The Best Use of Scarce Materials

Is SAF the most efficient path to economy-wide decarbonisation?

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NB: SAF One-Pager available here.

Executive Summary

The question of ***Could*** feedstocks be used for SAF has been answered, but the question of ***Should*** has not. It is perfectly possible to turn many materials into jet fuel, but there hasn't been much critical assessment as to whether doing so is the best choice for ensuring that we decarbonise in the most efficient and impactful way across all economic sectors.

Whether or not a raw material should be turned into SAF depends on a few, sometimes contradictory, factors. Firstly, pragmatic consideration should be given to questions of what is the feedstock used for now, and is that end product useful? Will that end product be useful in the short, medium and long term? Secondly, even if there are excess and genuine waste volumes now, is this potential feedstock best used in jet fuel? The answer can be subjective, but environmentally, there is often only one answer. And will that best use be needed in the short, medium and long term?

This creates an interesting paradox: can a SAF actually be described as sustainable if there is a better environmental use for its feedstocks? Is the "S" justified? In many cases, the answer is no.

Looking across proposed feedstocks for UK SAF, it becomes very difficult to say that the best use of any in the short term is jet fuel. Pragmatically, since some feedstocks are already used in certain industries which produce useful products we need - and therefore the plants, jobs and supply chains exist to sustain those industries - many would argue that feedstocks should continue being funnelled to those.

In the long term, the Government needs to decide the make-up and nature of both the electricity and gas grids. The UK's electricity grid will be dominated by offshore wind, solar and a few nuclear plants. But will there be any space for energy-from-waste plants? Or hydrogen plants? Or even biogas plants with CCS? If the answer is yes, then that means less of those feedstocks will be available to be turned into jet fuel. And for how long will we burn gas in our homes? It may make sense in the future for the UK to have a small gas grid that is entirely full of biogas produced in anaerobic digestion plants. And if that's the case, then that biogas feedstock can't be used for SAF.

The blunt truth is that there is not a single SAF feedstock that can't be used in another sector where it would bring a desirable environmental outcome. And in some cases, that outcome is already what a large proportion of the waste is already used for. This paper analyses the main SAF feedstocks being discussed in the UK today. And what it shows is that, in many cases, it is very questionable whether jet fuel is the best *environmental* use of those feedstocks.

Below is a critical assessment and overview of the major feedstocks that have been proposed and utilised thus far in the UK:

Q1: In most cases, feedstocks could be used in a variety of environmentally beneficial ways. Is jet fuel the best environmental use for the feedstock today?

- ✘ Absolutely not
- ? It's not clear
- ✔ Absolutely!

Q2: The future world will look very different to today. Will jet fuel be the best use of the feedstock in a net zero (2050) world?

- ✘ Absolutely not
- ? It's not clear
- ✔ Absolutely!

Q3: Pragmatically, current and proposed SAF feedstocks are utilised in a variety of ways: some poorly, and some well. To what level are UK levels of the feedstock currently utilised for something environmentally or socially beneficial?

- ✘ Overused or fully utilised: UK-produced feedstock is fully utilised already, and in some cases the UK may even import feedstock from other countries.
- ✔ Underused: feedstock is currently disposed of poorly and therefore some is available for jet fuel.

Feedstock (e-kerosene)	Q1	Q2	Q3	Description
Captured Carbon (for eKerosene)	✘	✘	✘	Captured Carbon can either be utilised or permanently sequestered under the ground, however it is always more energy-efficient to sequester captured carbon rather than use it as an eKerosene feedstock. The UK aims to sequester 23 Mt CO_2 annually by 2035, so it is unclear how much, if any, will be available for jet fuel.
Hydrogen / renewable electricity (for eKerosene)	✘	✔	✘	Green Hydrogen needs electricity to be produced, and environmentally, that electricity would have greater climate benefit decarbonising the power grid or being used directly in electric vehicles and heat pumps than in jet fuel production. Indeed, until green hydrogen is abundant, using it for jet fuel is one of the least efficient ways to cut emissions. Additionally, academic research suggests that hydrogen is better used in hydrogen planes rather than as a SAF feedstock.

Feedstock (waste)	Q1	Q2	Q3	Description
Agricultural, garden and food waste	✘	?	✔	Agricultural, food and garden (aka biogenic) waste is used to aid soil health and in anaerobic digestion (AD) plants to make biomethane (that displaces fossil gas), and digestate (that displaces grey-hydrogen-derived synthetic fertilisers). AD is supported through the Green Gas Support Scheme. As fossil gas use declines, jet fuel production may become a good use of biogenic waste. This won't happen for at least 15 years though.
Cover crops	✘	?	✘	Cover crops are used to build and maintain soil health. Harvesting them for jet fuel would result in less healthy soil, and therefore less food produced.
Non-biogenic waste in MSW	✘	✘	✔	Non-biogenic municipal solid waste (MSW) is predominantly plastics, which can be chemically recycled back into usable plastic. Currently, plastic waste is diverted to either energy-from-waste (EfW) plants (41%), which generate electricity, or landfill (22%). It is not clear if EfW is a better use than jet fuel, but environmentally recycling is always better than both. Landfill is generally seen as a poor use of waste though.
Recycled Carbon Fuels	?	✘	✔	Recycled Carbon Fuels (RCFs) are fuels derived from waste plastic or industrial off gases. As above, plastic waste can be mechanically or chemically recycled. Figures for off-gases are hard to reliably get hold of, as the gases are varied and distributed.
Sewage	✘	?	✘	Sewage sludge is already predominantly used as agricultural fertiliser in the UK, with 87% of it applied to land to improve soil health.
Waste oils and fats	✘	✔	✘	Waste oils and fats are used to produce HEFA fuels, which is what current SAF invariably is. In the UK, this is almost certainly imported used cooking oil (UCO): 90% of SAF uplifted in the UK in 2024 came from Chinese UCO. UCO has been turned into biodiesel for years, and any that is used for jet fuel means that more fossil diesel is burnt. Using UCO for biodiesel yields greater overall emissions reductions than using it for jet fuel, suggesting that as long as diesel is burnt in the UK, UCO should be prioritised for biodiesel over SAF.
Waste tyres	?	✘	✔	Waste Tyres are either retreaded (14%), used in sports and play surfaces (17%), incinerated in cement kilns (6%), or exported (63%). Around 50 million used tyres are produced annually (approximately 700,000 tonnes). Environmentally, the best uses are always to reuse and recycle them. Pyrolysis produces tyre pyrolysis oil (TPO) that can be used for fuels or chemicals, though its optimal environmental role is unclear. In a net-zero future, the most sustainable path would be full material recovery: reprocessing tyres into high-quality rubber and steel that can be used to create new tyres, as done by companies like Genan.
Woody residues	?	?	✘	Woody residues are currently used for panel boards, animal bedding and electricity production. Bioenergy with carbon capture and storage (BECCS) is expected to play a role in the UKs future net zero power mix. It is unclear how much, if any, would be available for jet fuel.

