Preparing for take off

Speeding up the switch to sustainable aviation fuel

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Summary

> **The spotlight is falling on aviation to do more to mitgate its climate impacts.”**

Unlike most other sectors in the UK, aviation’s climate impacts have not only grown significantly since 1990 but they are not predicted to fall for at least another decade.

As other sectors chart their course towards the 78 per cent reduction in greenhouse gas emissions, below 1990 levels, required by 2035, the spotlight is falling on aviation to do more to mitgate its climate impacts.

There are plenty of promises, from both the aviation industry and the government, that we will fly in zero emission aircraft at some point in the future. But, until that becomes a real option, we must rely on other solutions.

Sustainable aviation fuel (SAF) can play an important role in decarbonising the sector, especially power-to-liquid (PtL) fuel, which can offer a 100 per cent reduction in carbon emissions compared to fossil fuel kerosene. But this is not yet available at a level that can offer significant emissions cuts, especially considering the predicted growth in passenger numbers.

The way forward for more sustainable aviation is to employ a mix of measures, which involves

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The UK could cut aviation emissions twice as rapidly as the Committee on Climate Change recommends, if necessary infrastructure was scaled up quickly.”

immediately deployable changes, alongside scaling up technologies that can have a significant impact in future. This means starting to consider measures which manage demand in case technology does not offer the expected emissions reductions; for instance, using well targeted, fairer taxes on fossil fuel kerosene, keeping emissions down while the technological solutions have time to scale up. And, for fuel development, gradually increasing over time the amount of PtL blended with conventional jet fuel.

To make PtL, two primary feedstocks are needed: hydrogen and CO_2. For it to be zero carbon, the hydrogen must be green (from renewable energy sources) and the CO_2 must be captured from the atmosphere via direct air capture (DAC), not from another fossil fuelled process like industrial carbon capture.

A barrier to development is that these two industries are not yet mature enough to deliver PtL at scale; there are no commercial DAC or PtL plants in the UK. And green hydrogen production requires large amounts of renewable energy, competing with a range of other demands for green power.

However, our analysis shows PtL development in the UK could cut aviation emissions faster than the Climate Change Committee considers feasible, if more of the necessary infrastructure was scaled up quickly.

> The cost of inaction by the aviation industry will be huge."

A further barrier to growing the PtL industry in the UK is cost. Right now, PtL is more expensive than fossil fuel kerosene to produce. But, while there are significant upfront capital costs associated with development, DAC and green hydrogen can be used for other purposes in a decarbonising economy beyond aviation, and so growing them is a sound investment for the government. When the day comes that zero emission aircraft can replace existing aircraft, both industries will continue to be valuable to other areas of the UK economy.

The cost of inaction by the aviation industry, on the other hand, will be huge: there will be considerable social and economic dangers in exceeding the 1.5°C global warming target set by the UN Paris Agreement. This industry is now one of few outliers still pouring unabated greenhouse gas emissions into the atmosphere.

The UK imports over 70 per cent of its jet fuel, so moving to a domestic SAF industry can improve energy security.[1] As it relies on technologies not yet scaled up globally, it is also an important industrial opportunity to promote UK global leadership in sustainable aviation.

Our recommendations to the government to speed up sustainable aviation are:

Introduce a PtL fuel target, starting in 2025, alongside the wider mandate already proposed for SAF. This should be 0.7 per cent PtL in the fuel blend in 2030, rising to 28 per cent in 2050.

Reform aviation taxes, through measures such as a kerosene tax to fund PtL deployment.

Prioritise uses for green hydrogen for hard to abate sectors, including aviation.

Consider new measures to manage passenger growth if technology does not reduce emissions as expected.

Introduction

"In 2019, the UK's share of international aviation emissions peaked at its highest ever level."

Aviation is one of the most intractable problems of decarbonisation. It is currently responsible for around eight per cent of UK emissions, the majority of which (93 per cent) are from international aviation, which is now integrated into the UK's net zero carbon target. Unlike other parts of the economy, aviation emissions are rising and now sit 88 per cent above 1990 levels, as a result of steady increases in passenger demand.[2]

As the climate impact of other sectors dwindles, the share from flying will increase proportionately, assisted by policy allowing unconstrained growth in air travel.[3] In 2019, the UK's share of international aviation emissions peaked at its highest ever level. Despite government commitments to cut greenhouse gases by 78 per cent by 2035, there is little evidence to show the aviation sector will make significant progress towards this target and there are few supporting policies to cut emissions.

