AVIATION'S ENERGY TRANSITION

WAYPOINT 2050

All parts of the global economy must find ways to respond to the climate change challenge by reducing emissions. Air transport does not have 'off the shelf' solutions like many other sectors. How will we fly in the coming decades?

Options for an energy transition

Many parts of the economy have had low-carbon or zero-carbon options for decades: electricity can be produced using hydro, solar, wind, geothermal and nuclear; and many other forms of transport can shift to electricity.

Aviation's options have not been so readily available. Whilst efficiency has continued to improve, the fuel remained the same. However, there have been developments in the past ten years which are changing that:

» **Sustainable aviation fuel** (SAF) is a liquid replacement for traditional fossil-based jet fuel. It can be produced from a wide variety of sources and processes. It is a 'drop-in' solution, behaving in an almost identical way to conventional jet fuel which means it does not require new engines or infrastructure.

» **Electric aircraft** are a rapidly developing area of research, with around 200 projects underway to explore options for using either fully-electric propulsion or a hybrid of electric and liquid fuel.

» **Hydrogen** is also a potential source of energy for air transport, however this is will require substantial research and development over the coming decades.

Sustainable aviation fuels currently

<1%

of global jet fuel use.

365,000

Flights on SAF

Figures updated daily on www.enviro.aero/SAF

2% (~7 billion litres)

of the total aviation fuel supply could be SAF by 2025 with the right policy support, reaching a tipping point for SAF supply.

14 bn litres

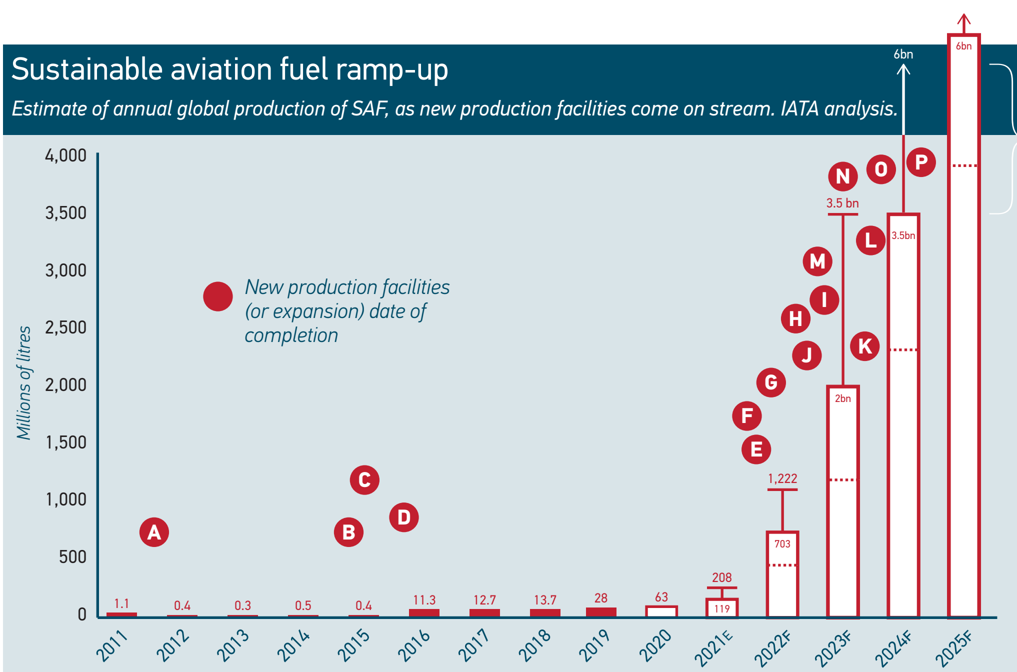
in airline SAF forward purchase agreements so far.

7

technical pathways to SAF development have been certified.

Sustainable aviation fuel ramp-up

Estimate of annual global production of SAF, as new production facilities come on stream. IATA analysis.



Difference between a low take-up of SAF from production facilities *(lower number)* and a high take-up, driven by policy and airline decision-making. The top number represents the full possible output of SAF production already in operation, under construction or in advance planning and financing.