Introduction

Waste is defined as "unwanted or unusable materials", which is odd, as the vast majority of 'waste' is taken and productively used by someone else: the proverb "One man's trash is another man's treasure" is grounded in fact. Biogenic waste has been used for centuries to help make soils healthier and make growing food more productive. Latterly, waste has been taken and recycled into other products, or burnt for electricity production, or used to create biogas that helps us warm our homes. Now, the aviation sector also wants to use some of that waste to create non-fossil jet fuel.

The theory around alternative aviation fuels - so-called sustainable aviation fuels, or SAF, is sound. Using non-fossil raw materials to create jet fuel means that fossil oil is displaced, and the carbon it contains stays under the ground. But this theory presumes that these raw materials are available in sufficient quantities that they can be channelled to the jet fuel industry. In many cases this is not true. The simple fact is that in the short to medium term, the supply of every single proposed SAF feedstock being discussed in the UK is not only limited, but often already used for something else that brings economic and environmental benefits. Given this scarcity, the question becomes: What is the best environmental use of a feedstock across the whole economy? What emerges is that some feedstocks should not be used for jet fuel. Indeed, doing so may increase overall emissions somewhere else by a bigger amount than the savings achieved in aviation.

There are two types of SAF: waste-based and e-kerosene. Waste-based can be derived from agricultural, food and garden waste, municipal solid waste (black bin bags), waste oils and fats, woody residues, sewage, cover crops, tyres, and recycled carbon fuels. E-kerosene is derived from hydrogen and captured carbon.

This paper is focused on UK SAF production, but many of the findings can be applied globally. Inevitably, there will be some countries that become better suited to making certain types of SAF as their economies evolve differently: for instance, SAF becomes a much better option for biogenic waste in a country that has no gas grid and a fully decarbonised electricity system. It's likely that the UK will be a net importer of SAF, so consideration should be given as to the alternative uses of feedstocks in exporting countries: the scarcity problem is global. It should also be noted that SAF should be used as close to its production site as possible, to reduce transport emissions. Therefore the most environmentally-friendly route is that producing countries satisfy domestic demand before exporting.

An overview of alternative uses

Most waste can already be turned into something that displaces fossil gas or fossil-derived plastic, or helps with growing food. Fossil gas is used in both the gas and electricity grids, and therefore displacing it has a direct environmental benefit. Fossil plastic is usually made from (fossil) crude oil-derived naphtha. Food is obviously eaten by everyone. With SAF displacing fossil kerosene, the question should be whether it is worth setting up a SAF industry *knowing that doing so will likely increase fossil fuel use in energy, plastics or food production?*

The Climate Change Committee (CCC) expects the burning of gas (which could be biomethane) with CCS and / or hydrogen to provide 48 TWh of electricity in 2050: only offshore wind (510 TWh), onshore wind (107 TWh), Solar (93 TWh and nuclear (79 TWh) provide more. Rather than being a theoretical issue for 2050 though, this is a problem for now: the Government's Clean Power Plan envisages a role in 2030 for "Low Carbon Dispatchable Power", which is exactly what burning biomethane would be. Biomethane is produced using biogenic waste - exactly the waste (agricultural, food and garden, cover crops, sewage and woody residues) being discussed for SAF production. The CCC's other proposed gas, hydrogen, is a core component of e-kerosene.

The CCC also expects gas to be burnt in people's homes into the late 2040s, and biomethane could displace fossil gas in the gas grid until that time. The main envisaged alternative to gas boilers are heat pumps (individual or communal), which require electricity, or low-carbon heat networks, which require a heat source.

All biogenic feedstocks can be used to help improve soil health, which ultimately means more and higher-quality food. Indeed, composting biogenic waste and spreading that back on the land has been used for centuries.

Detailed analysis of every feedstock can be found in the annexes. The analysis considers total volumes available, looks at what they are already used for, what they could be used for and, where possible, evaluates the best use environmentally.

Defining the question

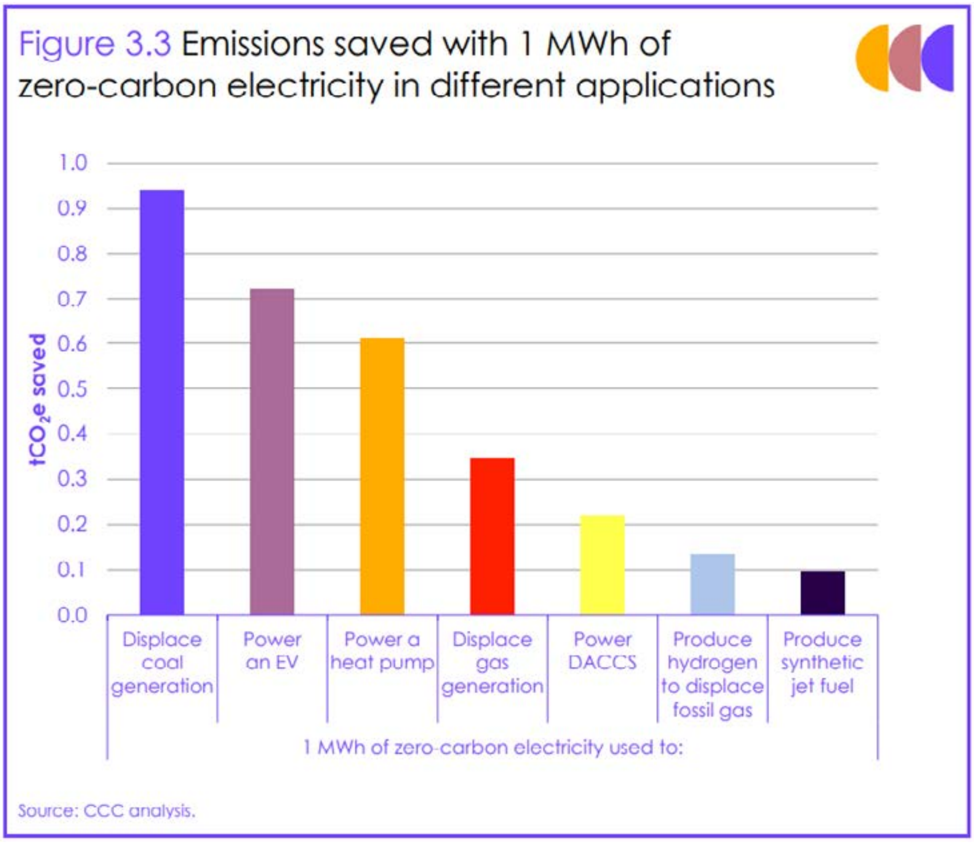
"What is the best environmental use of a feedstock?" is a question that, broadly, has not been considered in the SAF debate to date. Answering it means considering what the other current and future potential uses of a feedstock are, and the environmental effects those other uses have. To help answer this larger question, it is easier to split this into three smaller questions:

Question 1: What is the best current environmental use of a feedstock?

