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Sustainable Fuels UK Road-Map

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Sustainable Aviation would like to thank our following members for leading the contribution to this document:

Additionally Sustainable Aviation would like to thank our following members for contributing financially to this work:

Summary

Sustainable fuels have the potential to play an important role in achieving the UK's ambition to reduce carbon emissions from transport. This Road Map aims to identify and forecast the potential for sustainable fuel production to 2050. Its specific objectives are:

ENVIRONMENT — ***To highlight the potential contribution that sustainable fuels can make to supporting the decarbonisation of the UK economy;***

ECONOMIC — ***To explore the potential for job creation and economic growth in the sustainable fuels sector;***

GOVERNMENT — ***To call for support from the UK Government to develop a shared vision for sustainable fuels.***

Global development in the sustainable fuels market is progressing rapidly with those at the vanguard of new technology reaping the economic benefits of early investment into commercialising fuels.

The UK should 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.

Environment

Sustainable Aviation (SA) is committed to the development of sustainable fuels that meet strict technical approvals, significantly reduce life cycle greenhouse gas (GHG) emissions over fossil fuel, meet stringent sustainability standards and avoid direct and Indirect Land Use Change (ILUC).

The 2012 SA CO_2 Road-Map developed initial estimates of the impact of sustainable fuels to UK aviation. This Road-Map takes that initial analysis a stage further, with new independent research undertaken by sustainable energy consultants E4tech.

This analysis has shown that the use of sustainable fuels in the UK can contribute to a reduction in CO_2 emissions of up to 24% by 2050 for the aviation sector. However, achieving this result will require a step change in Government policy and investment frameworks.

Economic

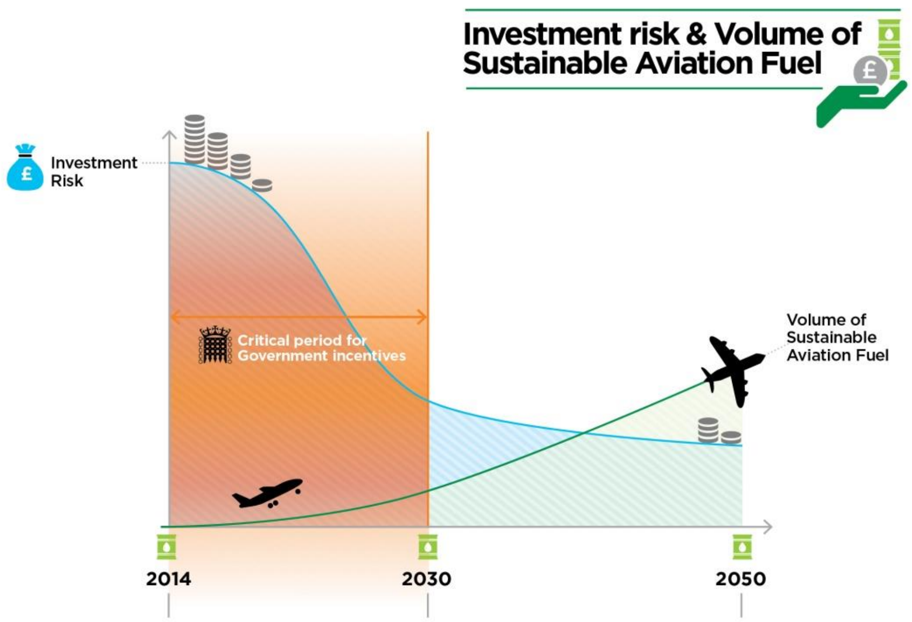
The UK's aerospace and aviation industries are important contributors to the UK economy. The UK has the largest aerospace sector in Europe and UK aviation provides £50 billion to the UK economy and around a million jobs.

If the UK can succeed in capitalising on the emerging sustainable fuels market, the benefits to economic growth and high value employment could be significant.

Scenario analysis estimates that in 2030 there may be 90-160 operational sustainable fuel plants globally, producing aviation fuels in combination with other fuels and products. Global revenue for these sustainable fuel plants is estimated to be £8-17 billion in 2030.

Development of a domestic industry for the production of sustainable fuels could generate a **Gross Value Added (GVA) of up to £265 million in 2030 and support up 3,400 jobs.** A further 1,000 jobs could be generated in global exports.

Many of these novel technologies fail in the transition from development to commercial scale production. This study outlines the need for support for the growth of early stage technologies in the critical period to 2030. The ability of the sector to decarbonise post 2030 will be curtailed without this support.



Enabling Sustainable Fuels Production by De-Risking Investment

Government

Industry is rising to the challenge. SA members are currently committed to developing a number of sustainable fuel initiatives. Success of these and future projects is dependent on SA continuing to work with the Government to create a shared vision for sustainable fuels. **SA recommends the establishment of a public–private sector initiative to progress this shared vision**.

Long-term policy stability and financial support for the scaling-up and rollout of sustainable fuel production capacity will also be needed. We therefore recommend:

LEVEL PLAYING FIELD

Allowing sustainable fuel producers to claim Renewable Transport Fuels Obligation certificates in line with road transport fuels;

FINANCE SUPPORT

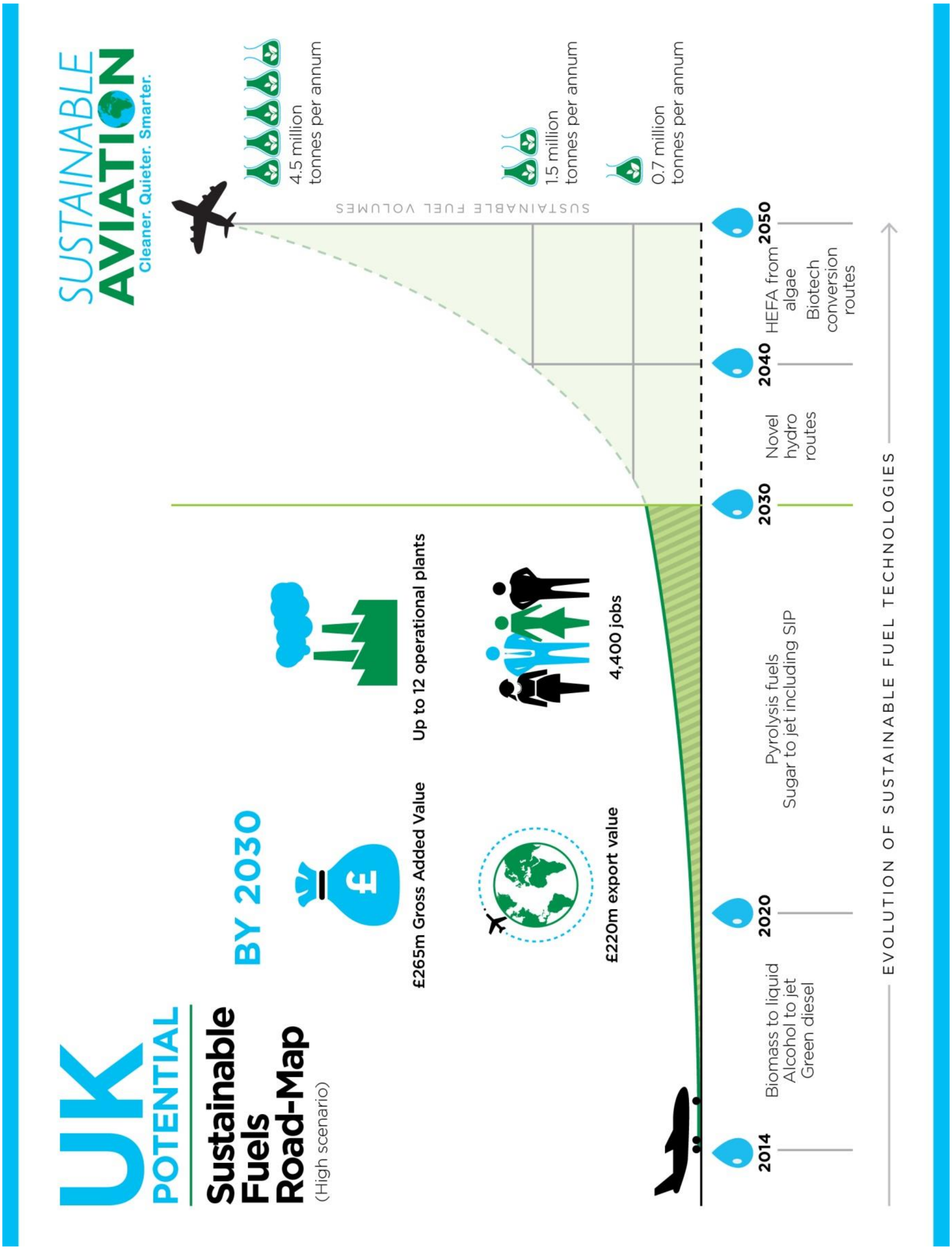
The financing of projects through existing institutions such as the Green Investment Bank, which involves the Government underwriting risk at different development stages;

R&D

That priority should be given to dedicated research and development (R&D) into sustainable fuels. Some countries are already providing R&D support for new feedstock sources and processing technologies to reduce fuel cost.

SA welcomes the Department for Transport's £25 million grant for demonstration scale advanced fuel plants as a positive first step. If the UK is to lead innovation and development of advanced fuels technology and to be an exporter, rather than importer of these technologies, a more focused approach to sustainable fuels will be required to build on the UK's competitive advantage in relevant areas of science and technology.

A stylised chart summarising the work of this Road-Map is shown on the next page.


UK
POTENTIAL
Sustainable Fuels Road-Map
(High scenario)
BY 2030
£265m Gross Added Value
Up to 12 operational plants
£220m export value
4,400 jobs
SUSTAINABLE AVIATION
Cleaner. Quieter. Smarter.
4.5 million tonnes per annum
1.5 million tonnes per annum
0.7 million tonnes per annum
SUSTAINABLE FUEL VOLUMES
2014
2020
2030
2040
2050
Biomass to liquid
Alcohol to jet
Green diesel
Pyrolysis fuels
Sugar to jet including SIP
Novel hydro routes
HEFA from algae
Biotech conversion routes
EVOLUTION OF SUSTAINABLE FUEL TECHNOLOGIES

Contents

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 of sustainable fuels usually yield higher greenhouse gas savings and often avoid the land use concerns associated with many first generation technologies and feedstocks.
Aviation fuel	Current aviation fuel 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 38^{o}C and a freeze point maximum of -47 ^{o}C. Jet A is only available in North America and has a higher freeze point (-40 ^{o}C).
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 can vary significantly depending on their source and processing.
"drop-in" fuels	A Fuel that can be used with current aircraft and engine technology and does not require modifications to aircraft engines and fuel systems and ground supply infrastructure.
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.
Low carbon fuel	Fuels that provide high greenhouse gas lifecycle savings (>60%) when compared with their fossil equivalents.
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.

Useful acronyms

ASTM	ASTM International. Previously known as American Society for Testing and Material. Owner of the major Jet fuel specifications ASTM D1655, ASTM D7566, ASTM D4054.
ATAG	Air Transport Action Group
ATJ	'Alcohol to jet' technology
BtL	Biomass to liquid technology
CAA	UK Civil Aviation Authority
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
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 owner of many industry standards an soon to be custodian of the DEF STAN 91-91 specification)
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
HDCJ	Hydro treated depolymerized cellulosic jet
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
SAK	Synthetic Aromatic Kerosene
SIP	Synthesized Iso-Paraffinic (fuel)
SK	Synthetic Kerosene
SPK	Synthetic Paraffinic Kerosene
UCO	Used Cooking Oil
WWF	World Wildlife Fund for Nature

Chapter 1

Introduction

Sustainable Aviation is committed to the development of sustainable solutions for the aviation sector.

1.1 Sustainable Aviation

Sustainable Aviation (SA) is committed to working collaboratively to accelerate the development and commercialisation of advanced sustainable fuels in the UK. Aviation fuels are most efficiently produced alongside other high value products such as advanced diesel and other bio-chemicals.

SA was launched in 2005 and brings together the main players from UK airlines, airports, manufacturers and air navigation service providers. SA has established a long term strategy that sets out the collective approach of UK aviation to tackling the challenge of ensuring a sustainable future for our industry. The aerospace and aviation sectors make a vital contribution to the UK economy (the economic benefits of the sector are provided in Appendix 1).

In 2012, Sustainable Aviation published its Carbon Dioxide (CO_2) Road-Map, setting out our combined view that UK aviation is able to accommodate significant growth to 2050 without a substantial increase in absolute CO_2 emissions. We also support the reduction of net CO_2 emissions to 50% of 2005 levels through internationally agreed carbon trading. This is shown in the chart below.

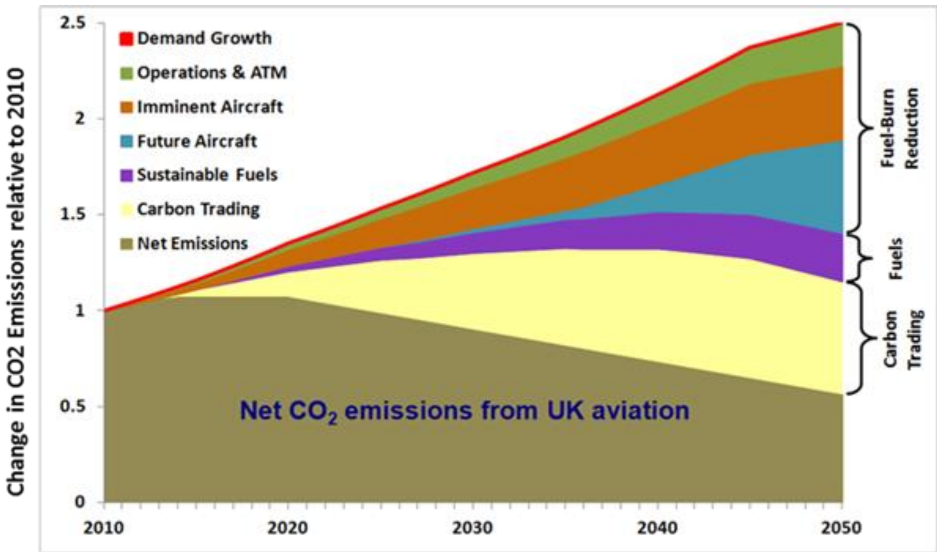


Figure 1.1 The SA CO2 Road-Map

SA estimated that by 2050 sustainable fuels will offer between 15% and 24% reduction in CO_2 emissions attributable to UK aviation. This assumption was based on a 25-40% penetration of sustainable fuels in to the global aviation fuel market, coupled with a 60% life-cycle CO_2 saving per litre of fossil fuel displaced. For the purposes of our Road-Map, we assumed an 18% reduction in CO_2 emissions from UK aviation through the use of sustainable fuels.

Progress in the development of "drop-in" fuels.

In recent years, significant technical progress has been made towards the commercialisation of sustainable alternatives to fossil fuel. Several demonstration flights have been undertaken, using '"drop-in"' solutions that replicate the characteristics of fossil fuel. Many different fuel production and conversion processes are being developed, using an array of different feedstocks including municipal waste and waste gases from heavy industry, algae, and sustainable crops i.e. those grown on non-agricultural land having no ILUC (Indirect Land Use Change) impacts and crop residues.

Following the approval, by the ASTM International fuels standards committee, of three processes for generating sustainable fuels, airlines have flown revenue flights - carrying fare paying passengers - using sustainable fuels blended with fossil fuel. Thus technically-feasible solutions already exist. However, at the moment, the market is 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 airports in the UK, and at airports for flights to the UK.