The Department for Transport (DfT) has published multiple pathways for aviation that could come to fruition, depending on which technologies are most cost competitive and scalable. The main options for cutting carbon emissions are sustainable aviation fuel (SAF), zero emission aircraft and managing passenger numbers. Developing SAF is a primary choice for the government. This looks like a sensible approach, if integrated with other solutions; however, there are no significant policies or regulations in place to encourage and guide its use.

In this report, we consider policies related to SAF, including the types of alternative fuel available and the consequences of different levels of uptake. We provide recommendations on how best to employ them to reduce aviation emissions.

Decarbonising aviation in the UK

> **"Even with ambitious policy and a technological breakthrough, emissions are not expected to fall until roughly 2030."**

Despite all the potential of technological solutions and advancements to cut carbon from aviation, such as more sustainable fuel and battery powered aircraft, it is important to be clear that these are not yet deployable at scale, and some may not be for decades.

At a time when the rest of the economy is legally obliged to reduce emissions by 78 per cent by 2035, it is reasonable to expect a reduction in aviation emissions, by whatever means possible, in the short term.

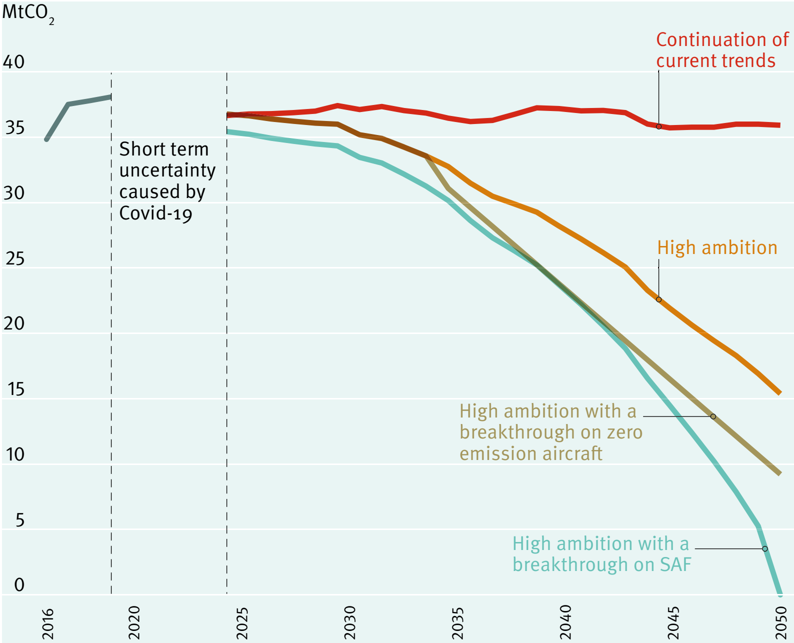
Demand reduction policies, such as a frequent flyer levy, which help to reduce the number of flights taken, are not reliant on technology and could be introduced today. This would help to reduce the risks of failure or delay in a technology-centred approach while cutting emissions in the short term, which is essential to address climate change and keep the possibility of meeting international climate targets within reach.

The government has, nonetheless, made it clear that zero emission aircraft and SAF are its priority solutions to decarbonising aviation. Transport Secretary Grant Shapps has said "We will still fly on holiday, but in more efficient aircraft, using sustainable fuel."[4]

The Jet Zero strategy

The Department for Transport (DfT) mapped four potential pathways for aviation emissions in its Jet Zero further technical consultation, as shown in the graph on page eight.[5] Even with ambitious policy and a technological breakthrough on SAF or zero emission aircraft, emissions are not expected to fall until roughly 2030 across all scenarios.

DfT's Jet Zero strategy emissions pathways[6]



“Zero emission aircraft are currently not developed at a viable level to contribute to the decarbonisation of aviation.”