Today, broadly, feedstocks can be grouped together based on their current final usage. Food, garden and agricultural waste, cover crops, and sewage are all currently used to enhance soil health on agricultural land, ultimately ensuring that enough food can be grown to feed the nation. Waste plastic can be recycled (mechanically or chemically) into new plastic. Used tyres are similar in that they can be recycled back into their virgin components.

Waste oils and fats deserve further consideration, as they are what the bulk of SAF has been produced from thus far. In the UK, used cooking oil (UCO) forms the vast majority of the waste oils and fats category. All UK-produced UCO from restaurants is already collected and turned into road fuel. However, according to Government RTFO statistics, UK-produced UCO has never accounted for more than 7% of the total feedstocks used for (FAME) biodiesel (the vast majority of the rest comes from Asia). Using UCO to make biodiesel is a good use of a waste product, as it displaces fossil diesel. Any UCO that's funnelled towards jet fuel cannot be funnelled towards road fuel, so the more jet fuel created from UCO, the less road fuel created and the more fossil diesel is burnt. Crucially, since FAME biodiesel needs less energy to make it than SAF, it is better for the environment if UCO is used to create diesel and displace fossil diesel than to create SAF and displace fossil jet fuel.

E-kerosene is made from captured carbon and hydrogen, and the hydrogen itself is made using zero-carbon electricity. As can be seen from the graph, the Climate Change Committee suggests that not only is the best use of a green electron initially to decarbonise the grid, but that following that, other uses give a better environmental 'bang for your buck' than producing synthetic fuels.



Question 2: What is the best environmental use of a feedstock in a net-zero world?

Just because a feedstock is best used somewhere now doesn't mean that will always be the case. In a post-2050 net-zero future, the makeup of the power system and what generates electricity will look very different. How we heat our homes will also have dramatically changed, but how we produce food will, in all likelihood, look very similar to how it does now.

Soil health will therefore be as important as it is currently, and biogenic waste will be needed to ensure soil is healthy and food production is maximised. The UK's electricity grid will be dominated by renewables and nuclear, but there may still be scope for biomass / biomethane generators, energy from waste plants and hydrogen plants.

As and when there is an excess of zero-carbon electricity, then the case for using renewable energy to create e-fuel becomes stronger. Interestingly, though, the aviation sector could be competing with itself, in that zero-emission hydrogen aircraft should be operational in large numbers in this future world, and research suggests that these planes will require less energy overall (and therefore be a better environmental option) than e-kerosene-fuelled planes to move a given distance.

In a net-zero world, all surface transport should be zero-emission, which means all UCO can be funnelled towards jet fuel. It should be noted though that under current policies in the UK new diesel cars will be able to be sold until 2034, and new diesel trucks till 2039. This means those vehicles will still be on the roads post-2050.

Question 3: What is the feedstock already used for, and how much is there?

Many simply look at what happens to the different feedstocks today, and suggest that since some feedstocks are disposed of poorly, then at least the poorly disposed portion should be funnelled towards SAF production.

Again, feedstocks can be grouped. On the one hand, there are those where the current disposal methods are environmentally (and often socially) poor, versus those that are environmentally sound. In the poor group are food and garden waste, plastics and tyres. The second group consists of waste oils and fats, agricultural waste and sewage (the answer is less clear for the remainder).

Just over 13,000 tonnes of municipal waste went to landfill in 2022. And of that, just over 6000 tonnes were biodegradable (which will become a source of methane emissions as it breaks down). Landfilled matter predominantly comes from food and garden waste, and plastics. 63% of the UK's used tyres are exported, and research suggests that the majority of these tyres are shipped to India, sold on the black market and disposed of in ways that harm both the environment and human health.

However, the entirety of some feedstocks are already disposed of well. As mentioned, all UK-produced UCO is already collected and funnelled towards road fuel production. For centuries, cover crops have been ploughed back into the land, where they decompose and further aid soil health. Agricultural waste (animal sewage and plant matter) has historically been composted or spread directly back onto the land, but latterly is also used for onsite power production (via AD plants).

It is clear that in the first group of feedstocks there is 'genuine' waste. However, this does not automatically mean that this waste should be funnelled towards creating jet fuel, especially if there is a better environmental use for it.

Government Policy

SAF Mandate

The Government has implemented a SAF mandate, which requires fuel suppliers to provide increasing percentage levels of SAF until at least 2040.[1] As part of the mandate, specific sustainability criteria were implemented. Alternative uses of feedstocks were, broadly, not explicitly mentioned on a feedstock-by-feedstock basis. However, the Government has committed to conducting waste assessments at feedstock level, and as part of the first SAF mandate consultation response, states the following:

> *"The waste hierarchy will ensure that the mandate only supports true wastes i.e. those which cannot be prevented, reused or recycled, and those wastes for which the use of biofuel represents the 'best environmental outcome arising from that waste'."*

This commitment was further reaffirmed in the Government's response to the second SAF mandate consultation. Clearly, therefore, the intention is to ensure SAF production does not cause undue environmental problems elsewhere. Interestingly, this commitment was explicitly acknowledged with the justification for the HEFA cap:

> *"The purpose of a HEFA cap is to ensure that introducing a SAF mandate does not divert feedstock away from existing uses or raise concerns over sustainability by increasing demand for certain feedstocks."*

Clearly, this begs the question of how it applies to other feedstock uses. The SAF mandate expects waste-based SAF to provide the vast majority of future SAF until 2040, with e-kerosene contributing relatively little. Yet clearly all proposed waste feedstocks already have competing uses.

The Government requires 22% of jet fuel supplied in 2040 to be SAF, which was modelled to 2.9 million tonnes. However, the CCC expects only 1.8 million tonnes - 38% less - to be supplied.[2] Regardless of what the final future volumes end up being, some million tonnes of SAF needs millions more tonnes of feedstock. Where is it going to come from, and what other sectors of the economy will not receive it?

1 It is envisaged that percentage levels will keep increasing after 2040, but those specific levels will be defined at a later date.

2 The CCC expects SAF to account for 17% of its expected demand of jet fuel supplied in 2040. It expects overall demand to be lower than the Jet Zero Strategy and SAF mandate have estimated.