Since publishing its CO_2 Road-Map in 2012, SA has continued to review its earlier assumptions about the role of sustainable fuels in achieving an 18% reduction in total CO_2 emissions from UK departing flights by 2050. As a consequence, SA believes the time has now come to develop a more detailed assessment of the contribution from sustainable fuels, their pathway towards commercialisation, and the economic and policy conditions that would maximise this potential.

Developing this Road-Map presented some challenges as 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 is presently working at a global level to model scenarios setting out the global potential of sustainable fuels. Inevitably the technical potential for this new industry will be realised only if governments support the development of sustainable fuel supply chains.

1.2 Purpose

Outlining the opportunities for the development of sustainable low-carbon fuels.

This Sustainable Aviation Fuels Road-Map explores the opportunities for reducing UK aviation carbon emissions through the use of fuels from sustainable sources.

The Road-Map identifies the opportunities that exist to progress sustainable fuels and offers proposals on the roles that industry and the UK government can play to realise this opportunity. The aerospace industry already has experience of successful collaborative initiatives working with government to grow and promote high value technologies and jobs – SA firmly believes that this model would form a good foundation to develop a similar approach for sustainable fuels.

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 2012 SA CO_2 Road-Map;**
2. **To show the extent that UK produced sustainable aviation 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 secure government engagement and support for sustainable fuels for aviation.**

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1.3 Developing sustainable fuels process

Developing sustainable fuels requires a number of processes to come together. This is depicted in the diagram below:

Impact on aircraft systems

Figure 1.2 Elements required to deliver sustainable fuels

1.4 The need for "drop-in" fuels?

There has been great progress in the development of sustainable alternatives to fossil fuel. These new fuels are often referred to as "drop-in" fuels as they have a similar chemical composition to fossil fuels and can be completely blended with existing fuels. New fuels that meet the performance specifications (referred to as certified fuels) are able to be delivered into bulk storage and delivery systems at airports and can be used alongside fossil fuel.

The context for "drop-in" sustainable fuels.

The fact that the fuels are "drop-in" means that no modifications have to be made to existing aircraft and engines or to airport infrastructure. This innovation has led to the creation of a new generation of fuels that often deliver emissions benefits alongside sustainability benefits.

Over the longer term, both aircraft and engine manufacturers are working on new innovative propulsion systems. These include electric hybrid systems, full electric propulsion systems and the use of solar power. All these have the potential over the longer term to reduce and possibly eliminate the need for liquid hydrocarbon fuels; however, these are not likely to reach commercial production within the next thirty years. The timeframe of the Road-map, i.e. to 2050, will focus exclusively on liquid hydrocarbon fuels that can be manufactured from renewable feedstock.

1.5 Structure of this Road-Map

This Road-Map considers each of the key elements in Figure 1.2, to ensure any fuels used in aircraft are safe and meet the sustainability criteria required. SA has worked closely with E4tech who have worked at the interface between energy technology, environmental needs, and business opportunities since 1997. Last year E4tech produced an EU harmonised Auto-Fuel biofuel roadmap[1] to 2030 giving them a thorough understanding of the biofuel market. E4tech has also recently advised the UK Government on the future potential of advanced sustainable fuels.

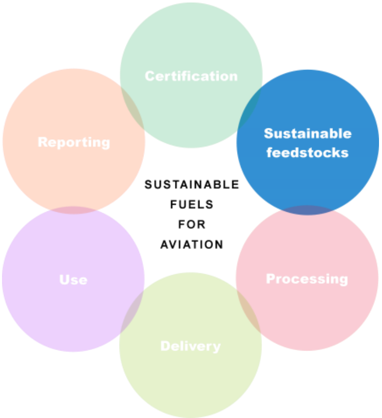
E4tech's has led the analysis of the role of sustainable fuels in the UK and globally.

E4tech has led Chapter 5 of our Road-Map which reviews current sustainable feedstocks and the processing options for the conversion of sustainable feedstocks to aviation fuels. The chapter estimates how much sustainable fuel is likely to be available for aviation, based on a range of possible future scenarios. From this E4tech has derived a view on how much sustainable fuel could be produced by 2050.

The other chapters of this Road-Map will explore the remaining elements identified in Figure 1.2. Earlier in 2014, we presented a discussion document, Fuelling the Future, outlining our initial thinking in this area. Chapter 10 of the Road-Map outlines our feedback from stakeholders, including Government policymakers, Non-Governmental Organisations (NGOs), industry and fuels experts.

The Road-Map will conclude with how much sustainable fuel could be available for aviation, with specific commitments from the aviation industry to take sustainable fuels forward and requests to Government for help in realising the potential.

[1] E4tech (2013) A Harmonised Auto-Fuel biofuel roadmap for the EU to 2030. Available from: http://www.e4tech.com/auto-fuel.html



Chapter 2

Sustainability and aviation fuels

At a glance

1. **SA supports advanced fuels production and any policy mechanisms to ensure that ILUC risk is addressed and mitigated.**

2. **The UK Government and aviation industry have a role to ensure that global aviation policy frameworks address the issue of sustainability and that sustainable fuels are incorporated into global climate change policy for aviation.**

2.1 Definition of sustainable fuels

Definition of Sustainable low carbon fuels

SA members are committed to the development of sustainable fuels that offer significantly reduced life cycle greenhouse gas (GHG) emissions over fossil fuels, including fuels that are produced from wastes, residues and non-food crops grown on degraded lands. These fuels must:

- 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;
- Not displace or compete with food crops;
- Provide a positive socio-economic impact;
- Exhibit minimal impact on biodiversity.

Fuel pathways and technologies modelled in this study by E4Tech use this definition of sustainable fuel and this is referred to more fully in section 5.1.

SA members are actively supportive of the Roundtable on Sustainable Biomaterials (RSB), widely recognised as the most robust global sustainability standard[2]. The RSB is an international, multi-stakeholder standard organisation that has developed a feedstock-and technology-neutral global standard for sustainability.

In addition to the direct impacts that can generally be measured and attributed

[2] WWF International (2013) Europe's biofuels not guaranteed sustainable, finds new study. [Online]. Available from: http://wwf.panda.org/?uNewsID=212791

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[3]. SA members have been heavily engaged with NGOs and policy-makers 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.

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 as a complement to the development of a global climate change policy for aviation.

[3] WWF International, Ecofys and EPFL (2012) *The Low Indirect Impact Biofuels (LIIB) Methodology.* Available from: http://www.ecofys.com/files/files/12-09-03-liib-methodology-version-0-july-2012.pdf

2.2 Feedstock availability and sustainability

Feedstock types and availability

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 recently published a report on the availability of cellulosic wastes and residues in the EU[4], 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[5] million tonnes of advanced fuel for all transport modes.

Some SA members are part of the ICAO international Advanced Fuels Task Force, which is currently assessing the availability of feedstock and technologies based on a 2050 timeframe. The group is also working to derive harmonised life cycle assessment methodologies.

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.[6 7]

2.3 Indirect impacts

Indirect impacts need to be addressed.

Direct impacts can generally be measured and attributed to the party that caused them. However, there is also concern that fuel production can have negative unintended consequences with the most cited examples being indirect land use change (ILUC) in which the production of newly demanded products on existing cropland displaces other agricultural activity to previously non-productive land. The possible extent of negative ILUC and the resulting GHG emissions that may occur as a result of additional demands for different crops in different regions is an issue that is a great concern to policy makers.

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[4] European Climate Foundation (2014) Wasted: Europe's Untapped Resource. Available from: http://europeanclimate.org/wp-content/uploads/2014/02/WASTED-final.pdf

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

[6] Low Carbon Innovation Coordination Group (2012) Technology Innovation Needs Assessment (TINA). Bioenergy Summary Report, Available from: www.lowcarboninnovation.co.uk/document.php?o=9

[7] Great Britain, Parliament, House of Commons (2014) Waste or resource? Stimulating a bioeconomy. London: Science and Technology Select Committee. HL 141 (2013-14). Available from: http://www.publications.parliament.uk/pa/ld201314/ldselect/ldsctech/141/141.pdf

Considerable work has been done to identify policies and practices that mitigate the risk of causing negative ILUC[8]. Members of the aviation industry have been heavily engaged in discussions with NGOs and policy-makers to ensure that the sustainable fuels they are considering using do not generate risks of having negative ILUC impacts. One major way of mitigating the risk of ILUC is through the use of feedstocks based on waste materials and residues. 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 (i.e. arable land and forestland).
- 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.

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 the key determinate of a fuel's sustainability is whether it can meet a robust independent standard which is independently audited.

Photo Copyright Boeing 2014

[8] WWF International, Ecofys and EPFL (2012) The Low Indirect Impact Biofuels (LIIB) Methodology. Available from: http://www.ecofys.com/files/files/12-09-03-liib-methodology-version-0-july-2012.pdf

2.4 Sustainability standards

The need for stringent 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.

The EU has a target of obtaining 10% of its transport fuel from renewable sources by 2020. To achieve this goal the EU Renewable Energy Directive (RED) establishes renewable energy mandates and financial incentives for eligible fuels. The RED specifies a number of sustainability criteria that fuel must meet in order to be deemed 'sustainable' within the EU.

- Minimum level of GHG emission saving of 35% compared to fossil fuels, rising to 50% from 1st January 2017, and 60% from 1st January 2018 for new plants that begin production from 2017.
- Areas of high carbon stock (wetland, forest and peat land), 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.

The EU RED is then transposed into national legislation by Member States. In the UK the RED is implemented through the Renewable Transport Fuel Obligation (RTFO). 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) earn double credits. These fuels receive twice as many RTFCs per litre. For all fuels sustainability data supplied must be independently verified by a qualified third party.

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.

As previously referenced, the premier biofuel sustainability standard is that offered by the Roundtable on Sustainable Biomaterials (RSB) – formerly the

Roundtable on Sustainable Biofuels. The RSB is an international, multi-stakeholder standard organisation that has developed a feedstock and technology-neutral global standard for sustainability. It is a fully qualified biofuels standard of the ISEAL Alliance. 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.

2.5 Aviation and sustainable fuels

SAFUG involves both airlines and aircraft manufacturers and is working to create new sustainable supply chains.

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 become members commit to consider specific sustainability criteria when sourcing 'sustainable' fuels. The Group now has 28 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[9]:

SAFUG Sustainable fuel requirements.

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.

Members of SA pursue specific sustainable fuel projects. The fuel is certified to ensure it meets robust sustainability standards. Details of specific projects that SA members are pursuing and their sustainability is provided in Appendix 2.

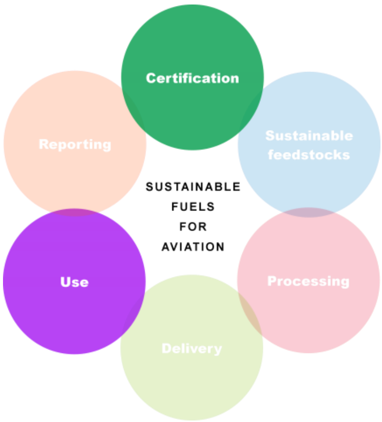
[9] Sustainable Aviation (2013) Fuels Progress Paper July 2013. Available from: http://www.sustainableaviation.co.uk/wp-content/uploads/SASFWG__-sustainable_fuels_final_doc-150713.pdf

2.6 Next steps

The number of sustainable routes to advanced fuels is increasing.

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, we at SA are fully committed to only deploying alternative fuels that meet the highest sustainability standards.

Photo Copyright Airbus 2014



Chapter 3

Development and certification of sustainable fuels for aviation

At a glance

1. **Three new production pathways have obtained aviation fuel specification approval (certification) 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.**

2. **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.**

3. **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.**

4. **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.**

This chapter explores how the aviation industry is working with other stakeholders to enable the use of sustainable fuels in aircraft. Technology and certification requirements of sustainable fuels are explored from fuel production to fuel deployment.

3.1 Safety and Certification of New Fuel Blends

Quality of fuel properties

To ensure the safe operation of flights specific limits are placed on fuel properties and requirements for fuel quality. In addition fuel 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.

Re-certification issues for new fuel

Complete re-certification of the aircraft would be required to use any other form of aviation fuel or fuel blend outside these limits: any new sustainable fuel has to be certified as being equivalent to either DEF STAN 91-91 JET A1 or ASTM D1655 JET A/A1 in order to qualify for use in the existing aircraft fleet. These sustainable fuel blends are referred to as “drop-in” fuels.

Mixing with fossil fuel

Currently any new sustainable fuel stock must be mixed with fossil fuel. Limits vary depending on the production process - from 10% to a maximum of a 50% blend. 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.

Current aviation infrastructure

As “drop-in” fuels are the most realistic and cost-effective means of reducing aviation’s contribution to carbon emissions within the foreseeable future, this is where SA has focused its efforts. The costs and nature of the current aviation infrastructure (airports, aircraft, etc.) offer few alternatives to “drop-in” fossil fuels. Conversely, the relatively limited number of fuelling locations worldwide compared to those necessary for ground transport vehicles (i.e. number of airports vs. petrol stations) offers 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.

Photo Copyright Boeing 2014

3.2 Understanding the impact of fuel on airframe fuel systems

There are a range of additional issues which need to be safely managed before using new sustainable fuels.

Impact on aircraft fuel systems

When considering the incorporation of new production pathways for "drop-in" fuels the effect on the fuel quantity gauging indication (FQI) systems has to be considered. Aircraft FQI systems depend on inherent properties (e.g. viscosity) of existing fossil fuels. 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.

Supply chain initiatives

Assessments of fuels on aircraft and airframe compatibility are part of the ASTM approval process. The Initiative towards Alternative Kerosene for Aviation (ITAKA) is a supply chain initiative launched in the EU for the production of sustainable HEFA fuels to be used regularly over a 3 year period[10]. This will permit production volumes with the ability to collect data on regular flights.

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 EU needs to provide more focus to support certification and to develop new pathways.

3.3 Ensuring fuel quality to aircraft in a complex supply chain

Ensuring quality in a novel fuels supply chain

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 with relatively less experience than those in the existing mature fuel supply chain. Airlines, engine and airframe manufacturers, and the wide number of fuel supply industry players will continue 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;
- FAA and EASA; (US and EU aviation regulatory bodies)
- The Energy Institute (EI);
- IATA;
- The Joint Inspection Group (JIG);
- Regulatory authorities.

[10] 50 Airbus flights by KLM will utilise 4,000 tonnes between 2012 and 2015

3.4 Future opportunities for sustainable fuel use

Exploring system boundaries

Activity on approving new fuels has focused on replicating the properties of fossil fuel and testing has mostly been designed to demonstrate "no harm" to airframe or engine systems.

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 feedstocks and processes.

The potential environmental and energy security benefits are considerable. SA members have worked on a number of other technology pathways[11]. Many of the technologies under development are able to use waste materials, waste gases or agricultural residues and many are feedstock flexible.

Increased blending levels of sustainable and fossil fuels

Specification limitations for "drop-in" aviation fuel blends impose restrictions on supply logistics such as requiring blending of the fuel prior to delivery to the airport. These limitations introduce more cost into the supply chain; and could lead to these products being used for less demanding applications. .

A primary reason for the requirement to blend some synthetic fuels with fossil fuel is because they 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. Experimental work is underway to further explore potential acceptable limits to reduce the proportion of fossil fuel that must be retained in the blend to deliver these performance requirements and this will allow increased use of sustainable fuels.