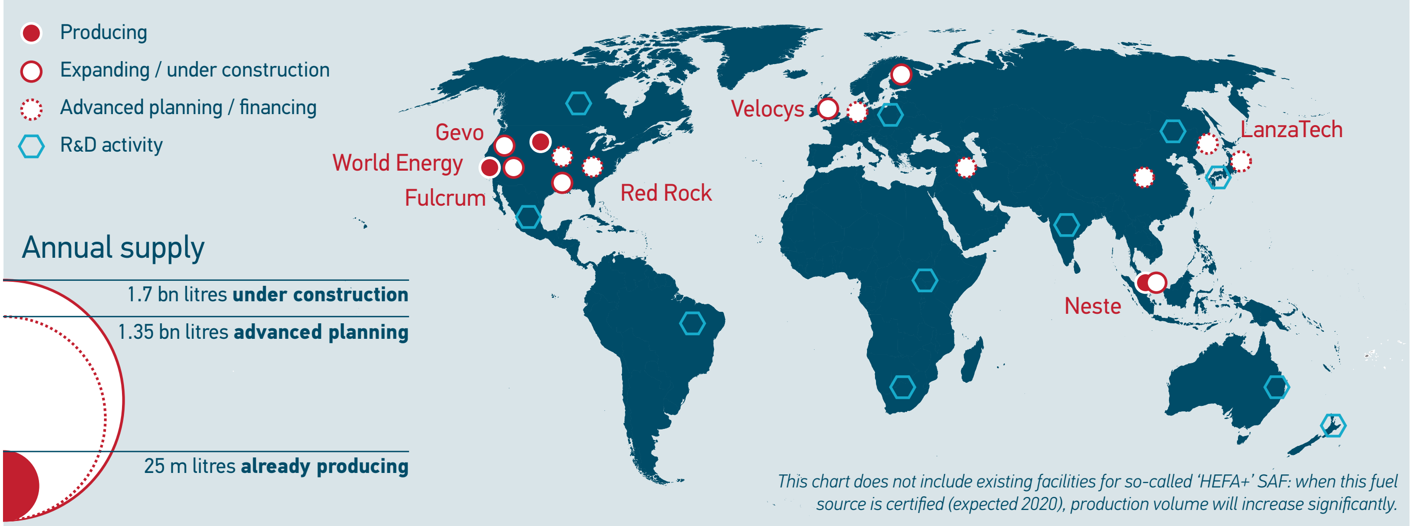
Without the correct policy measures, the fuel output could be optimised to go to other forms of transport – the lowest dotted line represents the least uptake of SAF (output goes to road transport).

This analysis does not include SAF capacity that has not yet been announced, is in concept stage, nor the impact of aggressive policy support which could double the potential by 2025.

- **A Neste** (Singapore / Finland)
- **B Gevo** (USA)
- **C Amyris** (Brazil)
- **D World Energy** (USA)
- **E World Energy** (USA)
- **F Fulcrum** (USA)
- **G Neste** (Singapore)
- **H LanzaTech** (North Asia)
- **I SkyNRG** (Netherlands)
- **J UPM** (USA)
- **K Red Rock** (USA)
- **L Total** (France)
- **M Diamond Green** (USA)
- **N REG** (USA)
- **O Preem** (Sweden)
- **P Velocys** (UK)

Global sustainable aviation fuel production ramp-up

Building the facilities needed to produce SAF: 2% of total aviation fuel supply possible by 2025



This chart does not include existing facilities for so-called 'HEFA+' SAF: when this fuel source is certified (expected 2020), production volume will increase significantly.

Development of SAF

The first test flight in a commercial aircraft took place in February 2008. Since then, the development of this new energy source has been relatively rapid. Despite operating at the cutting edge of technology, aviation is a cautious industry that will not deploy any new fuel without thorough testing and analysis.

In 2011, certification was given to allow commercial flights to start using SAF and in 2016 SAF started being deployed through Oslo and Los Angeles Airport fuel hydrant systems. The testing process continues, as the fuel standards body ASTM International continues to certify additional production pathways.

Biofuel or SAF?

"Sustainable aviation fuel" is used because many of the sources of feedstock are not 'bio' in a traditional sense: they can come from waste resources or synthetic processes as well as non-food crops grown for the purpose. However, "biofuels" can also be used as shorthand.

Cost of SAF

Currently, sustainable aviation fuel is more expensive than traditional jet fuel. Estimates range from 2x for some waste-based sources to 6-10x for synthetic fuels using carbon capture. This is mainly due to the small production runs and scarcity of the product. As the map above shows, however, further production facilities are being constructed and actively planned. On top of this, a number of leading airlines are signing significant forward purchase agreements which help provide offtake certainty to new energy suppliers, allowing them to finance new plants (or retrofits to existing fossil fuel refineries). This will help bring down the cost of SAF in the mid- to long-term.

Some innovative commercial agreements have allowed cost-competitive supply agreements to already be made with several airlines.

It is believed that reaching around 2% of the overall jet fuel supply would enable a tipping point in the supply / price balance, allowing more rapid deployment from that point. That would be around 14 billion litres of SAF in 2025.

16 SAF production plants and refineries currently operating, under construction or advanced planning: total capacity of 3.5 billion litres of potential SAF production per year by 2025.

Sources

The aviation sector is looking at a wide range of sources for these new fuels. This is to ensure security of supply, sustainability of options and local economic development opportunities. Aviation has the ability to look at whichever SAF option makes the most sense in each location. Eventually, they can supply the local airport instead of needing to ship fuels around the world as extensively.