Advanced Fuel Fund and other Government Policies

Biogenic (agricultural, garden and food) waste is the best example of both the above points. Under recently enacted Simpler Recycling legislation, all businesses with over 10 employees now have to separate out their food waste and have it collected. Local authorities will have to collect separated food waste from all households from next year. This should result in less overall volume of municipal solid (black bin bag) waste. At the same time, the Government is encouraging new anaerobic digestion plants, which will create biomethane destined to displace fossil gas, to come online via the green gas support scheme. This scheme is funded by a levy on fossil gas suppliers. With the Government forcing an increased demand for the feedstock in another sector of the economy, does it make sense that any is funnelled towards SAF?

Competing Priorities

It should be acknowledged that there are two important reasons why SAF production could be encouraged and incentivised in the UK: for domestic energy security and job creation in a national industrial strategy. Commenting on these is outside the scope of this report.

Conclusion

Ideally, for SAF production, a feedstock would be available in sufficient quantities now, and the best use of it both now and in a net-zero world, would be to make jet fuel. The reality is that there is not a single feedstock where this is the case. Some will say that pragmatism is most important, others will say that long-term matters most, yet others will say that the short-term is most important.

It's also worth considering the question of what sector do we consider to be more important in a climate-constrained world? One side will say it is hard to argue that food production, "keeping the lights on" and heating homes in winter are more important than flying predominantly higher-income people on holiday. The other side will say that there are more options available to decarbonise the power and heat sectors, and so scarce feedstocks should be funnelled towards the harder challenge.

What is clear from this paper's analysis is that the best environmental outcome for a lot of waste feedstocks over the next 15 years is not using it to make SAF: that is, overall total UK emissions will be *lower* if some feedstocks are used in other sectors. Since SAF use is being encouraged for climate reasons, this undermines the fundamental argument for its use.

Annex A: Feedstocks

The following sections all follow the same format for the main feedstocks being proposed in the UK:

- Initially, an overview of the feedstock is provided,
- Followed by a comment on current usage and potential availability,
- Followed by comments on the best current environmental use
- Followed by comments on what the best use for the feedstocks is in a future net-zero world
- And then finally, other relevant considerations are given, such as whether other Government policies are directing them elsewhere, what other trade bodies (that may already use the feedstocks) suggest should happen, etc.

This goes through the main waste feedstocks under consideration in the UK, then considers hydrogen and carbon (the raw materials for e-kerosene).

Waste

Agricultural, Garden and Food (AGF) Waste

Overview

Agricultural and garden waste volumes should be relatively constant over time, whereas food waste volumes should reduce with a more efficient food system, which the Government is committed to pursuing.

Regardless of the source of the waste, all of it can be used for either composting (to improve soil health) or to produce biomethane in anaerobic digestion (AD) plants. Additionally, all biogenic waste can, and often is, also turned into cleaning products, which will always be needed.

Current usage and availability

Estimating exact figures for the amount of agricultural waste created is difficult, as many farming practices do not report what happens to the non-food residues that are left after crops, fruit and vegetables are grown. Furthermore, some uses of this 'waste' are clearly useful: for example, last year 34% of straw from cereal husks was used for animal bedding, 41% was sold or exchanged for animal bedding, and 10% was used for biomass.

Figures are more reliable for food and garden waste. In 2021, WRAP estimated that the UK produced 10.7 million tonnes of food waste. The vast majority (60%) of this came from households. Other sources came from farms (15%),[3] food manufacturing (13%) and hospitality (10%). Only 2% came from retail (supermarkets). Additionally, around 3 million tonnes of garden waste are produced by households annually.

Of the 10.7 million tonnes of food waste produced, WRAP estimates that 5.1mt was either spread on the land or used in an energy-from-waste plant. 2.7mt was used for animal feed, 1.9mt was composted or sent to an anaerobic digestion plant, and 1.9mt was sent to landfill. This is backed up by DEFRA stats

3 Separately, a WWF investigation found that 3.3 million tonnes of food, worth £1.8 billion, is wasted on UK farms each year.

that suggest that in 2022, 6.3 million tonnes of biodegradable municipal waste were sent to landfill.

87% of separately collected food waste is sent to AD plants, but many of the UK's local authorities do not currently collect food waste. However, this will change next year, as local authorities will be required to collect household food waste weekly. Furthermore, under the recently enacted Simpler Recycling legislation, any businesses with over 10 employees are now required to separate and have their food waste collected weekly.

The UK currently has over 700 AD plants,[4] which typically produce 50-60% biomethane, which could be and is injected into the gas grid, and 40-50% carbon dioxide, which can be captured and used or sequestered. They also produce digestate, which can be used for fertiliser (thus displacing fossil hydrogen-derived nitrogen-based fertilisers). As of April 2022, there were 39 Biomethane-to-gas plants in the planning process.

Best short-term environmental use

As mentioned above, the CCC envisages gas being burnt in homes until the late 2040s, and some biomethane may be burnt to provide electricity. DEFRA estimates that using food and garden waste in an AD plant results in a better carbon result than burning it in an energy-from-waste plant. Carbon details for agricultural residues are not available, but it can be presumed that the same results would occur. Since converting any AGF waste to SAF would require energy, and the resultant fuel is burnt in the air, it can be presumed that supplying AD plants is a better environmental outcome. Additionally, AD plants also produce digestate, which can be used as a nutrient-rich fertiliser.

Best net zero environmental use

Post-2050, if the UK no longer burns any gas for heating or industrial purposes, nor requires biomethane for the electricity sector, then using biogenic waste for SAF could be the best option. However, no data is available as to whether burning biogenically-derived SAF would be better environmentally than burning biomethane in a CCS-enabled gas plant and sequestering the resulting carbon (which would count as carbon negative under the UK's carbon accounting rules).

Other considerations

The Government is committed, via the Food and Drink Pact, to halving food waste by 2030. Once volumes have been reduced, it is also committed via the Resources and Waste Strategy to ensure that there is no biogenic municipal waste (food waste, garden waste, paper, cardboard) landfilled from 2030. Furthermore, Government policy already encourages new AD plants that will require additional feedstocks, via the green gas support scheme. This scheme ends in 2028, but the 2021 Biomass Policy Statement and later documents have stated it will be replaced with a mandate or industry-supported CfD scheme.

The Anaerobic Digestion and Bioresources Association (ADBA) suggests that UK AD plants could

4 As of 2024.

reasonably generate 100 TWh of green gas annually, should the right conditions be in place. For reference, the UK currently uses around 700 TWh of gas a year, which goes towards heating, industrial uses and electricity generation.