Ambition to achieve 100% sustainable fuel with no blending requirement

In the near term it is unlikely that the 50% blend limit will impose any real limitation for many years as the volumes of HEFA and FT fuels available are currently very low. 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.

A number of fuel suppliers are exploring processes to produce synthetic aromatic compounds which can be blended with sustainable fuel, or be co-produced as part of a new fuel process.

Rolls-Royce and British Airways have collaborated as part of the FAA funded CLEEN programme, to test a number of new fuels containing synthetic

[11] Rolls-Royce and British Airways completed studies of novel technology pathways in 2012, which are currently awaiting final approval from FAA.

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)[12], a significant amount of testing is required by all stakeholders in the ASTM process prior to these fuels being approved for commercial use.

3.5 Conclusions

The challenges faced by the aerospace manufacturers in adapting their designs to take advantage of sustainable fuels have been set out. Details of the various projects and initiatives being invested by the aviation industry have been presented alongside the strict regulatory requirements that have to be met to ensure flight safety is maintained. Evidently, '"drop-in"' sustainable fuels must be the priority for current and planned sustainable fuels.

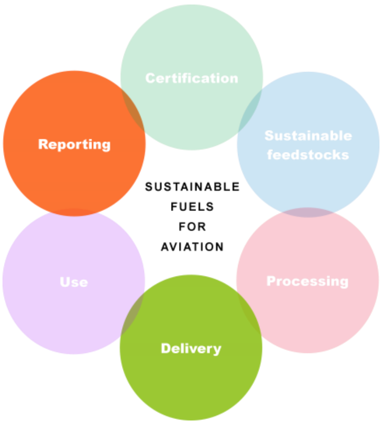
Lanzatech / Virgin Atlantic Sustainable Fuel Plant in Shanghai, China

Photo Copyright Virgin Atlantic Airways Ltd 2014

[12] CAAFI (2014) Fuel Readiness Level. [Online]. Available from: http://www.caafi.org/information/fuelreadinesstools.html#FRL

Solena Greenskies / British Airways Sustainable Fuel Plant schematic, Coryton, UK

Photo Copyright British Airways 2014



Chapter 4

Delivering and accounting for sustainable fuels

At a glance

As the fuels under development are “drop-in”, risks associated with supply and distribution are minimised. However, we expect that a variety of new suppliers will enter the advanced fuels market and these will need support to ensure that the stringent quality standards that exist for aviation fuel (Jet A1) are adhered to. Methods to account for and provide incentives for sustainable fuels must take account of the co-mingled supply chains for these fuels.

1. **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.**

2. **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.**

3. **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 16 Euro/tonne of fuel.) We welcome the recent guidance allowing purchase based accounting and recommend a pragmatic approach to accounting for third party purchases of biofuels.**

4. **If the EU RED does recognize fuels derived from fossil fuels wastes, under the definition of advanced fuels, measurement systems to account for mixed fossil/sustainable and pure fossil fuels will need to be developed.**

This chapter explores how the aviation industry is working with other stakeholders to enable the use of sustainable fuels in aircraft. Technology and certification requirements of sustainable fuels are explored from how the fuel is produced to how it is safely deployed on the aircraft.

4.1 Infrastructure and logistics

The ASTM fuels approvals process and alignment with DEF STAN 91-91

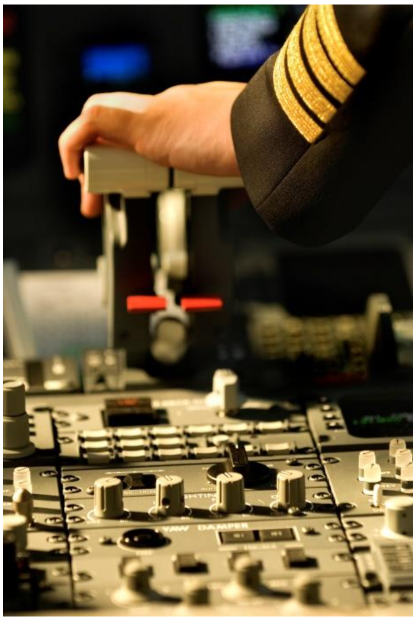
Sustainable fuel and blends with fossil fuel that are approved through the ASTM international approval process (specification D7566) are also recognized as meeting the US specification for JET A/A1 (D1655) and the UK DEF STAN 91-91 specification for JET A1. Consequently, the existing infrastructure – most importantly fuel pipelines and hydrant systems – can be used both for distribution to and fuelling at the airport.

However, existing distribution and storage infrastructure in the UK is either privately owned or controlled by the UK Ministry of Defence. This can create a barrier to entry for fuel suppliers. Present MOD standards do not allow synthetic fuels to enter MOD controlled pipelines; severely limiting the use of existing infrastructure. SA understands that the MOD is acting to address this barrier, but progress to date has been slow.

New indigenous supply of advanced fuels will add robustness and resilience to fuel supply in the UK and these fuels can play a strategic role in the UK's future fuel security. At present, around 60% of all fossil fuel is imported into the UK. There are seven UK refineries with capacity to produce aviation fuel but it is likely that UK capacity will reduce over time. It is therefore appropriate that the government plays a part in promoting the production, storage and distribution of sustainable fuel in the UK.

Appendix 4 provides a more detailed discussion around the relevant standards required to develop effective supply chain logistics for sustainable fuels.

Supply chains for aviation fuels are becoming increasingly fragmented and the growth in sustainable fuel production, often involving new entrants to the fuel supply chain, may have an impact on quality and safety. The introduction of a code of practice for fuel suppliers would give the necessary assurance that suppliers have met the required standards.



4.2 Developing sustainable fuels accounting

Accounting systems for dealing with co-mingled supply chains are needed.

Accounting systems for the use of sustainable fuel need to take account of the joint distribution of fuels. Sustainable aviation supports a "book and claim" accounting approach to ensure that airline operators can account for the greenhouse gas emission reduction benefits associated with the consumption of biofuels. "Book and claim" allows a consumer to purchase a renewable energy product, without the need to receive and use that product. This methodology removes the barrier of having to supply the fuel at specific locations and hence can reduce distribution emissions from extended supply chains. This would minimise the shipping emissions associated with the movement of large volumes of sustainable fuel and provide an efficient method to promote investment in sustainable fuel technologies.

The European Union ETS now allows purchase based accounting (this is a more stringent version of book and claim requiring proof of fuel supply to relevant airports.) Revised guidance issued in 2012[13] details the accounting methods to be used for aviation.

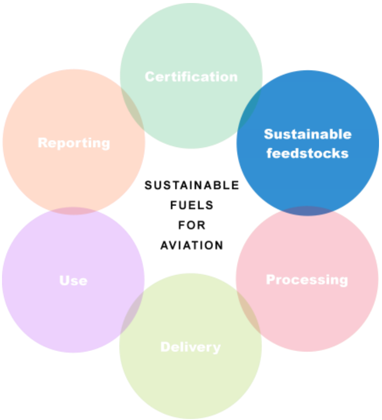
For those fuels meeting the sustainability requirements set out in the EU Renewable Energy Directive, (RED), a zero rating of emissions has been designated. Currently fuels produced from fossil waste gases are ineligible for a zero rating. Subject to these fuels being added to the RED definitions for advanced fuels, measurement and accounting methods specified will need to be amended to reflect these changes.

SA urges the UK to implement a pragmatic approach to tracking sustainable fuel purchases. Appendix 4.5 provides the full current guidance for aviation from the Monitoring Reporting Verification rules. These rules specify the data requirements for all participants in the ETS and the treatment for the accounting of sustainable fuel.

[13] European Commission (2012) Biomass issues in the EU ETS. MRR Guidance document No. 3, Final Version of 17 October 2012. Available from: http://ec.europa.eu/clima/policies/ets/monitoring/docs/g

4.3 Summary

This chapter has set out the challenges involved in 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 the use of sustainable fuels.



Chapter 5

Sustainable fuel supply potential

Rapid progress in the technological development of sustainable fuels for aviation has been made since the first sustainable fuel gained certification for commercial aviation in 2009. E4tech were appointed to estimate the potential role of sustainable fuels in achieving carbon reductions from UK departing flights[14] in the period to 2030 and to assess the role played of these fuels from 2030 to 2050.

This chapter presents E4tech's findings in estimating potential sustainable fuel production and associated CO_2 savings.

5.1 Scope

In this chapter we provide an estimate of how much sustainable fuel may be produced globally and in the UK to 2030, and the CO_2 emissions savings that may be achieved through the use of sustainable fuels. We then also estimate the volume of sustainable fuel required to meet the SA projections for 2050, and discuss the viability of these aims.

Scope and sustainability requirements for the E4tech analysis.

SA define sustainable fuels as those fuels that are produced from wastes (including the biogenic and non-biogenic fractions of post-consumer and industrial wastes), residues, and non-food crops from degraded land (avoiding food versus fuel conflicts and the impact of indirect land use change). This report therefore considers fuels fitting this definition and also additional sustainability criteria.

Due to the fuel supply infrastructure and fuel quality requirements, sustainable fuels are blended with fossil fuel. As a result, this report includes only sustainable fuels that have been or are expected to be approved as fossil fuel blending components by the relevant standardisation organisations.

The scope of the Sustainable Aviation CO_2 Road-Map includes all commercial flights departing from UK airports, and therefore the potential UK supply of sustainable fuels is presented relative to the projected fuel demand for all commercial flights departing from UK airports. At present, the majority of fuel used in flights departing from UK airports is dispensed within the UK and fossil fuel is imported to meet current UK demand. But in the case of sustainable fuels, the industry believes that in the near term, they will be used near the point of production, at least while volumes remain relatively low and prices

In the near term, we expect fuels will be used near

[14] This is consistent with UK government accounting principles and is the approach taken in previous SA Road-Maps.

the point of production.

high. In the longer term sustainable fuels may become commoditised and traded internationally as supply and demand dictates.

Our approach focuses on estimating global and UK production of sustainable fuels to 2030, and the potential CO_2 emissions savings that may be realised through their use. If the scale of ambition of the UK aviation industry to reduce CO_2 emissions remains high, and appropriate supportive mechanisms are in place, it is possible that UK aviation could access greater volumes of sustainable fuels to those produced in the UK, uplifting sustainable fuels at other airports, or importing sustainable fuels into the UK.

5.2 Approach

Approach and scenario modelling

Our approach assumes that the main constraint to the supply of sustainable fuels to 2030 is limited production capacity, due to the low levels of existing capacity and the early stage of development of the majority of technologies.

2020: sustainable fuel potential is equal to estimated UK and globally production capacity, based on an inventory of operational and planned plants, see Appendix 5.7.

2030: we assume sustainable fuels are produced by processes that have been proven at pilot scale as a minimum. Production capacity is estimated based on scenario analysis which defines plant build rates and production capacity growth between 2020 and 2030. The scenarios are defined based on the economic capacity for increased production capacity across the sustainable fuels sectors and the scale of ambition for sustainable fuels in the aviation sector. We present the following three scenarios for sustainable fuel availability to 2030:

- **Business as usual (BAU)**: Business as usual describes a situation in which continued policy uncertainty leads to low growth in sustainable fuel production capacity for all transport modes.
- **Low**: This scenario describes a future in which strong growth in the production of sustainable fuels for road transport results in availability of fuels for aviation, although aviation continues to consume only a small proportion of fuel production. This scenario may emerge from a policy framework that continues to promote the use of sustainable fuels in road transport, but where the implementation of policy to support the use of sustainable fuels in aviation is largely delayed beyond 2030[15].
- **High**: The high scenario describes an ambitious trajectory where low financial constraints result in strong growth in the production capacity for sustainable fuels, and strong market pull from the aviation sector, due to for example strong supportive policy, results in a high proportion of new capacity producing sustainable fuels.

[15] The scenario analysis found constrained growth in the production of sustainable fuels and strong demand from the aviation sector lead to a similar result

2050: we have estimated the volume of sustainable fuel required to achieve GHG emission savings of between 18% and 24%[16] in the UK, and quantified the annual growth rates required to achieve this aim.

UK aviation is not alone in its ambition to achieve carbon neutral growth, and interest in using sustainable fuels in order to achieve these ambitions. We have therefore estimated global demand for sustainable fuels based on equal international GHG emission saving targets.

Under this approach the UK's use of sustainable fuel is assumed to be proportionate to its share of the commercial aviation market. UK aviation could however play a greater role in stimulating the demand for sustainable fuels.

Photo Copyright TUI Travel Plc 2014

16 Corresponding to the central and high projections of the Sustainable Aviation CO2 Road-Map

5.3 Assumptions

Supply potential 2020

The sustainable fuel potential is based on an inventory of operational and planned plants that could produce "drop-in" fuels suitable for aviation, based on publically available information on pilot, demonstration and commercial plants. A summary of the available technologies in the near term are described in Appendix 3 and the list of present and projected capacity are given in Appendix 5.

The inventory provides an estimate of the pipeline up to 2020. However, there is uncertainty over how many plants will be successfully established due to a wide range of technical and market barriers. Individual projects have therefore been assigned a realisation potential factor based on the stage of development[17].

Total production capacity in 2020 is calculated as a function of reported plant size, potential aviation fuel fraction, and realisation potential. Where the volume of fuel is not stated, we have assumed the fossil fuel fraction is equal to the low boundary of the ranges presented in Table 5.1. For the UK, 2020 production capacity is based on planned plants and a higher estimate is based on the UK share of the commercial aviation market. In 2020, the UK share of commercial aviation is estimated by Sustainable Aviation on the basis of Revenue Passenger Kilometres at 4.8%.

Supply potential 2030

The global production capacity increase between 2020 and 2030 is calculated based on the lower and upper build rates, average plant size, and aviation fuel fraction presented in Table 5.1. Under the BAU scenario, production capacity increase is calculated as the product of the lower build rate, average plant size and lower aviation fuel fraction, summed for all technology groups. Under the low scenario, production capacity increase is calculated as the product of upper build rate, average plant size and lower aviation fuel fraction for technologies, and under the high scenario, production capacity increase is calculated as the product of the upper build rate, average plant size and upper aviation fuel fraction for all technologies. The plant build rate assumptions are based on the current technology status, historical build rates, and the number of technology providers[18].

Between 2020 and 2030, UK production capacity is estimated to grow in line with global production capacity, at average annual growth rates of between 8% and 26%. Due to there being a small number of plants, we have added an integer analysis to ensure total volumes represent full scale plants.

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[17] Operational plants and those under construction allocated a realisation factor of 1, and 0.75 is allocated to projects at the advanced stages of development; which may be indicated by site identification, planning and permits, and/or off-take agreements. Projects at earlier stages of development 0.5, and announcements which indicate an aim or interest in developing plants 0.25.
[18] E4tech (2013) A harmonised Auto-Fuel biofuel roadmap for the EU to 2030. Available from: http://www.E4tech.com/PDF/EU_Auto-Fuel-report.pdf

Table 5.1: Assumptions for global production capacity growth for each technology group (2030)

	Number of plants		Average plant size	Sustainable fuel fraction	
	Lower	Upper	Tonnes P.A.	Lower	Upper
HEFA	8	16	280,000	20%	60%
FT	12	28	124,000	20%	50%
SIP	36	67	40,000 – 115,000[a]	20%	60%
ATJ	12	52	55,000 – 155,000[b]	50%	50%
HDCJ	6	14	120,000	20%	60%

a. SIP represents a group of technologies expected to operate at different scales. We have therefore applied different assumptions on plant size under the BAU and low/high scenarios.
b. Ethanol plant sizes, the range represents different plant locations.