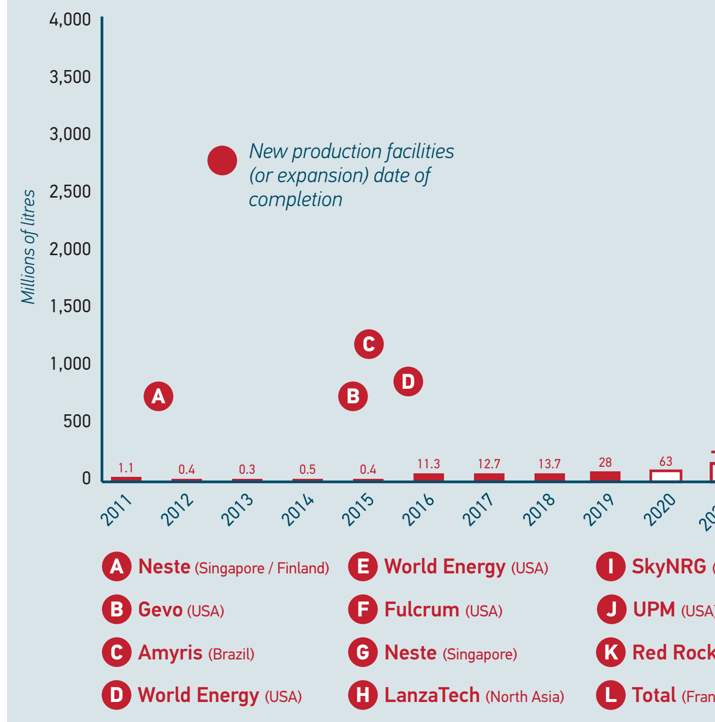
» **Waste:** from used cooking oils and tallows, forestry, municipal solid waste, agriculture and even waste gases. This allows secondary use of these resources and avoids them going to landfill (creating methane), or being burnt. *Current lifecyle CO_2 reduction: 70-80%.*

» **Sustainable crops:** a number of non-food crops may also play an important role. From halophytes which can grow in salt water, to carinata which is a rotation crop, helping to impregnate soil with nitrogen and actually boost food crop yields in off years. Care will need to be taken to ensure that any crop sources do not impact food crops, water or land use. *Current lifecyle CO_2 reduction: 80-100+%.*

» **Synthetic fuels (aka 'electrofuels'):** these are produced from air-captured CO_2 and generated using electricity. They are in very early stages of testing, but if they can be commercialised and produced with renewable electricity, they could be a good source of energy for aviation. Currently there has only been laboratory-level production and any renewable energy used in wide-scale deployment would need to be on top of the energy needs for the wider economy. *Expected lifecyle CO_2 reduction: 95%.*

Sustainable aviation fuel ramp-up

Estimate of annual global production of SAF, as new production facilities come on



Pathways for sustainable aviation fuel production

Approved following careful review by experts coordinated by ASTM

Pathways and processes	Feedstock options	Date of approval	Current blend
FT-SPK	biomass (forestry residues, grasses, municipal solid waste)	2009	up to 50%
HEFA-SPK	algae, jatropha, camelina	2011	up to 50%
HFS-SIP	microbial conversion of sugars to hydrocarbon	2014	up to 10%
FT-SPK/A	renewable biomass such as municipal solid waste, agricultural wastes, forestry residues and energy crops	2015	up to 50%
ATJ-SPK [isobutanol]	agricultural waste products (stover, grasses, forestry slash, crop straws)	2016	up to 50%
ATJ-SPK [ethanol]	agricultural waste products (stover, grasses, forestry slash, crop straws)	2018	up to 50%
CHJ	triglyceride-based feedstocks (waste oils, algae, soybean, jatropha, camelina, carinata, tung)	2020	up to 50%
HHC-SPK	biologically derived hydrocarbons such as algae	2020	up to 10%

For further information, see www.enviro.aero/SAF

Sustainability

Aviation was several years behind the road transport sector in looking to alternative sources of energy. This was mainly due to the need for chemistry which mimicked the special properties of Jet A1 fuel. However, it allowed the aviation industry to learn from some of the errors made in deploying the first generation of biofuels, particularly the types of crops used and the impact on water use, land use and food prices.

All 290 airline members of the International Air Transport Association agreed a resolution in 2017 supporting sustainability standards which "conserve an ecological balance by avoiding the depletion of natural resources". In addition, 27 airlines representing a third of global jet fuel demand are members of the Sustainable Aviation Fuel Users Group and pledge to high sustainability standards for any SAF they will use. Sustainability is the most important aspect of SAF deployment and the industry works closely with organisations such as the Roundtable on Sustainable Biomaterials to implement global standards.

Policy options

Given the lack of alternatives for air transport, the industry believes that aviation should be a priority user of some of these sources of fuel, alongside other hard-to-abate sectors (such as heavy trucking and chemicals). Road transport should transition to electricity or hydrogen and even shipping has other options such as ammonia.