Cover Crops

Overview

Cover crops are plants that are sown after a main cash crop has been harvested to improve soil health (in preparation for the next cash crop). Traditionally, farmers would have either ploughed the crops back into the land (which would improve soil health further) or allowed grazing animals to eat them. A recent British Ecological Society report confirmed that using cover crops increases cash crop yields in both the short and long term. Conversely, soil degradation was estimated (in 2010) to cost the nation £1.2 billion annually.

Crucially, at no point would a cover crop be classified as "waste" - the value of a cover crop is the fact that the soil is more productive after its use. Should a jet fuel company wish to buy the cover crops, then the crops could not, by definition, be classified as waste: they would have value, would therefore be classified as an energy crop, and be banned under the existing SAF mandate regulation.

Current usage and availability

In theory, every field that grows a cereal crop could have a cover crop grown on it. Cereal crops cover around 3 million hectares, or 12% of the UK. Predominantly this is wheat (1,530,771 hectares), barley (1,193,919 hectares), oats (182,046 hectares) and oilseed rape (293,231 hectares) (2024 figures).

Best short-term environmental use

Should cover crops be harvested, then the soil would need additional fertiliser added afterwards to get to the same levels of health.[5] Fertiliser contains ammonia, which chemically is one nitrogen and three hydrogen atoms. Should cover crops become raw material for jet fuel, then more hydrogen would be needed for agriculture, and less would be available to e-kerosene production.

Best net zero environmental use

Should farming completely change and soil health becomes maintained through crop rotation and fallow periods, then in theory there could be a scenario where harvesting cover crops does not deplete soil health by too much.

Other considerations

5 It should be noted that there are currently no UK-based fertiliser manufacturers. Therefore encouraging additional fertiliser use could be a food security concern.

It's very hard to argue that growing food is less important than moving people around in an aeroplane. Soil health is essential for food production - over the longer term, the worse the soil is, the less food will be produced. The National Farmers Union supports the use of cover crops, but does not give explicit guidance on what should happen at the end of a cover crop's life.

Non-biogenic waste (in MSW)

Overview

Municipal solid waste should follow the waste hierarchy, in that any waste should be prevented where possible, then reused, then recycled and only then used for "recovery", which is where it could be used for SAF. This is crucial, as it means that if any part of the waste could be recycled, it should be.

Around half of household waste is currently recycled. Currently, the majority of non-recycled UK-produced municipal solid waste (both biogenic and non-biogenic) is sent to energy from waste (EfW) plants. As of 2023, there were 60 operating EfW plants, which produced 3.1% of the UK's electricity that year. 54% of the waste was estimated to be from biogenic sources (see the AGF waste section above). The vast majority of the rest can be presumed to be plastics.

Current usage and availability

According to the 4th monitoring progress report on the Resources and Waste Strategy, around 25 million tonnes of waste are collected by local authorities annually. Of this, the vast majority comes from households, with the rest from small businesses (larger businesses have waste collected privately). Of that, around 10 million tonnes are recycled, with the rest sent to landfill or EfW plants.

In 2022, in total (from local authorities and private collectors) 13 million tonnes of waste were sent to landfill, with 17.5 million tonnes sent to UK EfW plants.

Best short-term environmental use

In the long term, it is questionable if EfW plants will be needed in the future power system. However, the CCC's balanced pathway predicts a role for EfW plants fitted with CCS, because of their ability to capture carbon (and it then be sequestered). However, the CCC doesn't comment on the source of the waste (construction waste would still exist, which is outside the scope of this section). Regardless, if the Government's waste reduction targets are met, then absolute feedstock levels for AD, EfW or SAF plants (or all) will have dramatically reduced.

Other considerations

EfW plants will be included in the UK ETS from 2028, which means they will have to pay for the carbon emitted and therefore are being incentivised to install CCS facilities. EfW with CHP plants qualify for electricity CfDs, so government policy already has a revenue support mechanism in place to enable new EfW plants.

RCF

Overview

Recycled carbon Fuels (RCFs) are fuels produced from fossil wastes. Broadly, these fall into two camps: the fossil fraction of refuse (usually plastic waste) and industrial waste process gases. When RCFs are burnt, fossil carbon is released. No reliable figures for off gas production could be found, however there are reliable figures for how much plastic waste is produced. This section therefore focuses on plastics, and many of the points are similar to the section above.

Current usage and availability

According to the British Plastics Federation, in 2022 the vast majority of plastic waste was either burned to make electricity or sent to landfill. The table below details how the UK deals with its plastic waste:

	Kt in 2022	2022 Percentage
Total Plastic Waste	5589	100
Mechaincially recycled in the UK	880	16
Mechanically recycled abroad	773	13
Chemically recycled	1	0
Sent to energy from waste plants	2299	41
Sent to landfill	1239	22
Other	416	7

Source: British Plastics Federation Recycling Roadmap 2024 (percentages are rounded)

Best short-term environmental use

The supply of waste plastic in the medium term is limited. Usual current plastic recycling is via "mechanical" means, but this is limited as not all plastics can be mechanically recycled. However, chemical recycling can recycle everything. Chemical recycling is where waste plastic is converted (back) into chemical building blocks and then reused. The chemical recycling industry is as nascent as the SAF industry, but one plant on Teeside exists, and other UK plants are planned.

Since the carbon stored in plastics is inert, there is an argument that the best environmental use of waste plastic is to simply store it until it can be recycled. Provided that recycled plastic directly displaces fossil plastic, then less fossil oil will have been extracted.

Best net zero environmental use

In the long term, when fossil oil is no longer used to create plastics, then all plastics will have to be recycled to maintain the same levels in the system.

Other considerations

The Government is committed, via the 25 Year Environment Plan, to eliminating plastic waste by 2042. One of the tools it will use to achieve this is the Plastic Packaging Tax, which came into force in 2022, with plastic importers and manufacturers required to pay £217.85 per tonne for all plastic that contains less than 30% recycled plastic. These plans are mirrored in Scotland with the Circular Economy Bill (and in the EU with the Circular Economy Action Plan).

This is backed up by many countries, including the UK, negotiating a global plastics treaty, which should commit those countries to dramatically reducing the amount of virgin plastic produced. These negotiations were due to finish in 2024, but are still ongoing. Regardless of the outcome of the Treaty, the UK is already part of the High Ambition coalition to end plastic pollution before 2040.

Furthermore, the British Plastics Federation has produced a roadmap that envisages 65% of all plastic being recycled by 2030, and the Chemical Industries Association is very supportive of chemical recycling.