GHG emissions savings

The GHG emissions for each fuel type have been estimated based on reported literature values for a representative range of feedstocks. We have assumed annual improvements in lifecycle GHG emissions of 1% per year for established technologies (HEFA and FT), and 2% per annum for technologies at an earlier stage of development which may achieve greater efficiency improvements (SIP, ATJ, and HDCJ). Emission savings are calculated based on a GHG emissions factor for fossil fuel of 3.15 tCO_2eq/t.

Table 5.2: GHG emission saving estimates for each technology group (tCO_2eq/t)

	Emission savings factor 2020	Emission savings factor 2030	Emission savings factor 2050
HEFA[a]	2.9	2.9	2.8
FT	3.0	3.0	3.0
SIP	2.5	2.6	2.7
ATJ	2.3	2.5	2.6
HDCJ	2.2	2.4	2.5

a. Emissions savings for HEFA reduce to 2050 as a result of feedstock diversification. As the demand for HEFA increases beyond the supply of waste oils, growth continues based on low ILUC oil crops and microalgae.

5.4 Results

Supply potential 2020

The potential global supply of sustainable fuels for aviation is estimated at 1.3 million tonnes in 2020. This includes between 50,000 and 60,000 tonnes of UK production, and represents approximately 0.45% of total aviation fuel demand.

The prospects for the UK are largely dependent on the success of the BA/Solena plant in London. In addition, some other technologies, such as the Virgin Atlantic/Lanzatech plans to process waste gases from steel production, could also be implemented in the UK before 2020.

Supply potential to 2030 – critical ramp-up

The main focus of this study is the estimation of the potential supply of sustainable fuels up to 2030. This is estimated based on scenarios for growth which consider:

- **Economic capacity**: the capacity of the sustainable fuels industry to invest in new production capacity and to commercialise technologies at early stages of development. This determined the potential growth in production of sustainable fuels.
- **Scale of the ambition for sustainable aviation**: the market pull for sustainable fuel, which includes the scale of ambition of the industry, political focus and regulatory support for the use of sustainable fuels in aviation. This determines the volume of sustainable fuel allocated to aviation.

The purpose of the scenario analysis is to determine the range of possible futures in 2030, rather than to focus on the potential for specific technologies or products. For this reason, growth has been modelled based on five categories of sustainable fuels that may be suitable for aviation, which represent the wide range of technologies currently under development.

Global and UK potential to 2030

It is estimated that in 2030, between 3 and 13 million tonnes of sustainable fuels may be produced globally (3.6 – 16.3 billion litres). Equivalent to 0.7 – 3.3% of global aviation fuel use, and GHG emissions savings of between 8 and 35 million tonnes of CO_2 eq. This would require an average growth rate of 9-26%.

In comparison, the IEA estimate that global biofuel production increased from 16 billion litres in 2000 to more than 100 billion litres in 2010, based on commercially mature technologies, to provide 3% of total road transport fuel globally (on an energy basis). Representing an average annual growth rate of 20%, a central point between the scenarios.

In the UK, we estimate that sustainable fuel production could reach between 100,000 and 640,000 tonnes per annum in 2030. This translates to between 5 and 12 sustainable fuel plants in the UK, producing between 20% and 60% of aviation fuel in combination with road transport fuels.

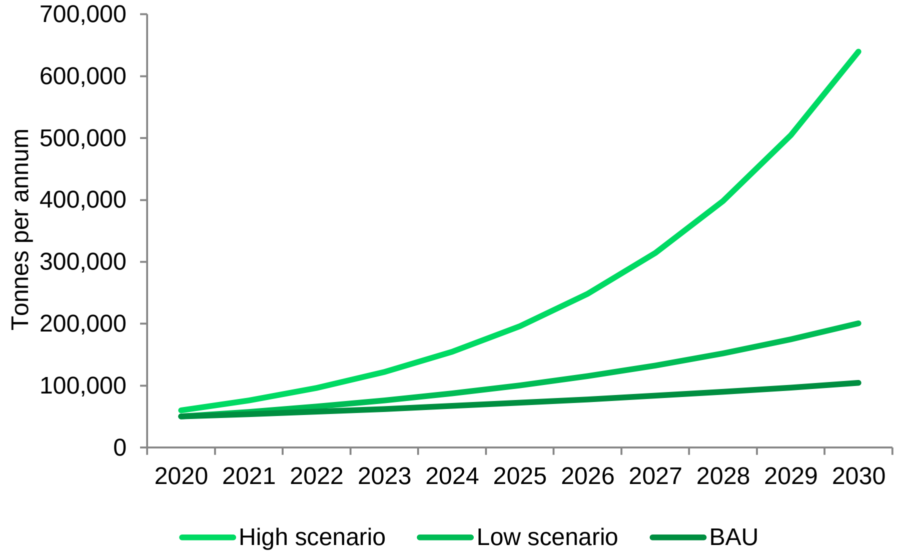


Figure 6.1 – Estimated UK sustainable fuels production to 2030 (tonnes per annum)

5.5 Trajectory to 2050 – sustained growth

Growth potential in the longer term.

In 2012, SA estimated that by 2050, sustainable fuels should offer between 15% and 24% reduction in the CO_2 emissions attributable to UK aviation, with a central scenario of 18% CO_2 emission reduction. This was based on the assumption that sustainable fuels contribute between 25% and 40% of the aviation fuel market, and achieve life-cycle CO_2 emissions savings of 60% compared to fossil fuel.

Most sustainable fuels may actually achieve GHG emission savings of between 80 and 95%, and we estimate that **the volume of sustainable fuel required to meet the SA GHG aims in the UK is between 3.3 and 4.5 million tonnes per year in 2050. International commitment to these targets would require between 140 and 190 million tonnes of sustainable fuel in 2050 (equivalent to 17% -28% of total fuel consumption).**

Linking back to the Carbon Road-Map estimates.

To achieve the high 24% GHG emissions saving target, based on the high scenario for production to 2030, would require a sustained annual growth rate of around 14% per year between 2030 and 2050. Whilst to achieve the central aim of 18% GHG emissions savings, from the low scenario for production to 2030 would require a sustained annual growth rate of 18% between 2030 and 2050.

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%. But, to achieve this level of growth, the production and use of sustainable fuel must be mainstream by 2030, having overcome technical barriers and market entry barriers. For comparison, the IEA BLUE Map Scenario estimates that global demand for sustainable fuels will reach

760 million tonnes per annum by 2050, including almost 200 million tonnes for aviation[19].

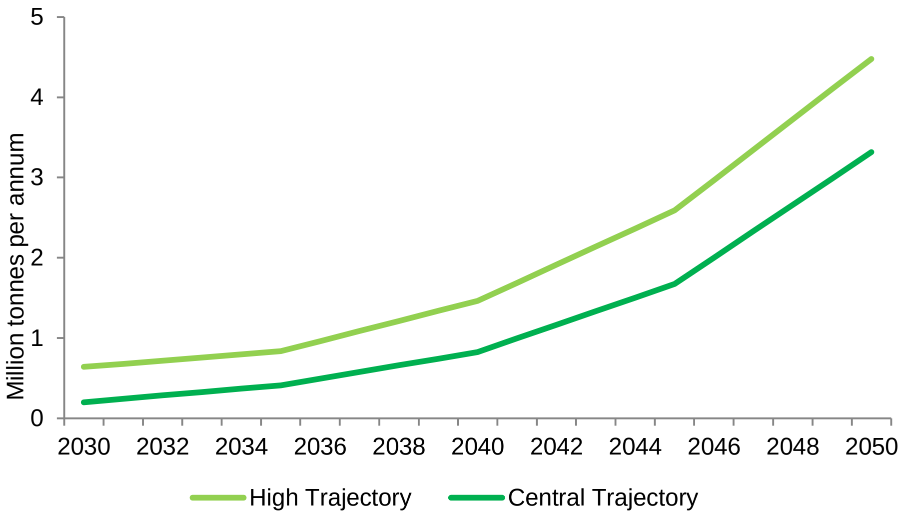
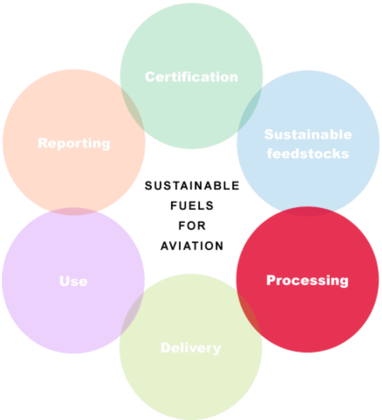


Figure 6.2 – Trajectory for UK sustainable fuel use to 2050 (million tonnes per year)

Photo Copyright Rolls-Royce 2014

[19] IEA (2011) Technology Roadmap: Biofuels for Transport. Available from: http://www.iea.org/publications/freepublications/publication/Biofuels_Roadmap_WEB.pdf



Chapter 6

Strategic thinking in sustainable energy

UK value in developing sustainable fuels

As the sustainable fuels industry grows there is potential for UK deployment to deliver revenues and support UK jobs. And also for additional economic value to be realised by UK-based businesses competing successfully in non-UK markets.

This section provides an estimate of the value to the UK of keeping pace with international deployment of sustainable fuels to 2030.

Scenario analysis estimates that in 2030 there may be 90-160 operational sustainable fuel plants globally; producing aviation fuels in combination with fuels for road transport and other modes. Global revenue for these sustainable fuel plants is estimated at £8-17 Billion in 2030.

There may be 5-12 sustainable fuel production plants producing 20-60% sustainable fuels in combination with road transport fuels in the UK by 2030. The potential value of the sustainable fuels industry to the UK is based on a methodology developed in the context of the UK Department of Energy and Climate Change's Technology Innovation Needs Assessment.[20] This assessment uses global deployment figures to estimate the potential gross value added (GVA) contribution to the UK economy for technology areas.

Economic benefits to the UK.

Turnover figures are calculated from global deployment scenarios and expected technology costs. These are then converted to GVA figures based on known turnover-to-GVA ratios for similar industries (e.g. basic manufacturing, agriculture, high tech services, etc.) which range from 10-65%. Then the proportion of the global market that might be accessible (or 'tradable') to UK based companies is estimated. Finally, the proportion of the globally accessible market that the UK can capture is estimated based on its competitive advantage. The UK's competitive advantage is graded from low to high, which is used to estimate a percentage of the available market which the UK could potentially be expected to take.

Development of a domestic industry for the production of sustainable fuels could generate a gross value added (GVA) of £70-265 Million in 2030. To realise these scenarios, the capital investment in production plant capacity

[20] Low Carbon Innovation Coordination Group (2012) Technology Innovation Needs Assessment (TINA). Bioenergy Summary Report, Available from: www.lowcarboninnovation.co.uk/document.php?o=9

required between 2020 and 2030 is estimated at £0.5-1.3 Billion. Equivalent to £50-130 Million per year.

The successful development of a domestic industry is estimated to support 900-3,400 jobs: in plant construction and operation, feedstock supply and fuel distribution, and the design and development of conversion technology components and processing plants.

The successful capture of global sustainable fuel opportunities could generate additional value for the UK. The value of global exports is estimated at £100-220 Million in 2030 with the support of 500-1,000 jobs. The majority of the value and jobs are in the supply of technology components and engineering services related to the design and development of conversion technology components and plants – since these are exportable, protectable through IP and well aligned with the UK's commercial strengths.

Figure 6.1 illustrates the total number of sustainable aviation fuel announcements made between the period 2006 to 2013 as reported by the International Civil Aviation Authority (ICAO).

The UK currently represents a 2.8% share of global sustainable fuel initiatives

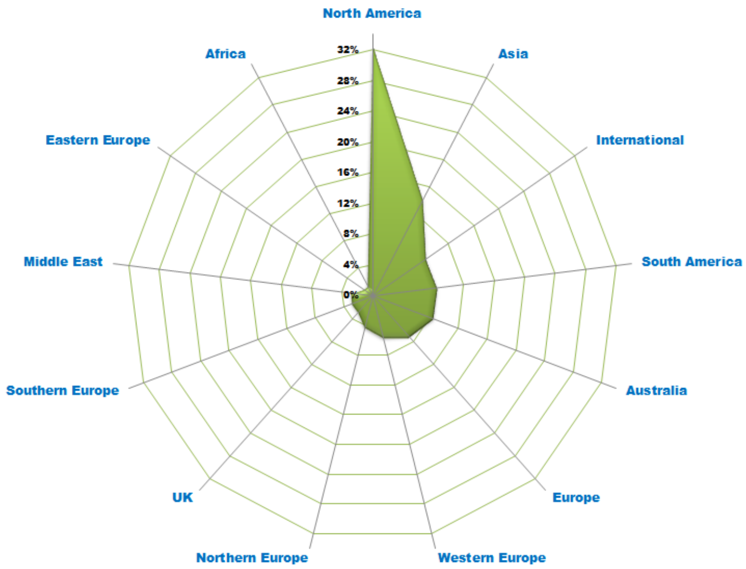


Figure 6.1 – Global sustainable fuel project announcements between 2006 and 2013[21]

[21] ICAO (2013) Synthesis of GFAAF database – December 2013. [Online]. Available from: http://www.icao.int/environmental-protection/GFAAF/scripts/Multi-stakeholders.html

Chapter 7

Overcoming development barriers

At a glance

1. **Scale up for new emerging technologies remains a challenge.**

2. **The UK should introduce coherent policy, incentives for investment, and prioritised R&D and support for commercialisation projects to realise the full potential of sustainable fuels.**

3. **Greater coordination for aviation fuels within Government and a specific focus on aviation sustainable fuels needs to be prioritised.**

4. **Long-term goals with incentivised frameworks for sustainable fuels are required to boost investor confidence and ensure the UK attracts inward investment for sustainable transport fuel projects.**

This analysis has estimated the potential contribution that sustainable fuels may make to the aviation industry. The E4tech study outlines the importance of the period to 2030 in establishing an industry for sustainable transport fuels. Realisation of the potential outlined is dependent on overcoming barriers that currently constrain the supply of sustainable fuels and the market demand or pull.

Both the central or high scenarios presented in chapter 6 require a combination of conversion technologies, which utilise a range of feedstock. These conversion technologies are at different stages of development, and therefore the Road-Map must recognise the need to overcome demand side barriers, which currently limit the volumes of sustainable fuel used in aviation; and supply side barriers that will continue in influence the production capacity and availability. This chapter outlines the most significant barriers to the increased production and use of sustainable fuels, and identifies the most pressing actions for UK Government and industrial stakeholders to enable increased uptake of sustainable fuels.

The emissions savings and economic benefits of sustainable fuels can only be realised if steps are taken to actively promote and support their development. Members of SA are playing a leadership role in accelerating the development and commercialisation of these fuels. This includes coherent policy, a level playing field, incentives for investment and prioritised R&D and support for commercialisation of projects.

7.1 Economic barriers

Early stage technologies and barriers to development

As with all emerging technologies, there are significant initial barriers to commercialisation. In the near term sustainable fuel pathways are not economic in their own right and carry with them material first-of-a-kind technological risk for investors and developers. Support is needed to reduce investor risk in bringing the technology to commercial scale, to stimulate market demand in the medium term while production costs are high, and to level the playing field with fuel incentives in other sectors. Over the long term, support can be scaled back as the fuels must become competitive without intervention.

