fact many processes can operate on all three of these feedstocks so the total demand on ligno-cellulosic feedstocks is most relevant to give here.

[45] The percentage demands on some feedstocks appear higher, but this was based on an assumed feedstock split for the thermochemical processes between agricultural residues, forestry residues and missing word here?

[46] The value of two development RTFCs is used because a qualifying fuel made from wastes and residues qualifies for two development RTFCs. Department for Transport, Renewable Transport Fuel Obligation (RTFO) guidance: Year 11 (London, 2018)

[47] Office for National Statistics, Labour productivity measures from the Annual Business Survey: 2006 to 2015 (2017) <https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/articles/labourproductivitymeasuresfromtheannualbusinesssurvey/2006to2015> [accessed November 2019]

[48] No displacement effects are taken into account for the purpose of these calculations.

[49] The Committee on Climate Change has been clear that critical to success in reducing carbon emissions from aviation are partnerships between industry with the UK Government, through both the Aviation Strategy and other relevant Government strategies. In its recent 'Net Zero' report5 the Committee on Climate Change states that: "clear leadership is needed, right across Government, with delivery in partnership with businesses and communities ... Policies must be fully funded and implemented coherently across all sectors of the economy to drive the necessary innovation, market development and consumer take-up of low-carbon technologies, and to positively influence societal change ... Emissions reduction cannot be left to BEIS and Defra or to the Treasury". It adds that "Policies must be fully funded and implemented coherently across all sectors of the economy to drive the necessary innovation, market development and consumer take-up of low-carbon technologies". SA fully agrees with this assessment, which is why we place such emphasis on the importance of the UK Government recognising the strategic importance of sustainable aviation fuels and the benefits of a new Office for Sustainable Aviation Fuels, including representation from BEIS, DfT, HM Treasury and Defra, to act as an convener and enabler of what remains a nascent industry, but one with huge environmental and economic potential for the UK.

[50] Sierk de Jong, et al., 'Life-cycle analysis of greenhouse gas emissions from renewable jet fuel production', Biotechnolo Biofuels 10(64) (2017)

[51] Innovation outlook: Advanced liquid biofuels (International Renewable Energy Agency, 2016)

[52] Directive (EU) 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) [2018] OJ L328/82

[53] Patrick Schmidt, et al., 'Power-to-liquids as Renewable Fuel Option for Aviation: A review', Chemie Ingnieur Technik 90(1-2) (2018) pp. 127-140

[54] Wasted: Europe's Untapped Resource (European Climate Foundation, 2014)

[55] This is a technical potential calculated on the basis of feedstock potential and assumes no limit in terms of conversion capacity.

[56] Low Carbon Innovation Coordination Group, Technology Innovation Needs Assessment - Bioenergy Summary Report (LCICG, 2012)

[57] Science and Technology Select Committee, Waste or resource? Stimulating a bioeconomy, 6 March 2014, HL 141 2013-14

[58] J. van de Staaij et al., The Low Indirect Impact Biofuels Methodology (LIIB, 2012)

[59] Low ILUC Risk Biomass Criteria and Compliance Indicators (Geneva: Roundtable for Sustainable Biomaterials, 2015)

FOOTNOTES

60	Commission Delegated Regulation (EU) …/… of 13 March 2019 supplementing Directive (EU) 2018/2001 as regards the determination of high indirect land-use change-risk feedstock for which a significant expansion of the production area into land with high carbon stock is observed and the certification of low indirect landuse change-risk biofuels, bioliquids and biomass fuels [2019] C(2019) 2055
61	Methodology for Displacement Emissions (Geneva: Roundtable for Sustainable Biomaterials, 2018)
62	Fuels Progress Paper (Sustainable Aviation, 2013)
63	CAAFI (2014) Fuel Readiness Level. [Online]. Available from: http://www.caafi.org/information/fuelreadinesstools.html#FRL
64	For more information visit: https://www.altalto.com/
65	See https://blog.virginatlantic.com/virgin-atlantic-and-lanzatech-celebrate-as-revolutionary-sustainable-fuel-project-takes-flight/
66	For more information, visit www.virginatlantic.com/changeisintheair
67	For more information visit: https://www.airbus.com/search.html?q=Sustainable+fuels or https://youtu.be/7gNTGRy4qY8
68	See https://youtu.be/UM1xW0KseKg
69	For more information visit: https://boeing.mediaroom.com/news-releases-statements?item=130450
70	For more information visit: https://www.boeing.com/features/2019/01/biofuel-flight-etihad-01-19.page
71	For more information, see http://www.safug.org/
72	See Chapter 2, Table 2 on p. for details on the constraints set on blending under ASTM D1655 and Appendix 3 for the technical reasons for these blending limits.

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