Interestingly, the default counterfactual fate (for determining a greenhouse gas lifecycle assessment) for RCF feedstocks under the current SAF mandate rules is against EfW plants that only produce electricity. This counterfactual will have to change as and when CCS technology becomes a standard feature on EfW plants, and will have to be updated as and when there are sufficient chemical recycling plants: The Department for Transport already has strict rules that state that the waste hierarchy must be strictly adhered to. This means that, should an RCF feedstock be able to be recycled, it should. What is clear is that the feedstock supply of waste plastic will become increasingly limited, and recycled carbon fuels from some industrial processes (e.g. steel production) should also reduce as these sectors decarbonise and change production processes. It should be noted that there will always be some RCFs from some industrial processes (notably cement production), but these future UK production volumes will be relatively small compared to current volumes.

Finally, according to research from Bellona, ZeroWasteEurope and Rethink Plastic, when municipal solid waste consisting mostly of plastic is turned into fuel, the overall impact could be worse than simply burning fossil kerosene.

Sewage

Overview

Sewage needs no introduction. It is produced by humans and disposed of by water companies in sewage plants, where the raw sewage is treated and turned into effluent (treated water) and sewage sludge (remaining solids).

Current usage and availability

In 2022, the UK produced 811,693 tonnes of sewage sludge. 87% of treated sludge is used on agricultural land as a fertiliser. 4% is burnt, 3% is used in industry (typically as a fuel for cement production), and 6% is used in land reclamation. Obviously, levels should remain broadly constant: only rising or falling with any population level changes. Potential SAF producer Firefly estimated that if all UK sewage were turned into jet fuel, it would equal 5% of the country's jet fuel demand.

Best short-term environmental use

For centuries, sewage has been used as fertiliser in agriculture. Initially, it was spread straight onto the ground. More recently, it has been treated first. Should less be available to agriculture, more fertiliser would be needed, which would involve using more hydrogen (which is a feedstock for e-kerosene).

Best net zero environmental use

Food will obviously still be needed in a net zero future, so the demand for fertiliser will still exist. Should British farming change completely and fertiliser demand fall dramatically then some sewage sludge could be available for jet fuel.

Other considerations

None.

Waste Oils and Fats

Overview

Today, any airline using SAF is invariably using HEFA (hydrotreated esters and fatty acids), which is jet fuel made from vegetable oils, waste oils or fats. Vegetable oils come from purposely grown crops, so are banned under the UK SAF mandate; therefore, any UK HEFA comes from waste oils or waste fats. Invariably, though, this has been Asian used cooking oil (UCO). In fact, provisional figures suggest that

90% of UK SAF uplifted in 2024 came from Chinese UCO.

UCO is already turned into FAME biodiesel, and this has been used as road fuel in the UK for nearly two decades. When producing HEFA, some HVO (a type of biodiesel) is produced as a side-product.

Despite being the most mature SAF technology, there are no dedicated HEFA production plants in the UK, although some HEFA is produced by the Phillips 66 plant on Humberside via co-processing.

Current usage and availability

Around 250 million litres of UCO are collected in the UK annually. This could produce around 167 million litres of jet fuel,[6] which would equal only 1.2% of the 11.1 million tonnes of jet fuel burnt in 2023.[7] UK-produced UCO only equals around 7% of the total UCO used to create British-burnt biodiesel. The vast majority of the feedstock is imported from Asia.

If UCO is funnelled to jet fuel, there is a displacement risk that the counterfactual use of the UCO will be met with virgin palm oil. The SAF mandate will act as an extra demand pull for more UCO, but unless people change their diets and start eating more, supply levels, by definition, won't change, so other industries will look for alternatives to UCO. The same is true for animal fats. We already know, via a Farm Europe investigation, that some of the supposed UCO used in the UK is, in fact, virgin palm oil. This is supported by the European Biodiesel Board admitting that there were likely fraudulent declarations in its imports of Chinese biodiesel.

Best short-term environmental use

Whilst diesel is burnt as road fuel, displacing fossil diesel will be better environmentally than displacing fossil jet fuel. This is because overall emissions reductions are higher if waste oils are used for FAME than for jet fuel. Producing FAME biodiesel requires less energy than producing HEFA SAF, and burning a unit of diesel emits slightly more carbon than burning a unit of kerosene.

Best net zero environmental use

The clear intention of Government policies is to completely phase out diesel use. New diesel cars and small trucks will not be allowed from 2035, whilst new large diesel trucks will not be allowed from 2040. There are no policies in place yet to electrify static generators, non-road mobile machinery or rail (although half the UK's rail lines have been electrified).

Regardless, environmentally, it is always better to use a product closer to where it is produced, to avoid transport emissions. The Chinese Government has announced that it will implement a SAF mandate, although full details have not been revealed. To prepare for this, in December 2024, China changed the tax rules around exporting UCO, to make domestic use more preferable. Total UCO exports fell 60% between November and December 2024.

6 Using the StudioGearUp conversion figures.
7 Presuming 1 tonne of jet fuel equals 1250 litres.

Other considerations

Road fuel suppliers are already required to supply minimum percentage levels of biodiesel, but some end users with road fleets are looking to take this further. Recent announcements have come from DPD (which plans to switch its entire fleet of 1600 HGVs to HVO use), Royal Mail (which plans to use 2.1 million litres of HVO annually), Fed Ex (which started a HVO trial in November 2023), Travis Perkins (which is switching 200 vehicles), DHL (has plans to use 24 million litres of HVO across 20 sites annually), and PepsiCo (has plans to drive 9 million km on HVO annually). ScotRail has also announced it will be trialling using a type of biodiesel (HVO) on its trains.

The renewable transport fuel obligation is also changing: the percentage share of total biofuels supplied by road fuel suppliers will rise from 9.6% now to 14.6% in 2032. It should be noted that this rise could be covered by other types of biofuels, though.

Outside of transport, the Government recently committed to consulting on the use of renewable liquid fuels in rural properties that currently are heated by kerosene (also known as heating oil). There are already 150 oil-heated homes that have converted to running on HVO, as part of a demonstration project organised by trade bodies UKIFDA and OFTEC.

Not one announced project has confirmed where the source of the additional (marginal) waste oils will come from.

Waste Tyres

Overview

The UK produces around 50 million used tyres annually that need to be disposed of. Current reuse uses for them are; retreading, which is where a new tread is added to a worn tyre; and shredding and used for 3G sports pitches, equestrian centres and children's playgrounds. They can also be converted, via pyrolysis, into oil, carbon black and steel. Used tyres have been banned from landfill since 2006.

Wastefront hopes to process up to 10 million tyres a year at its facility in the North East. Construction started in February 2025.

Current usage and availability

According to the British Tyre Manufacturers Association (BTMA), 14% of used tyres are retreaded, 17% are turned into rubber crumbs for playing and sports surfaces, 6% are incinerated in cement kilns, and 63% are exported. Of exports, the main destination was to India for pyrolysis, despite the importing of tyres into India for pyrolysis being banned.