The cost of currently available sustainable fuels are reported to be considerably higher than fossil fuel, for example HEFA (the only fuel currently produced on a commercial scale today) is reportedly 2.5 times the cost of fossil fuel. There is potential for products at an earlier stage of development to reduce production costs as production is scaled up and optimised (especially those derived from wastes/residues.) In the immediate term appropriate support mechanisms are required to enable process scale-up and optimisation, and reduce production costs.

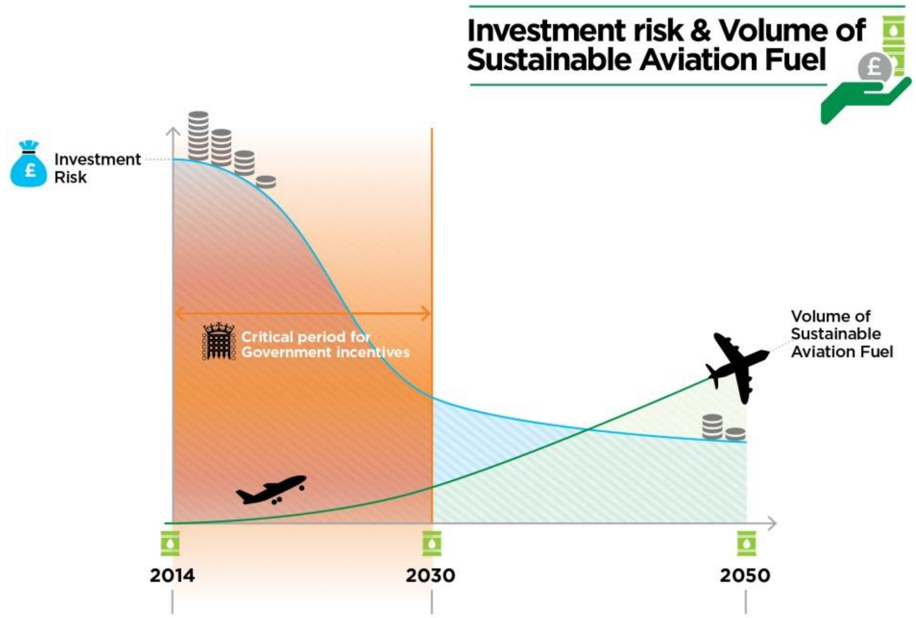


Figure 8.1 – Enabling Sustainable Fuels Production by De-Risking Investment

The aim is for these fuels to become cost competitive with fossil fuels.

Fuel costs account for 30-50% of the operating costs for the aviation industry, and the ability of airlines to absorb an increase in fuel price is very limited. Therefore, to remain an effective option, sustainable fuels must become economically viable and cost competitive over the long-term compared to fossil fuel plus carbon costs in the short-term however, before scale up occurs, a price disparity may occur and additional short-term support is required to ensure that continued development of these critical technologies is pursued.

7.2 Policy barriers

There are a number of non-economic barriers relating to factors that either prevent deployment altogether or lead to higher costs than necessary or distorted prices. These barriers may be related to a lack of, or, distortions in policy support. They can also relate to a lack of expertise in developing new technologies or a lack of public acceptance. The main barriers affecting the deployment of sustainable fuels are described here.

The strength of the market pull is of immediate importance as a number of conversion technologies are looking to progress from demonstration to commercial scale production. In the UK and across Europe policy mechanisms generally drive use of sustainable fuels in the road transport sector, as mandates and incentive mechanisms create the market for investment. Immediate action is needed to create a level playing field between aviation and other markets for sustainable fuels.

In part as a result of this inequality in policy support, aviation appears to be a low priority for UK policy makers, despite recognition at a strategic level of the long term need for sustainable fuels in aviation. Currently there is no specific focus in the Department for Transport on the role of sustainable fuels for the aviation sector. This situation creates a perception that may undermine the commitments made by the aviation industry, and lead to missed opportunities to reduce GHG emissions in transport. The Bioenergy Review[22] published by the Climate Change Committee pointed to the need to prioritise the use of bioenergy for aviation in the period to 2050.

Present policy uncertainty throughout the EU and the UK is damaging investor confidence. Without adequate targets for advanced transport fuels to 2030 investments in domestic production capacity will cease. Long-term policy certainty and a focus on instruments that de-risk investment are needed. Long-term goals for sustainable fuels together with an incentive framework to stimulate investment send an important signal to the investment community and to project developers.

7.3 Financing barriers

The supply of sustainable fuels is limited by delays in the progression of conversion technologies from demonstration to commercial production. The main barriers to development relate to project finance and risk.

Global factors have reduced the availability of various forms of project finance over the last five years. The UK banking sector is currently averse to providing debt finance to high risk projects, as the criteria and terms have typically shortened, and as a result payback hurdle rates cannot be achieved by the majority of sustainable fuels projects. Venture capital investment has also declined in Europe, as the US is currently seen as a more attractive market for investors.

The risks associated with sustainable fuel projects inherently affect the

[22] Climate Change Committee (2011) Bioenergy Review. Available at: http://archive.theccc.org.uk/aws2/Bioenergy/1463%20CCC_Bioenergy%20review_bookmarked_1.pdf

availability of project finance and the associated terms. One of the main issues impacting project risk is the price and competing uses of feedstock which can represent 50-90% of production costs, and project returns are therefore highly sensitive to feedstock price variations. Competition for feedstock with energy and non-energy sectors is likely to grow and whilst high demand will stimulate increased production of sustainable feedstock, this variability adds to project risk.

Technology push will also be important if the UK economy is to take advantage of the demand for new technologies and intellectual property. For new technologies, the scale up of production volumes and reference plant data (obtained by demonstration at scale) is necessary to reduce the risk of commercial scale development. However, securing the investment required to support these stages of development is a major barrier. The EU [23] has previously supported the development of first-of-a-kind biofuel plants through FP7, NER300 and EIBI, and will continue to do so through Horizon 2020. Experience from the NER300 call has demonstrated that successful funding applicants are still undergoing significant challenges including a lack of fuel off-take agreements. In addition, the terms associated with Horizon 2020, may limit the suitability of the scheme to leverage the level of investment needed.

7.4 Technical barriers

Fuel qualification and certification is necessary to ensure continued high levels of safety in the aviation industry. This demands high levels of investment from both airframe and engine manufacturers. To date, engine and airframe manufacturers have responded strongly to the requirement to test and approve new fuels. As a result three synthetic fuel pathways i.e. BTL, HEFA & SIP are approved under ASTM D7566, and others are in the process of approval.

Previous technical approvals of new fuels have been facilitated by a significant investment and testing done by the US Department of Defence. The budget for this work has been reduced and the engine and airframe OEMs do not have sufficient resources (funding) to do the level of testing previously supported by the US Department of Defence. This will inevitably reduce the amount of testing carried out and the availability of future fuels. This may act as an on-going barrier to the development of new fuels and conversion routes.

[23] EU has supported a number of funding instruments including the Framework Programme funding, New Entrant Reserve (NER) fund and the European Industrial Bioenergy Initiative (EIBI)

Photo Copyright Airbus 2014

Chapter 8

Enabling sustainable fuels in the UK

At a glance

1. **SA believes a specific focus on aviation fuels is needed to establish an advanced aviation fuels sector in the UK and recommends the establishment of a public-private sector initiative.**

2. **Policy equivalence with other advanced fuels is necessary to ensure investment in sustainable fuels production. In the short term this can be achieved by allowing sustainable fuels to "opt in" to the Renewable Fuels Transport Obligation.**

3. **SA welcomes the UK Government's announcement of a £25 million funding support for the development of novel advanced fuels technologies.**

4. **The military procurement policy for sustainable fuels can help de-risk the investment case – as in the case of the USA "green fleet" programme – and should be considered by the UK Government.**

5. **R&D funding programmes should prioritise technology pathways with the highest probability of reaching commercial scale and the most effective means to reduce greenhouse gas emissions.**

8.1 Policy certainty

The need for long-term stable policy for advanced fuels.

The present RTFO structure officially extends to 2020, providing project developers no policy certainty beyond this date. The policy for renewables in the EU beyond 2020 also fails to provide policy certainty. Therefore we call on the UK Government to articulate long-term goals for sustainable fuels and establish an incentive framework to stimulate investment, sending an important signal to the investment community and to project developers. Without adequate targets for advanced transport fuels to 2030 investments in domestic production capacity will cease. Long-term certainty and bankability of policy incentives are needed.

We welcome the Government's recent announcement on the appointment of a Bio Economy Champion to establish a cross-Government Steering Group. We look forward to engaging with this process and with the UK Department for Transport to develop a clear strategy to 2030 and beyond for transport fuels, including aviation. We believe that a single point of contact should be established for sustainable fuels in order to align UK Government departments, policies and action.

We recommend the establishment of a public–private sector initiative to enable sustainable fuels. The taskforce should be low cost and agile, building on the experience of existing initiatives such as CAAFI in the USA. This partnership could also enable opportunities for making direct strategic investment. We already have experience as an industry of successful collaborative programmes which have been springboards for new technology development, skills development and training.

Photo Copyright Boeing 2014

SUSTAINABLE AVIATION
Cleaner. Quieter. Smarter.

8.2 Market incentives

Policy support for aviation within the existing Renewable Transport Fuels Obligation.

The UK RTFO is a blending mandate (obligation) to fuel suppliers of road transport fuels to meet renewables commitments specified in the EU Renewable Energy Directive. The RTFO provides a market incentive to the producers of road transport fuels in the form of RTFCs, worth 200 – 300 USD per tonne of fuel. This currently has the effect of dis-incentivising investment in, and production of, sustainable aviation fuels because they are not eligible under the RTFO.

Thus we believe that aviation fuel suppliers should be eligible for market incentives in the form of Renewable Transport Fuel Certificates (RTFCs) that are currently awarded to qualifying road transport fuels under the UK Renewable Transport Fuel Obligation (RTFO), but without directly obligating them in the system. The effect of this incentive is to reduce effective production costs, providing investors and suppliers with confidence to invest and to produce the fuels when costs would otherwise have been uncompetitive.

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By extending eligibility to aviation fuel suppliers, the incentives playing field would be levelled with road fuels, without the need to extend the obligation to those suppliers. This approach is already being successfully pursued in the Netherlands and the USA. In the UK, this option could be implemented by a straightforward extension of the RTFO, with **no implications for additional costs to road fuel suppliers, road users or government.**

Achieving a level playing field with other fuels is essential.

If a mandate was applied directly to aviation fuel without consideration of market distortions, then competitive imbalance and carbon leakage[24] would result. This would happen if, for example, the UK were to impose an obligation on all aviation fuel uplifted to flights from the UK. The result would be an increase in the cost of fuel for UK based airlines above the cost faced by competitor airlines in the same markets.

Where an obligation can be applied without causing market distortions, it might be considered as a future policy option to support the development of sustainable fuel.

Whilst a zero rating for eligible fuels in the EU Emissions Trading System (EU ETS) is welcome, it only provides a very modest market incentive that does not make a material difference to investment decisions.

In the US, the Department of Defence has been playing a significant role in stimulating the development of sustainable fuels by creating market demand. The UK Government should consider how the military procurement policy for sustainable fuels can help to de-risk the investment case, as in the case of the USA “green fleet” programme for example.

[24] Carbon leakage is the term often used to describe the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries which have weaker constraints on greenhouse gas emissions. See http://ec.europa.eu/clima/policies/ets/cap/leakage/index_en.htm for details.

8.3 Investment incentives

Investment support is needed for first of a kind technologies.

SA welcomes the Department for Transport's £25 million grant for demonstration scale advanced fuel plants as a positive first step. If the UK is to lead innovation and development of advanced fuels technology and an exporter, rather than importer, a more focused approach to sustainable fuels will be required to build on the UK's competitive advantage in relevant areas of science and technology.

Development support through the provision of grants and equity co-investment are needed to reduce investor risk in funding demonstration plants. The Green Investment Bank (GIB) can play a key role in helping initial commercial scale production plants become established through the provision of financial support that reduces investor risk through for example loans and loan guarantees. At present, the GIB has a limited role in this area. Also there is no obvious source of development funding within the EU to provide development support. Even if it becomes available, in the absence of long-term policy support it is of limited use. A number of EU projects have been cancelled or delayed over concerns that there is insufficient policy support to provide a long-term market for advanced fuels.

Photo Copyright Airbus 2014

8.4 Research and development (R&D)

Research and development.

The priority given to innovation into sustainable fuels should be reviewed. R&D is being pursued around the world to demonstrate new feedstock sources and processing technologies with the aim of reducing fuel costs and broadening the range of supply chain opportunities. The pace of development has been rapid with US-based companies playing a notable role. There are significant market failures during innovation and action by the public sector been critical to advancing the sustainable fuels industry.

In the UK the government has been funding some selected cross-department work through bodies including the Research Councils, the Carbon Trust and the Centre for Process innovation (CPI) involving research into feedstocks and development of conversion technologies. Bioenergy research support has been limited but we understand that the Biotechnology and Biological Sciences Research Council (BBSRC) is seeking to provide more funding in the future. The Department for Transport has also announced its intention to issue a call for proposals for demonstration scale advanced fuel plants. However, currently none of this work is focused on the production of aviation fuels.

Pyrolysis oils and gas capture of waste carbon gases from industrial processes also have potential in the UK. In order to result in commercial solutions, funding programmes should prioritise those technology pathways that have the best chance of reaching commercial scale, by using sustainable feedstock and processes that produce scalable solutions at cost parity with fossil fuel.

A stronger innovation focus could contribute to re-balancing the UK economy through the nurturing of new businesses and the stimulation of employment and technology export opportunities. Establishing a government-industry initiative could be a key first step to developing a more focused approach.

8.5 The role of industry

The industry's commitments.

Sustainable Aviation signatories and other industrial stakeholders have key roles to play in overcoming development barriers, in particular those relating to project risk, and also project finance. Sustainable Aviation members have demonstrated the importance of effective partnerships with technology companies, and a continuation and expansion of these activities is required.

Opportunities to reduce project risk include ensuring contracts spread risk in an appropriate way across the supply chain, including Engineering Procurement Construction (EPC) services, feedstock supply contracts, and fuel off-take agreements. Airlines and airports have a role to play in establishing fuel off-take agreements. Joint purchasing agreements may have an additional benefit to fuel producers by decreasing project risk, and increasing the availability of off-take contracts (on a fuel volume basis), as it enables small airlines to participate who may otherwise find this challenging. The development of purchasing groups may provide an opportunity for fuel users to share the associated cost and risk, and to hedge the risk of higher prices.

The role of government

The sustainable aviation fuels industry is at an early stage of development and therefore strategic investors have an important role to play in providing project finance. Strategic investors may include public sector organisations and also industry stakeholders with a vested interest in sector growth. The scale of investment required for early commercial projects is large, and there will be a limited number of actors able to make such contributions to project financing. However, in the short term these strategic investments are being demonstrated as being vital to technology development.

The development of sustainable fuels requires the concerted efforts of actors across the supply chain, as demonstrated by the ASTM fuel testing programmes. Sustainable Aviation brings together the main players from UK airlines, airports, manufacturers and air navigation service providers, to set a collective approach towards ensuring the sustainable future of the industry. However, additional action is required to bring together a wider collection of stakeholders including sustainable fuel producers, researchers and representatives from UK Government to specifically focus on the issues effecting sustainable fuels and ensure the delivery of this Road-Map.

BIS, DfT and the CAA should play a central role in the interaction between the sector and government. Existing successful collaborative programmes involving BIS and the aerospace sector to the need for a public-private approach.