Best short-term environmental use

According to the waste hierarchy, reuse and recycling should always take precedence over energy recovery. Reuse and recycling can be done via retreading tyres; turning tyres into children's playgrounds, 3G sports pitches or equestrian centres. It is unclear what the best environmental use of tyre pyrolysis oil actually is, but it is worth noting that TPO can be turned into diesel and chemicals, as well as jet fuel.

Best net zero environmental use

In a circular economy, the best use of end-of-life tyres is to turn them back into raw materials and use those materials. In this respect, one company stands out: Denmark's Genan. Its basic business model is to take waste tyres and process them back into the constituent rubber and steel, the quality of which is so high that it can be substituted for virgin rubber and steel. In other words, the waste tyres could be recycled into new tyres.

Other considerations

The British Tyre Manufacturers Association does not have a definitive position on what should happen to used tyres, but is committed to 100% of tyres going into "compliant recovery routes". Its website does flag that pyrolysis would produce some component parts that could be used in new tyres. Conversely, the Tyre Recovery Association has called on the Government to ban the export of whole tyres as *"the UK is […] exporting an environmental problem that it is capable of processing domestically".*

Woody Residues

Overview

Woody residues are the waste wood products from wood use, so they include offcuts and sawdust from saw mills and the leftover parts (twigs, bark, etc) of a tree after logging.

Current usage and availability

The UK forest area available for wood supply is 3.11 million hectares. (Straw is also used for electricity production: just under 1 million tonnes per annum). According to the Wood Recyclers Association, around four and a half million tonnes of waste wood are generated annually. Waste wood is used for the panel board industry, as well as for animal bedding, equestrian surfaces, and play areas. More recently, waste wood has been burnt to produce electricity. Small biomass plants (excluding Drax) generate around 1% of the nation's electricity needs, whereas Drax itself generates around 5%.

Best short-term environmental use

Panel boards and animal bedding will always be needed, whilst the CCC envisages there being around 10 TWh of electricity provided by BECCS until at least 2040, although it should be noted that this is spread across all types of bioenergy and not limited to woody residues.

Best net zero environmental use

The exact make up of the future net zero electricity system is unknown. If woody residues are not used in the electricity system, then some will be available to make jet fuel.

Other considerations

All of the UK's woody residues (whatever the type) could, in theory, be used at Drax Power Station in North Yorkshire. The power station currently sources the majority of the wood pellets it uses from North America. Wood pellets are classed as renewable, although that is controversial.[8]

E-kerosene

E-kerosene has two distinct feedstocks: carbon and hydrogen (which under UK SAF mandate rules has to be green). Both are detailed below.

Carbon Dioxide (biogenic, industrial waste and air-captured)

Overview

Carbon dioxide (carbon) is an essential component of any hydrocarbon. Environmentally, if a company has captured a unit of carbon from somewhere, be it from industry, from organic matter or directly from the air, then it is clear that the best use of it would be to permanently sequester that carbon under the sea.

Current usage and availability

In theory, an almost unlimited amount of carbon could be captured by direct air capture (DAC), but that requires a huge build-out of zero-carbon generation. Currently, there are no large-scale DAC plants in the UK. City Science assessed the feasibility of UK DACCS (direct air carbon capture and storage) for the Climate Change Committee and, under its standard scenario, estimated that 23 MT/CO_2 could be captured in 2050.

Biogenic and industrial waste carbon can also be captured in EfW and gas power plants and industrial sites that have CCS technology attached to them.

8 For example, see this published by the World Resource Institution, or this, published in Nature.

Best short-term environmental use

In both the short and long term, there will always be a trade-off between releasing captured carbon into the air versus sequestering it underground. However, because it will always use less energy and be cheaper to burn fossil carbon and then sequester an equivalent unit of captured carbon underground than to use it as a building block of jet fuel, environmentally, whilst fossil crude oil is still being refined into kerosene, sequestration is the best environmental outcome. Academic research suggests that twice as much energy is needed to capture carbon and store it rather than turn the carbon into e-kerosene.

Best net zero environmental use

See paragraph above.

Other considerations

The Government has supported carbon capture projects via the Direct Air Capture and Greenhouse Gas Removal Innovation Programme, which closed in November 2024. Its current aim is to construct a CfD-type GGR Business Model, which would pay businesses to capture and permanently remove carbon from the air or sea. The Government's ambition is to remove 5 Mt/CO_2 a year by 2030, rising to 23 Mt/CO_2 a year by 2035 and 75-81 Mt/CO_2 by 2050. (The CCC's seventh carbon budget estimations are more pessimistic: it expects 2.6 (Mt/CO_2/year) to be removed in 2030, rising to 12.7 in 2035 and 35.8 annually in 2050). It should be noted that these targets are for sequestered carbon: any additional carbon captured and used in jet fuel would be in addition to this.

Crucially, any future business model would only pay out for sequestered carbon, so any carbon captured and used for jet fuel would not qualify for the scheme, although the scheme's strike price would set the minimum price for any carbon demanded by UK SAF producers.

The CCC envisages that DAC'd carbon will be used as a feedstock for aviation starting in 2033 and that just over 4 MtCO_2 will be provided to jet fuel via DAC in 2050.

Hydrogen

Overview

Where industries have the option to electrify, they should, as this will always be the most energy-efficient (and therefore cheapest) option. However, it is currently envisaged that UK-produced hydrogen will be used for steel,[9] long-duration energy storage in the power sector, long-distance shipping, chemicals and high-temperature industrial processes. Hydrogen-derived SAF would have to compete with these sectors.

Incredibly, it would also have to compete with the nascent zero-emission flight industry: academic research suggests that using hydrogen combustion or fuel cell planes will use less energy than planes powered by e-kerosene (which would, of course, not emit greenhouse gases whilst in use).

Only green hydrogen qualifies for the UK's SAF mandate, so only that is considered here. The mandate has a specific obligation to provide e-kerosene from 2028, set at 0.2% of jet fuel supplied. This rises to 0.5% in 2030 and 3.5% in 2040 (although it should be noted that suppliers can "buy out" if they cannot supply intended volumes).

It should be noted that hydrogen is a short-lived climate pollutant.

Current usage and availability

Total UK hydrogen use in 2023 was 474 Kt, with refineries using just under 60% of that, and chemical (including ammonia) production using 30%. 473 kt - well over 99% - of that was grey hydrogen.

To generate just 1% of 2030's expected jet fuel demand would require 0.68 GW, or nearly 14% of all anticipated green hydrogen production. This would need 5.9 TWh of electricity (for context, total wind generation in 2021 was 49 TWh). Clearly these are substantial figures.

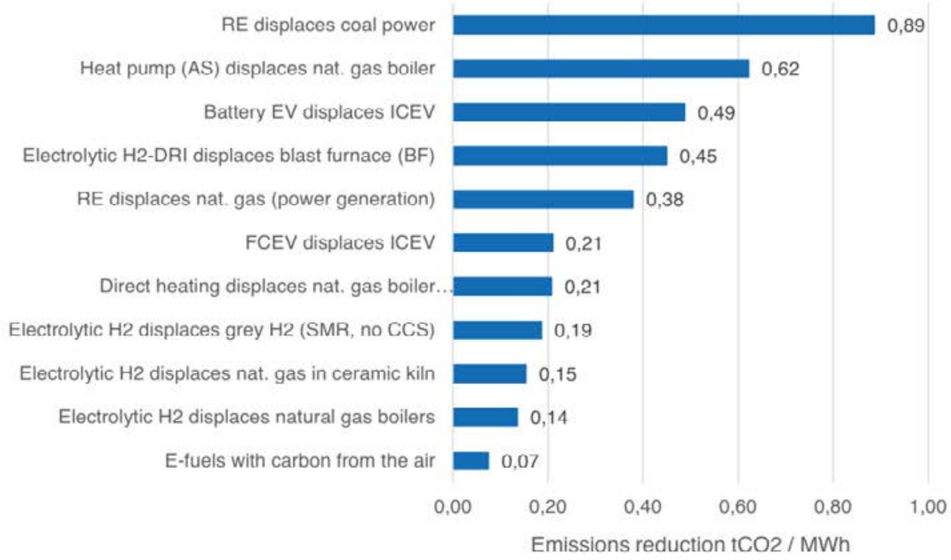
In theory, in the long-term the amount of hydrogen available is only limited by the amount of zero-emission electricity available. However, in practice there are many competing demands for zero-emission electricity, and it is unclear that there will be enough for jet fuel before 2050.

Best short-term environmental use

In the short term, using electricity for almost any other use (e.g. decarbonising the grid, or powering electric vehicles) would result in significantly greater emissions reductions than producing hydrogen for use in e-kerosene. The following graph from Bellona demonstrates, there are better uses environmentally than producing hydrogen. This holds true until the power grid is decarbonised, heat pumps replace the vast majority of gas boilers, and all surface transport is electrified. Very conservatively, this won't happen till 2040 at the earliest.

9 Whilst electric arc furnaces can be used to make steel itself, hydrogen would be needed to prepare the iron for primary steelmaking. See E3G's June 2024 briefing on this.

Chart 1: Emissions savings from using 1MWh of renewable electricity for various applications



FCEV: Fuel Cell Electric Vehicle, EV: Electric Vehicle, ICEV: internal Combustion Engine Vehicle RE: Renewable Electricity, DRI: Direct Reduced Iron

Source: Bellona analysis.[5] The use of renewables will usually focus on electricity but in some cases may include a component of renewable heat.

Crucially, in the short term, the best environmental use of the underlying feedstock (renewable electricity) is to decarbonise the existing power system.[10]

The CCC has suggested that hydrogen should be used for long-duration energy storage in the future net zero power system, which Labour is trying to implement by 2030. Crucially, the CCC also envisages there being a shortfall between overall hydrogen demand and UK supply. Societally, it is hard to argue that SAF is more important than "Keeping the lights on", and therefore the power sector needs should be prioritised.

Best net zero environmental use

In the long-term (post-2050), hydrogen is the only feedstock that has the potential to be always available in large amounts without any significant adverse environmental effects or better environmental uses. However, environmentally, it is better to use hydrogen directly in a plane rather than use SAF, as SAF still emits the same amount of greenhouse gases as fossil kerosene when burnt, whereas using hydrogen dramatically reduces the greenhouse gas emissions (and in the case of hydrogen fuel cells usage, eliminates them all apart from water vapour). Loganair has said it wants to run the first commercial hydrogen fuel route in Scotland.

Even after the UK's power sector is decarbonised, there will be hydrogen demand from other sectors. Notably, replacing grey hydrogen in fertiliser manufacture would have a significantly greater decarbonisation impact. However it should be noted that the UK does not currently have any fertiliser producers.

10 This applies to both the UK and any other country we may import hydrogen-derived SAF from. The UK plans to have a 95% decarbonised power system by 2030, but this is not true of other nations. According to Our World in Data, in 2021, there were only 19 countries where over 90% of their electricity came from low-carbon sources.

Other considerations

The UK's Hydrogen Strategy was published in August 2021, and explains the steps the Government is taking to encourage hydrogen production, with ambitions for 5GW of fossil-free (green) hydrogen production. It therefore consists of supply-side policies. The SAF mandate is the first explicit demand-side hydrogen policy (with no others on the horizon), however there is no requirement for any resulting SAF to be produced in the UK.

There are currently no large commercial-scale green hydrogen producers in the UK, however the Government is supporting developers via the Hydrogen Production Business Model, and has allocated budget to developers across two rounds (known as HAR1 and HAR2).

Trade body Sustainable Aviation sees a role for both zero-emission aircraft and SAF in the future. Its roadmap predicts that 16% of the hypothetical reduction from a do-nothing baseline comes from zero-emission planes, whilst 39% comes from SAF.

Annex B: Advanced Fuel Fund Winners

Name	Feedstocks	Predicted Annual Jet Fuel Volumes	Due to be operational	Awarded (£m)
WINDOW TWO				
Abundia Biomass-to-Liquids	Sawmill and forestry residues	2.6 kt	2026	4.484
Alfanar Energy	MSW	124.2 kt	2028	8.664
Arcadia e-fuels	Biogenic CO_2 and green hydrogen	67.7	2028	12.341
Carbon Neutral Fuels	Direct air capture and green hydrogen	12	2027	12.341
Esso Petroleum	MSW	179	2030	6.065
Nova Pangea Technologies	Agricultural and woody waste	2.7	2025	9.063
OXCCU Tech	Biogenic CO_2 and green hydrogen	7.4	2026	2.814
Willis Sustainable Fuels	CO_2 and green hydrgoen	14	2026	4.721
Zero Petroleum	Biogenic and direct air capture CO_2	6.1	2026	3.492
WINDOW ONE				
Alfanar Energy	MSW	86.6 kt[11]	2028	11.001
Fulcrum Bioenergy Ltd[12]	MSW	83.7	2027	16.74
Lanzatech UK	Steel mill off gases	79	2026	24.961
Velocys	MSW	37.4	2028	27
Velocys	Fossil CO_2 and green hydrogen	Not given	Not given	2.523

11 This is different to the Window two figure. No explanation given on the competition winners page.

12 Fulcrum Bioenergy filed for bankruptcy in September 2024.