Chapter 9

The Sustainable Aviation fuels Road-Map

This Road-Map uses a different approach from its predecessors: CO_2 and noise. This is necessary as fuel/carbon efficiency and noise are already part of an established international regulatory regime and there is greater certainty about technology development over the period to 2050. In the case of sustainable fuels, much depends on how emerging technology deployment is supported. There is great potential for an advanced fuels industry able to meet the demands of modern aviation and to serve those other sectors dependent on liquid hydrocarbons for the medium term (e.g. freight.) ICAO has established a global Advanced Fuels Task Force to estimate the technical potential of these fuels. They are also working on the harmonisation of international sustainability standards and criteria.

9.1 The Road-Map

The opportunities for the UK

This Sustainable Aviation Fuels Road-Map has explored the opportunities for reducing UK aviation carbon emissions through the use of new and rapidly evolving, sustainable sources of fuel. There is a role for aviation in supporting the transition to more sustainable pathways using wastes, residues and low value feedstock in the short-medium term. In the longer term as more novel feedstock e.g. waste gases, algae are developed and move to larger scale production, we expect this opportunity to expand.

Applying this to the CO_2 Road-Map

Future fuels offer the opportunity to achieve high greenhouse gas savings (in the range 60-95%) over the emissions associated with fossil fuel equivalents. One aspect highlighted by the work shows the critically important role that sustainable fuels development will play in the period to 2030. Without this early policy support, the technologies needed post 2030 will not be technically proven and scale up will be slow.

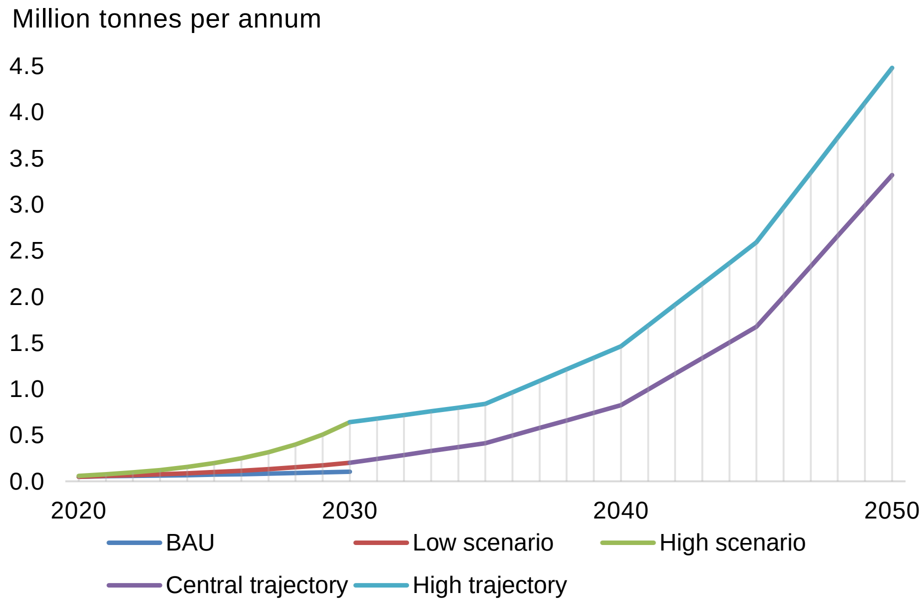


Figure 9.1 – Sustainable fuel production in UK

SA'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. It may be necessary to redraw the sections of the CO_2 Road-Map to properly reflect this. The Road-Map will need to be reviewed as new sustainable fuels pathways are constantly evolving.

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.

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	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

SA members are working on oil feedstock production models that prevent ILUC – for example Camelina production on contaminated land. If these methods are found to be successful we expect greater volumes of sustainable oil feedstock in future.

These projections are consistent with recent estimates from the International Energy Agency who predicted sustainable fuels production of 27% of transport fuels in 2050. The IEA BLUE Map Scenario estimates that global demand for sustainable fuels will reach 760 million tonnes per annum by 2050, including almost 200 million tonnes for aviation[25].

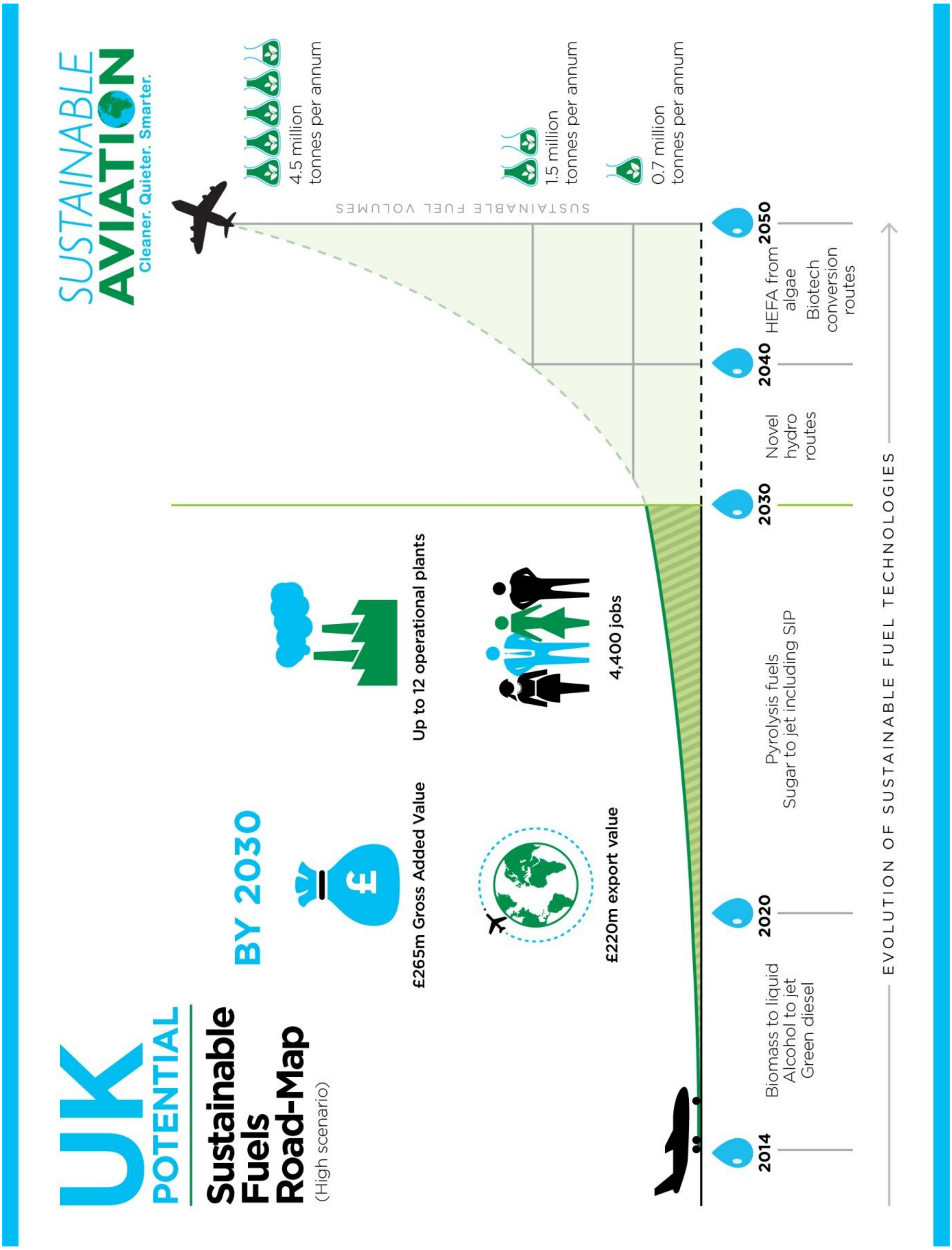
9.2 Conclusions

As a result of reviewing the current, new and emerging sustainable fuels market this Road-Map has determined that, with the right policy and investment framework UK aviation can reduce its CO_2 emissions by up to 24% by 2050. Achieving this result will require a step change in the current policy and investment framework for sustainable aviation fuels and SA welcomes the opportunity to collaborate with Government to establish the UK as a leader in this exciting new industry.

A stylised graph summarises the work of this Road-Map on the following page.

Photo Copyright Rolls-Royce 2014

[25] IEA (2011) Technology Roadmap: Biofuels for Transport. Available from: http://www.iea.org/publications/freepublications/publication/Biofuels_Roadmap_WEB.pdf


UK POTENTIAL
Sustainable Fuels Road-Map
(High scenario)
BY 2030
£265m Gross Added Value
Up to 12 operational plants
£220m export value
4,400 jobs
SUSTAINABLE AVIATION
Cleaner. Quieter. Smarter.
4.5 million tonnes per annum
1.5 million tonnes per annum
0.7 million tonnes per annum
SUSTAINABLE FUEL VOLUMES
2014
2020
2030
2040
2050
Biomass to liquid
Alcohol to jet
Green diesel
Pyrolysis fuels
Sugar to jet including SIP
Novel hydro routes
HEFA from algae
Biotech conversion routes
EVOLUTION OF SUSTAINABLE FUEL TECHNOLOGIES

Chapter 10

How we answered you

In July 2014 SA published "Fuelling the Future' A discussion paper", which set out our initial thoughts on sustainable fuels for UK aviation. This was followed by a consultation with a range of stakeholders until mid-October. As a result a number of stakeholders provided comments on the Road-Map, either by submitting written responses or through face to face meetings. Sustainable Aviation wishes to thank all those who have contributed to the Road-Map. A summary of the main comments is provided below.

10.1 Political Stakeholders

During September and early October SA met with a wide range of politicians and party members from the Conservative, Labour and Liberal Democrats during their autumn party conferences. We sought their views on the *Fuelling the Future* discussion paper and views on the potential for a public-private initiative going forwards.

The feedback was broadly supportive of a public-private initiative, but there were a range of queries on the detail of how the initiative would work. SA agreed to continue the discussions with the political parties and government regarding these moving forward.

A range of additional issues were raised, but by far the largest issue was ILUC concerns from the production of feedstocks for fuels. During the discussions we explained the fuels we are looking to develop focus on feedstocks that minimise ILUC risk. There was broad support and interest in the new waste and residues pathways. On the matter of potential changes to future policy on fuels and how to de-risk future investment there was universal support to continue the conversation with a desire to better understand the specific issues and how they could be resolved.

10.2 Non-Government Organisations (NGOs)

SA met representatives from both Greenpeace and WWF-UK in October and following brief discussions concerns about ILUC and any residual waste products were raised. SA agreed to follow up with both organisations to explore their concerns in more detail.

Section 2.3 summaries the key issues raised with SA during the consultation and where we have addressed these in this Road-Map.

10.3 Summary of main response themes

Topic	Comments	Road-Map Section
Assumptions within E4tech analysis	Some commentators queried the methods used to calculate Gross Value Add and more explanation has now been added to the document.	See chapter 7.
Economics and cost of initial capacity	An estimate of the levels of investment required to deliver the capacity outlined in the 2030 estimates was requested.	See chapter 7 for an estimate of required levels of investment.
Public-Private Initiative	An indication of the potential membership and organisation for the group needs development as a basis for ongoing discussion.	To be developed in consultation with key stakeholders.
Equity investment	What is deterring investors in this space?	See chapter 8.
Fossil refining in the UK	Will bio refining displace fossil and will jobs be displaced from the traditional refining industry?	This has been accounted for by the Technology Innovation Needs Analysis. See chapter 7.

Appendix 1

UK aviation's socio-economic value

UK aviation contributed £49 Billion GBP to UK GDP in 2011

Aviation brings economic benefits to society as a whole and to the UK in particular, supporting trade, investment and employment. In 2011, the combined activities of airlines, airports, ground services and aerospace directly contributed £52 Billion GBP to UK GDP and £8.7 Billion GBP to UK tax revenues whilst directly supporting 960,000 jobs in the UK. The aviation sector's supply chain contributed a further £16.6 Billion GBP to UK GDP in the same year according to the Oxford Economics 2014 study of the economic benefits from air transport in the UK.[26]

UK's aerospace manufacturing sector alone employs 105,000 people

The UK's aerospace manufacturing sector is the world's second largest, directly employing 105,000 people and directly generating £10.3 Billion GBP of UK GDP in 2009, with a further £7.6 Billion GBP of UK GDP being generated by the aerospace sector's supply chain. The sector brings further economic benefits through the generation of intellectual property which frequently has spin-off benefits in other sectors.

[26] Oxford Economics (2014) Economic Benefits from Air Transport to the UK. Available at: http://www.aoa.org.uk/2014/11/new-report-shows-uk-aviation-contributing-52-billion-in-overall-gdp-960000-jobs-and-8-7-billion-in-taxation/

Appendix 2

SA members' work to support sustainable fuels

A2.1 Successful trials and demonstration flights

Over recent years, the industry has been heavily involved in:

1. Evaluating more sustainable replacements for fossil fuel
2. Characterising their sustainability profile plus physical and chemical properties
3. Testing their performance in flight and on the ground

Beyond the extensive and rigorous laboratory and ground fuel rig scale testing efforts to approve advanced fuels, SA members have also participated in several different programmes to research and demonstrate the potential of sustainable fuels. For example, a number of flight demonstrations have been carried out, generating additional data for fuel certification approval and highlighting the potential of the fuel for commercial use:

6 revolutionary demonstration flights using sustainable fuels have been conducted between February 2008 and June 2013

Feb 2008

Airbus A380 gas-to-liquid (GtL) Filton to Toulouse using 50% blend in one engine. This was completed to support the ASTM approval process for GtL and FT fuels generally (including BTL).

Feb 2008

Virgin Atlantic/Boeing undertook the first biofuel 'proof of concept' demonstration flight using a commercial aircraft, using sustainably sourced coconut and babassu oils as feedstocks.

Dec 2008

Air New Zealand / Rolls Royce/ Boeing conducted a demonstration flight using 50% jatropha-based HEFA.

Oct 2011

Thomson Airways first commercial biofuel flight by a UK operator, operating from Birmingham to Arrecife using a blend of 50% biofuel, sourced from used cooking oil (UCO) in one engine.

Jun 2012

Airbus (A319) and Air Canada complete world's first international Perfect flight from Toronto to Mexico City

Jun 2013

Airbus, Air France, Safran and Total organised the "Joining Our Energies – Biofuels Initiative France" demonstration flight on an Airbus A321 (SIP Fuel blend) with sharklets to illustrate the French industry's capacity to integrate sustainable fuels.

A2.2 British Airways sustainable fuels activities

GreenSky London is a British Airways (BA) flagship project to construct an advanced fuels facility that will annually convert around 500,000 tonnes of waste into a number of sustainable low-carbon fuels – including aviation fuel. The new plant will be sited at Coryton, Essex which was the site of a fossil refinery until 2012. The location east of London on the Thames estuary has excellent transport and distribution links and is close to large volumes of waste.

British Airways has committed to converting half a million tonnes of waste into sustainable low-carbon fuels through the launch of GreenSky London.

The project will use high temperature gasification to convert low-value residual waste (i.e. material that is presently going to landfill) into a renewable biosynthetic gas: or "BioSynGas". The BioSynGas will then be cleaned and passed through a Fischer-Tropsch unit to produce low carbon fuels; yielding 50,000 tonnes each of sustainable fuel and green diesel and 20,000 tonnes of bio-naphtha.

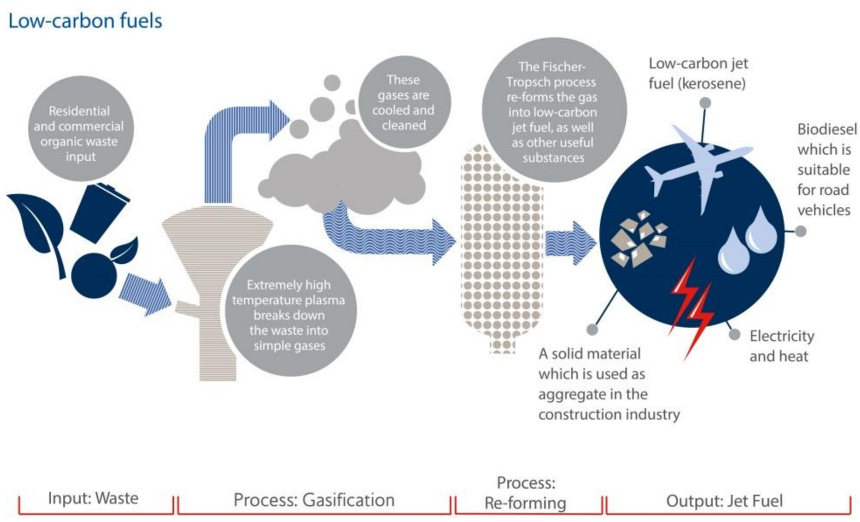


Figure A2.1 – Low carbon fuels process

The self-sufficient process will produce the electricity required to power the plant. As well as the low-carbon fuels produced, bio-naphtha can be used to make renewable plastics or blended into other fuels. The process also produces a solid aggregate-type material that can be used in construction and road building.

Detailed front end engineering and design (FEED) work is now underway and is being led by Fluor who are one of the world's biggest Engineering, Procurement and Construction companies. A number of technology partners have been selected including Honeywell UOP and Velocys (suppliers of the Fischer-Tropsch reactor).

The sustainability benefits of this fuel are wide ranging: using waste avoids the indirect land use change impacts associated with many crop-based sustainable fuels. In addition, the fuels produced are extremely clean burning and provide air quality benefits as the fuels emit very low levels of particulates. The final fuel is projected to deliver greenhouse gas savings of more than 60%

compared to fossil fuel.

British Airways has committed to the purchase of $500 Million USD worth of sustainable fuels through GreenSky London alone

British Airways has committed to buying the sustainable fuel produced by the plant for 10 years, equating to $500 Million USD at today's prices. BA will also be an investor in the project. The British Airways off-take agreement represents the largest advanced sustainable fuel commitment made to date by an airline.

The British Airways and Solena partnership project represents a significant investment in new green technology in the UK. It will provide an innovative sustainable green energy and low-carbon fuel solution for the UK's aviation sector. GreenSky London has signed an exclusive option on a site for the facility, and consent work for the site has begun. The facility will create over 150 operational jobs, and 1,000 construction positions.

Barclays has been appointed as advisor to explore the funding opportunities through export credit agencies. A Competitive Letter of Interest has been obtained from an agency and includes associated term funding. Construction is due to commence late in 2014 and we anticipate that fuels will be produced from 2017.

For more information visit:
http://responsibleflying.ba.com/whats-new-archive/ba-sustainable-fuel-project-greensky-lands-in-essex/

A2.3 Virgin Atlantic's sustainable fuel activities

Virgin Atlantic and Lanzatech have secured RSB approval for their first production plant in China

In 2008, Virgin Atlantic was the first airline to conduct a biofuel test flight - a ground breaking initiative that challenged the status quo. In October 2011 they announced their partnership with Lanzatech to pioneer the first of the next generation of low carbon fuels. Their technology uses a microbe to convert waste carbon monoxide gases from steel mills (which would otherwise be flared off direct to the atmosphere as CO_2) into ethanol. The alcohol is then converted to aviation fuel through a second stage process. Initial Life Cycle Analyses (LCAs) suggest that the resulting sustainable fuel will emit 60% less carbon than the fossil fuel it will replace, fossil fuel. Moreover, because it uses a waste-stream, the sustainable fuel produced does not impact on land use or food production.

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.

In 2012, Lanzatech successfully established two demonstration level ethanol facilities in China, with a capacity of 100,000 gallons of ethanol per year. The biofuel plant near Beijing was the first RSB-certified facility in China, and the first certification of its kind anywhere for industrial carbon capture and utilisation.

Virgin Atlantic and Lanzatech scalable technology has the

The technology is scalable. The first plant in China will produce enough fuel for Virgin Atlantic to uplift all of its fuel out of Shanghai as a 50:50 mix with fossil fuel, with plenty left over for other customers. In addition, Lanzatech estimates potential to alone provide up to 19% of global aviation fuel demand

that its process could apply to 65% of the world's steel mills, offering the potential to provide up to 19% of the world's current aviation fuel demand.

The current focus is on working hard to see the technology through to commercial use in aircraft and in October 2014, HSBC joined the partnership. The addition of HSBC's vital support along with Boeing and other technical partners means a proving flight, as a key step towards technical approval, of the new technology will take place within the next year.

For more information visit:
http://www.virgin-atlantic.com/gb/en/footer/about-us/sustainability/carbon.html

A2.4 Airbus' sustainable fuel activities

Airbus's sustainable fuel strategy is focused around three central principles:

1. To support certification and qualification of new sustainable fuel pathways, to ensure compatibility with existing and future Airbus product policy
    - Support qualification campaigns, support and promote fuel approval within International aviation fuel certification and specification bodies.
    - Anticipate the evolutions of fuels within future designs.
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.

Airbus has a proven track-record of proactively building international partnerships and research projects to successfully tackle the challenges of sustainable fuels

Airbus's strategy is managed around the world through partnerships, research projects and engagement in aviation fuel specification bodies:

Airbus actively participates in international fuel specification committees Def Stan 91-91 and ASTM D1655. Airbus in collaboration with associated engine OEMs and other airframe OEMs has assessed and approved the three sustainable fuel pathways that have been approved already and continues to assess the compatibility all new sustainable aviation fuel pathways to facilitate the development of a sustainable aviation fuel industry.

Airbus actively promotes the use of the RSB sustainability standard for all its projects some of which are identified below.

2012: 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. Furthermore, a Perfect Flight was completed by Airbus and Air Canada in 2012, bringing together all best practices including operational, maintenance, air traffic management and the use of sustainable fuels to achieve an over 40% reduction in CO_2 emissions on a commercial flight from Toronto to Mexico City.

2013: Following the successful partnership with Air Canada in 2012, 2013 saw the launch of an initiative with BioFuelNet Canada and Air Canada to assess the solutions in Canada for the production of sustainable fuels for the Canadian aviation market. Airbus also came together in 2013 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 JET A-1 fuel from Total/ Amyris produced through an innovative conversion of sugar (SIP process producing Farnesane). Further collaborations launched in 2013 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 commercialization of sustainable fuels in the region.

Airbus firmly believes strong support from UK government will be pivotal in ensuring sustainable fuels are commercially competitive with fossil fuels at a global level

2014 and beyond: Airbus established a Malaysian Centre of Excellence to assess local solutions for sustainable bio-mass 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. The first assessment is expected to be completed by December 2014. Airbus is also working closely with the EU commission through ITAKA (Initiative Towards sustAinable Kerosene for Aviation). This collaborative project is framed in the implementation of the European Union policies specifically and aims to contribute to the short-term (2015) EU Flight Path objectives.

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.

For more information visit:
http://www.airbus.com/innovation/eco-efficiency/operations/alternative-fuels/

A2.5 Boeing's sustainable fuel activities

Boeing are working closely with their customers and stakeholders to meet their goal of sustainable biofuel serving at least 1% of global aviation fuel demand by 2016

Boeing is committed to take action to protect the environment and support the long-term sustainable growth of commercial aviation. As part of this commitment, Boeing is leading industry efforts worldwide to develop and commercialize sustainable aviation fuels, which emits 50-80% less carbon dioxide on a lifecycle basis than fossil fuel.

Boeing's goal is that by 2016, sustainable fuel will meet 1% (600 million gallons) of global aviation fuel demand, and we believe this goal can be met.

Boeing works proactively with customers and other stakeholders to identify and develop sustainable feedstocks and approve new fuel pathways that will expand aviation biofuel supplies globally and regionally.

Boeing's long-term intent is not to predict winners in feedstocks or fuel pathways, but to identify candidate biomass sources that can be grown, harvested and processed sustainably and at a price point that is competitive with fossil-=fuels.

Boeing led the aviation community's effort in 2011 to include a blend of up to 50% of sustainable fuel produced through the HEFA (hydroprocessed fatty acid esters and free fatty acid) process in international aviation fuel specifications ASTM D7566 and UK MoD DEF STAN 91-91. This approval was based on several years of research and testing conducted by Boeing, our customers and others throughout the aerospace industry. Since then, airlines around the world have flown more than 1500 regularly scheduled commercial flights using a blend of fossil and sustainable fuels.

Boeing have lead work on the "drop-in" use of green diesel as a price-competitive aviation biofuel with a current potential production capacity of 800 Million gallons

In 2014, Boeing was the first to propose the direct, "drop-in" use of green diesel – a renewable diesel fuel used mainly today for road transport – as a price-competitive aviation biofuel. Green diesel, made sustainably from plant oils and waste animal fat, has production capacity of 800 million gallons in the US, Europe and Asia that could rapidly supply 1% of global aviation fuel demand. The price of green diesel, including incentives from the US and other governments, is about the same (approximately $3 USD/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 also has active sustainable fuel development projects on six continents and in many countries, including the United States, Europe, China, the Middle East, Southeast Asia, Brazil, South Africa and Australia. In particular, we work closely with airlines, research institutions, governments and others to develop regional sustainable fuel supply chains using a variety of sustainable feedstocks. We are proud to partner with many of our customers in this effort, including United Airlines, Alaska Airlines, Etihad Airways, KLM, South African Airways, Air China, Gol and AeroMexico. Our sustainable fuel supply chain efforts include:

UAE: Boeing and Etihad Airways fund the Sustainable Bioenergy Research Consortium (SBRC), which is hosted by the Masdar Institute of Science and Technology, to research and develop the efficient use of halophytes fed by seawater to produce sustainable fuel.

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.

Brazil: Boeing partners with Gol, Embraer and others on alcohol-to-jet fuel conversion technologies, as well as how to establish a sustainable fuels industry.

Southeast Asia: Boeing collaborates with the Roundtable on Sustainable Biomaterials (RSB) to assess opportunities and challenges for smallholder farms to produce sustainable fuel feedstocks.

United States: Boeing partners with United Airlines, Honeywell UOP and others to develop a sustainable fuel supply chain using leftover corn stalks and leaves from Midwestern farms.

Boeing also was a co-founder in 2008 of the Sustainable Aviation Fuel Users Group (SAFUG), a group of 28 leading global airlines, industry leaders, environmental organizations and fuel technology leaders. SAFUG, which accounts for more than 33 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.

Regional sustainable fuel efforts supported by Boeing utilize principles established by the international Roundtable on Sustainable Biomaterials (RSB) to evaluate these issues. These sustainability principles address greenhouse gas emissions, local food security, conservation, soil, water, air, and technology, inputs and waste management.

For more information visit:
www.newairplane.com/environment/

Appendix 3

Technology

A3.1 Technologies and standards

There are a number of technologies - already available or in development - for producing sustainable fuel blends, at varying levels of readiness. The following chart graphically shows the processes presently approved or being assessed by ASTM:

Figure A3.1 represents technologies being developed to produce sustainable fuels

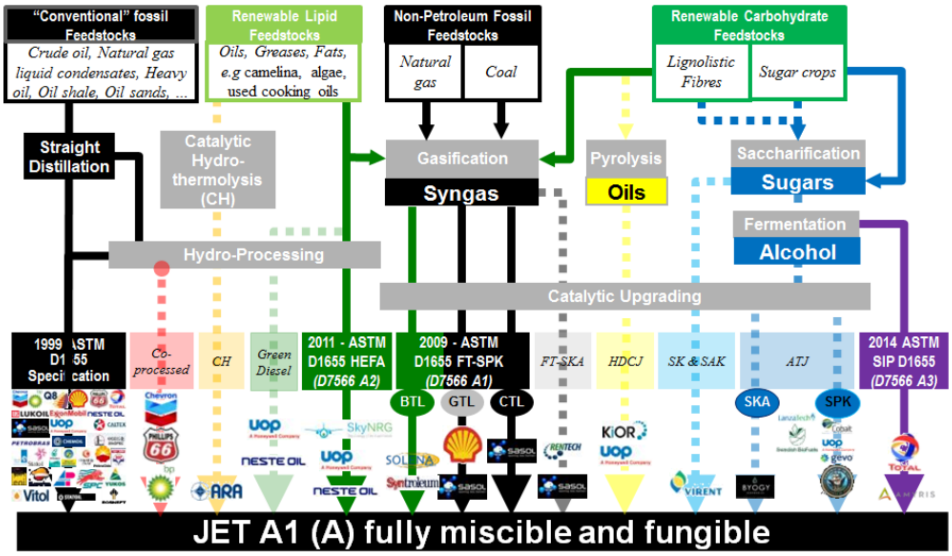


Figure A3.1 – Processes for producing sustainable fuels

These processes include:

Approved processes

Fischer Tropsch (FT) – in which the feedstock is first converted to a mixture of carbon monoxide and hydrogen, with a subsequent catalytic process leading to a mixture of hydrocarbons. The properties of the final fuel are completely independent of the feedstock and are solely influenced by the F-T process conditions. While the process was originally developed for use with coal, as Coal-to-Liquid (**CtL**) technology, the FT technology is also suitable for other feedstocks, including natural gas for Gas-to-Liquid (**GtL**) and waste streams, other sources of biomass and gases, for Biomass-to-Liquid (**BtL**).

Hydrotreated esters and fatty acids (**HEFA,** formerly called hydro treated renewable jet or **HRJ**) – in which oils are extracted from feedstocks, for example, from jatropha or algae, which are then refined into fuel in a similar way that crude fossil oil is refined. The residue from the processing – the meal – can in many cases also be of commercial use. For example, the meal from the processing of jatropha can be used as fuel for burning on fires and in stoves and the meal from algae oil production can be used for fertiliser and animal feed. Used cooking oil can also be used as a feedstock**.**

Synthesized Iso-Paraffinic Fuel (SIP). In the SIP pathway, microbes or yeast are fed sugars (starch, sucrose, cellulose) and the organism produces straight hydrocarbons which must then be further processed to achieve the required range of hydrocarbon molecule sizes to make aviation fuel.

Processes under assessment

Alcohol to Jet (ATJ) begins with alcohols such as ethanol, propanol and (iso)butanol. These alcohols are usually obtained through fermentation of sugars or starches, but obtaining alcohols from cellulosic material and waste carbon monoxide is also being explored. In the ATJ process the alcohol molecules are dehydrated and oligomerized to end up with a mixture of hydrocarbons of different chain lengths. This is then goes through distillation and hydrogenation. There are two forms of ATJ under development: one without aromatics (ATJ-SPK) and one with synthetic aromatics (ATJ-SKA). Synthesising aromatics could lead to more rapid approval of 100% sustainable fuels by removing the necessity to blend with fossil fuel.

Hydrotreated depolymerized Cellulosic Jet (HDCJ) or Pyrolysis. This process uses a liquefaction pyrolysis process to obtain a bio-crude oil from ligno-cellulosic materials (such as forestry residues and grasses), that are then refined into aviation fuel through a process of upgrading. The bio-crude oil mixture is similar to fossil crude oil but requires additional hydro treatment. This step, together with final distillation, could potentially happen in a traditional oil refinery where the process has been well established for many years.

Catalytic Hydrothermolysis (CH). This process uses oils from plants (or algae) as a feedstock. The CH process uses water to convert the feedstock oils into a crude oil intermediate, which is then hydrotreated and fractionated with conventional refinery catalysts.

Synthetic Kerosene (SK) and Synthetic Aromatic Kerosene (SAK). Processes take liquid sugars and catalytically upgrade them to form fuels in the aviation fuel range with and without aromatics. The advantage of producing SAK is that it could remove the need to have a blended sustainable fuel**.**

Green diesel. This is made from oils and fats, is chemically similar to HEFA fuel and is produced using a process that is the same as the first stage of the HEFA process. However, it is chemically different and a different product than the fuel known as 'biodiesel'. Green Diesel for aviation could be a sub-annex of the HEFA approval as it uses the same feedstocks and a similar conversion process but would have slightly different properties.

Co-Processing. This is where vegetable and petroleum oils are blended and co-processed. It is a further innovation which is currently being investigated.

Developments in the ASTM fuels approval process

As discussed in the main report, aviation has very strict performance and safety requirements, and these also apply to fuel developments. Most of the world's aviation fuel is delivered according to the fuel industry's 'Joint Fuelling System Checklist for Jet A-1', which requires that all new fuels meet the most stringent performance and safety tests of the UK Ministry of Defence DEF STAN 91-91 and the ASTM International ASTM D1655 standards.

Aviation Fuel Quality Requirements for Jointly Operated Systems

Engine and airframe manufacturers that have participated in both DEF STAN 91-91 and ASTM D1655 specifications, have ensured that any changes to fuel profiles result in fuels that are fully compatible with aircraft and engine performance requirements. Thus, engine and airframe manufacturers are actively involved in the processes for supporting increased uptake of sustainable fuel in commercial use.

In 2003, based broadly on the work performed to approve the first FT fuels, engine and airframe manufacturers played an active role in developing the ASTM D4054 approval process for new fuels and fuel additives. This is the industry standard, which enables fuels to be evaluated and potentially certified in a thorough and optimised manner.

The first new fuel process to be approved for routine commercial use was Fischer-Tropsch (FT). In 1999, the industry completed pioneering work to permit the use of alternative pathways to produce aviation fuel through the DEF STAN 91-91 specification body, by approving the first FT fuels made by Sasol Ltd from coal as a 50% CtL blend. In 2008 100% CtL was approved. ASTM D1655 incorporated the Sasol FT approval by reference to DEF STAN 91-91.

In 2009, ASTM developed the ASTM D7566 standard specification for aviation turbine fuels containing synthesised hydrocarbons. This specification described acceptable processes for generic FT fuels production from coal, natural gas and biomass as feedstocks, but limited approval to up to 50% blend ratio with fossil fuel. This specification is now incorporated into both the ASTM D1655 and DEF STAN 91-91 JET A1 fuel specifications.

In 2011, ASTM expanded the types of fuels covered by D7566 to include HEFA (hydrogenated esters and fatty acids) as a 50% blend with fossil fuel. Typically, pre-approval non-commercial demonstration flights are used to gather data for the approval process. Demonstration flight data is then used to support the approval process. Once approved, the fuel can be used in commercial flights. As such, HEFA fuels were used in a series of demonstration flights (pre-approval) since 2008 and have been used in commercial passenger flights (post approval) since 2011.

In 2014 a new annex to ASTM D7566 was added to cover SIP (Synthesized Iso-Paraffinic fuels). Demonstration flights with sugars based Fuels (e.g. SIP) were performed in 2013 to collect data and to prepare the research dossier for the ASTM qualification and certification process. SIP fuel blends are currently being used for commercial flights.

Future fuel approvals candidates

On-going work will be focusing on approval of new fuel processing routes to either blend stocks and/or final 100% sustainable fuel product.

Developing production capability for approved processes

FT HEFA and SIP technologies have already been approved through the ASTM process. FT and HEFA fuels can be blended up to 50% (known as

50:50) with fossil fuel. SIP fuels are limited to 10% blends with fossil fuels Other technologies like ATJ and pyrolysis are expected to follow in the coming months and years. SIP fuels are already in commercial production by Total/Amyris. HEFA fuels are already being produced by a number of suppliers, for example NESTE and Dynamic Fuels (using the UOP process). FT is being produced by, for example Shell (GtL) and production capacity being established by Solena using waste feedstock (BtL)[27].

Assessing and approving new pathways

The following pathways are actively working through the ASTM D4054 approval process for inclusion via the ASTM D7566 to the international aviation fuel specifications e.g. the UK Def Stan 91-91 and ASTM D1655:

Alcohol to Jet (ATJ). Fuel companies developing and pursuing this processing route (without aromatics) through ASTM currently include: Byogy, Gevo, Lanzatech, Swedish Biofuels, Cobalt/USN and UOP. Byogy, Lanzatech & Swedish Biofuels are also pursuing the route to produce ATJ with synthetic aromatics.

Hydrotreated depolymerized cellulosic jet (HDCJ). Fuel companies developing and pursuing this processing route through ASTM currently include: UOP and KiOR.

Catalytic Hydrothermolysis (CH). The CH process is being developed primarily by ARA (Applied research Associates)

Synthetic Kerosene (SK) and Synthetic Aromatic Kerosene (SAK). The SK and SAK processes are being developed by Virent.

Green diesel. Green Diesel production already exists. Neste's NExBTL, ConocoPhilips H-BIO and UOP/Eni Ecofining are just three of the existing processes. The potential approval and maximum blend percentage for Green Diesel will be determined during the approval process.

[27] Also see British Airways project with Solena in Appendix A2.2

Appendix 4

Sustainable fuel logistics and blending

A4.1 Traceability and chain of custody of sustainable fuel

The requirements of DEF STAN 91-91 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. Also, technical documents demonstrating fuel quality must accompany the product to its destination.

The most common of these documents are:

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

A detailed description of these documents and processes follows.

Existing purchase records and refinery certificates of quality (RCQ) provide sufficient detail of batch contents to satisfy requirements on traceability and chain of custody. Information relating to sustainable fuel purchases is provided to airlines by fuel producers, whose records are generally subject to audit.

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 91-91 and ASTM D1655. This is widely used as a common voluntary standard. As with DEF STAN 91-91, synthetic components are permitted, but “shall be reported as a percentage by volume of the total fuel in the batch”. In addition there is an ICAO Manual, ICAO 9977 which reflects global minimum standards.

For sustainable fuel an additional Certificate of Sustainability (CoS) must be produced using an approved voluntary certification scheme. Batches of both fossil 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. As sustainable fuels become commoditised products, it will be necessary to design a new method for tracking fuel sustainability certificates on a global basis.

A4.2 Blending/co-mingling of sustainable fuel

Co-mingling occurs in a variety of ways. Current fuel specifications require synthetic fuels to be blended before delivery into the fuel distribution system. Once fuels have been delivered, co-mingling occurs in pipelines, joint airport storage and distribution systems. However, the blending itself is subject to constraints. For FT and HEFA fuels the specifications permit, a blend ratio of up to 50%, and 10% for SIP fuels, subject to the fuels meeting other defined specification requirements. Depending on the properties of the fossil fuel available for blending, the blend ratio actually achievable may be considerably lower.

Further support is required to fund research on overcoming aromatic content barrier sustainable fuels currently face

The main limiting factor is likely to be the aromatics content, as the blend needs to have an aromatics content of at least 8.4%, due to concerns about preservation of seal integrity. Since FT, HEFA and SIP based fuels have no aromatics content, the fossil fuel needs to have an aromatic 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 aromatics content below that figure. Other factors potentially limiting the blend ratio are density and lubricity. Chapter 4 recommends further research activity in this area.

A4.3 Adapted DEF STAN 91-91 descriptions

The following document descriptions were adapted from DEF STAN 91-91:

- The Refinery Certificate of Quality (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 authorized signatory.
- 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 authorized signatory.

Note: A COA shall not be treated as an RCQ.

- 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.

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

- RCQ - sustainable fuel blend cannot be certified to ASTM D7566, ASTM D1655 or DEF STAN 91-91 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.

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

A4.4 General procedure for certification under ASTM and DEF STAN

1. Neat synthetic component is produced to the requirements of Annex A1, A2 or A3 of Specification D7566.
    a. 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).
    b. 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.
    a. 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 91-91 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 91-91 and of known synthetic fuel content.
    b. 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.

c. Representative samples of the blend are tested against the primary specifications (as opposed to those in the Annex) of Specification D7566.
d. Test results and additives are listed in a new RCQ.
e. 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.
f. 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 91-91 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*".
g. A new CoS is produced for the blend, indicating the blend volume % of the synthetic-component.

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
    a. RCQ or COA of the blend, indicating percentage sustainable,
    b. RCQ or COA of the neat bio-component,
    c. CoS of the blend, and
    d. Purchase records (bill of lading, purchase receipts, or other verifiable documentation detailing the quantities transferred).

A4.5 EU ETS rules on sustainable aviation fuel accounting

1. The aircraft operator must ensure that:

a. 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 by either:
   I. a sustainability scheme approved by the Commission under the RES Directive, or
   II. ensured by appropriate national systems (like e.g. guarantee of origin registries), or
   III. by other appropriate evidence provided by the fuel supplier(s) to the aircraft operator.

b. 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.

c. 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 sustainable fuels to third parties;
   - No double counting of sustainable fuels 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.

d. 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.

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:

a. 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.

b. 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.
c. 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.
d. The system for accounting of sustainable fuel shall be set up in a transparent way, ensuring that no double counting of sustainable fuel can occur.
e. 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.

Appendix 5

E4tech analysis on technical supply potential

A5.1 Available conversion technologies

There are a wide range of conversion technologies at various stages of development for the production of aviation fuels from wastes, residues and non-food crops. There have been several demonstration flights and programmes using different fuels. A key challenge is scaling existing technologies to provide commercially viable quantities.

SIP, HEFA and FT fuels are certified for use in aviation, with SIP and HEFA deployed at commercial scale today (but only 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. An inventory of technology developers, including scale of operation and locations is provided in Appendix 5.7. This inventory forms the basis of the assessment of sustainable fuel supply potentials to 2020.

New processes are being developed which are currently at laboratory stage. These new processes are not the focus of this Road-Map in terms of the potential for deployment to 2030. But, their successful development could result in these processes contributing significant volumes of sustainable fuel to the aviation industry between 2030 and 2050. Thus, supporting the achievement of 2050 sustainable fuel use targets discuss in later sections. As such, the needs of these processes in terms of technical milestones, appropriate funding, and commercialisation strategy should not be overlooked.

A5.2 HEFA

HEFA is produced by the conversion of vegetable oils or waste oils and fats. It can be used as "drop-in" blending components for the production of diesel and aviation fuels. The hydro treatment 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.

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.

Government can incentivise existing HEFA plants to configure their production to 60% aviation fuels

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 of aviation fuels. 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 hydro treatment, 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.

A5.3 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 (H_2) – 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.

British Airways and Solena are developing a commercial scale plant to produce a sustainable fuel which can be used by British Airways flights out of the UK from 2017

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. British Airways is developing a first of a kind commercial scale plant in partnership with Solena. The London plant will produce sustainable fuel from municipal solid waste (MSW) and will be used by British Airways to fuel part of its flights out of the UK from 2017.

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.

A5.4 Synthesized Iso-Paraffinic (SIP) routes

Support for SIP work could lead to the production of sustainable fuels using biological processes

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 a relatively early stage 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.

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 hydro treatment.
- 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 hydro treatment processes. As developed by Virent.

5.5 Alcohol-to-jet (ATJ) routes

Virgin Atlantic, Lanzatech and Swedish Biofuels are working together to prove the production of sustainable fuel from waste carbon monoxide gases

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. Virgin Atlantic has formed a strategic partnership with Lanzatech, to demonstrate the production of ethanol from waste carbon monoxide gases, and the subsequent catalytic conversion to sustainable fuels.

A5.6 Hydrotreated depolymerised cellulosic jet (HDCJ)

Certain processes in the production of HDCJ can be integrated into existing oil refinery operations

Hydrotreated depolymerised cellulosic jet (HDCJ) is produced by the pyrolysis of lignocellulosic biomass to an intermediate bio-crude oil, followed by hydro treatment and fractionation to gasoline, aviation fuel and diesel products. Hydrotreatment and fractionation of pyrolysis oil may take place in dedicated facilities or may be integrated into existing oil refinery operations. The process is the pilot to demonstration stage, with several pilot plants either operational or under construction, including UOP and Allenotech. KiOR have built and operated a large demonstration facility in the USA but the plant has been idle since March 2014.

A5.7 Summary of operational and planned plants

TPA (tonnes per annum) corresponds to the approximate annual capacity of a chemical plant to produce aviation fuel in tonnes

It can be seen that currently UK commitment to sustainable fuels is a mere 2.8%

Process	Producer	Location	Status	TPA
ATJ	Fulcrum Biofuels	US	Planned - advanced	10,000
	Lanzatech	China		40,000
	Swedish Biofuels	Europe	Planned - advanced	10,000
	Terrabon	US	Operational	Pilot
			Operational	1,500
FT	Forest BTL	Finland	Planned - early	115,000
	Haldor Topsoe	US	Operational	1,000
	Red Rock Biofuels	US	Planned - early	50,000
	Solena	India	Announced	300,000
		UK	Planned - advanced	100,000
		Australia	Planned - early	100,000
		Germany	Planned - early	100,000
		Ireland	Announced	100,000
		Italy	Announced	100,000
		Sweden	Announced	100,000
		Turkey	Announced	100,000
	TRI	Canada	Operational	20,000
		US	Planned - early	40,000
			Planned - early	20,000
	UPM	Finland	Under construction	100,000
		France	Planned - early	100,000
HEFA	Alt Air	US	Under construction	95,000
	Darling Int. and Valero	US	Under construction	450,000
	Dynamic Fuels	US	Operational	235,000
	Emerald Biofuels	US	Planned - early	270,000
			Planned - early	470,000
	ENI	Italy	Operational	315,000
	Neste	Finland	Operational	190,000
		Finland	Operational	190,000
		Netherlands	Operational	800,000
		Singapore	Operational	800,000
	UOP	US	Operational	10,000
STJ	Amyris	Brazil	Operational	40,000
			Planned - advanced	40,000
	LS9	Brazil	Planned - early	235,000
		US	Planned - early	30,000
	Solazymes	US	Operational	100,000
	Virent	US	Operational	Demonstration
UPO	Allenotech	US	Operational	Pilot
	BTG	Netherlands	Planned - early	17,000
	UOP	Hawaii	Under construction	Pilot
Other	Biochemtex	Europe	Planned - early	2,000

Blue Sun	US	Planned - early	4,000
Licella	Australia	Operational Operational	Pilot 17,000

A5.8 Other key assumptions

The estimated percentage volumes quoted in the E4tech analysis were based on the SA's updated CO_2 Road-Map of 2012.

These figures are taken from the spreadsheet used to construct the SA CO2 Road-Map, using assumptions documented at:
http://www.sustainableaviation.co.uk/wp-content/uploads/SA-CO2-Road-Map-full-report-280212.pdf

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Sustainable Fuels UK Road-Map

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