While the industry gears up for zero emission aircraft, the government is laying the groundwork for the uptake of SAF, in the hope that this will be an interim solution.

It established the Jet Zero Council in 2020, a cross-industry collaborative group tasked with developing solutions to bring the aviation sector closer to net zero, which is primarily focused on research and development on zero emission aircraft and SAF. DfT also confirmed a 2030 SAF target of ten per cent in the 2021 net zero strategy, placing an obligation on fuel suppliers to meet a minimum level of SAF in the jet fuel blend up to 2050.

SAF vs zero emission aircraft

Zero emission aircraft, powered by hydrogen fuel cells or batteries, are currently not developed at a viable level to contribute to the decarbonisation of aviation, although some very light aircraft have undertaken short haul flights with success. There is rightly speculation about when these aircraft will be able to reduce emissions from the sector. DfT modelling assumes that fully electric aircraft and hydrogen aircraft will not be operational by 2050.

There could be breakthroughs in new aircraft before 2050, but the time needed to design, test, manufacture and scale up would still be several decades, leading to likely widespread commercialisation in the 2040s, and probably only on domestic routes which currently make up just three per cent of aviation emissions in the UK.[7]

> **"Sustainable aviation fuel can be added to existing aircraft fuel and has lower overall lifecycle carbon emissions than fossil fuel kerosene."**

SAF can be added to existing aircraft fuel and has lower overall lifecycle carbon emissions than fossil fuel kerosene. Regardless of the type used, it is still responsible for other sources of climate change, beyond CO_2, such as particulate matter, nitrogen oxides and water vapour, all of which contribute to atmospheric heating.

While not a perfect solution, SAF can be used to bridge the gap until other solutions are developed. Fortunately, industries required to produce it – direct air capture (DAC) and green hydrogen – can also be used in other sectors, so scaling them up will mean they are ready for use elsewhere, if and when zero emission aircraft displace the need for SAF in the future.

Sustainable aviation fuel: the bigger picture

"The CEO of Heathrow Airport says investors are keen and ready to invest in SAF projects."

The UK uses 14 billion litres of aviation fuel a year and this is set to increase if passenger numbers rise as steeply as DfT expects.[8] The move from fossil fuel kerosene to more sustainable fuel will be no easy feat and, while government and industry have started to acknowledge the challenge, for example with the establishment of the Jet Zero Council, there are significant policy levers missing which could stimulate industry investment and the development of alternative fuels.

John Holland-Kaye, the CEO of Heathrow Airport, says investors are keen and ready to invest in SAF projects but he has highlighted that the correct policy framework is needed to give investors confidence.[9]

Types of SAF

Despite its name, SAF is not necessarily ‘sustainable’. Some types are derived from non-fossil fuel sources but still emit greenhouse gases and have other environmental impacts.

DfT’s SAF mandate consultation defines three alternative types:

Waste-based biofuel

There are two main types of biofuel:

- **Crop-based biofuel**
  Derived from crops such as palm and soy, these fuels could displace food production and directly or indirectly contribute to deforestation. DfT’s SAF mandate consultation states that SAF produced from food or feed crops will not be eligible for use under the mandate.
- **Biogenic waste fuel**
  These are derived from waste products such as used cooking oil and agricultural residues. There is limited availability of truly sustainable biomass of this nature meaning it could not feasibly make up 100 per cent of the UK’s jet fuel demand.

Recycled carbon fuel (RCFs)

These are produced from unavoidable fossil fuel wastes, such as waste gases from industry. DfT includes these fuels as an option to increase the production of SAF. However, there are concerns that including them will tie the government into long term contracts with fossil fuel suppliers.

Power-to-liquid fuel (PtL)

This is non-biological transport fuel. It has low land use impacts, as it is synthetic, and can be carbon neutral under certain circumstances. When derived from renewable energy sources (green hydrogen) combined with CO_2 from direct air capture (DAC), it is carbon neutral. DfT also proposes that nuclear power could also be an eligible energy source. Manufacturing costs are predicted to fall as the technologies mature. However, cost is currently a barrier, making greater use of PtL unlikely without further legislation.

SAF types compared

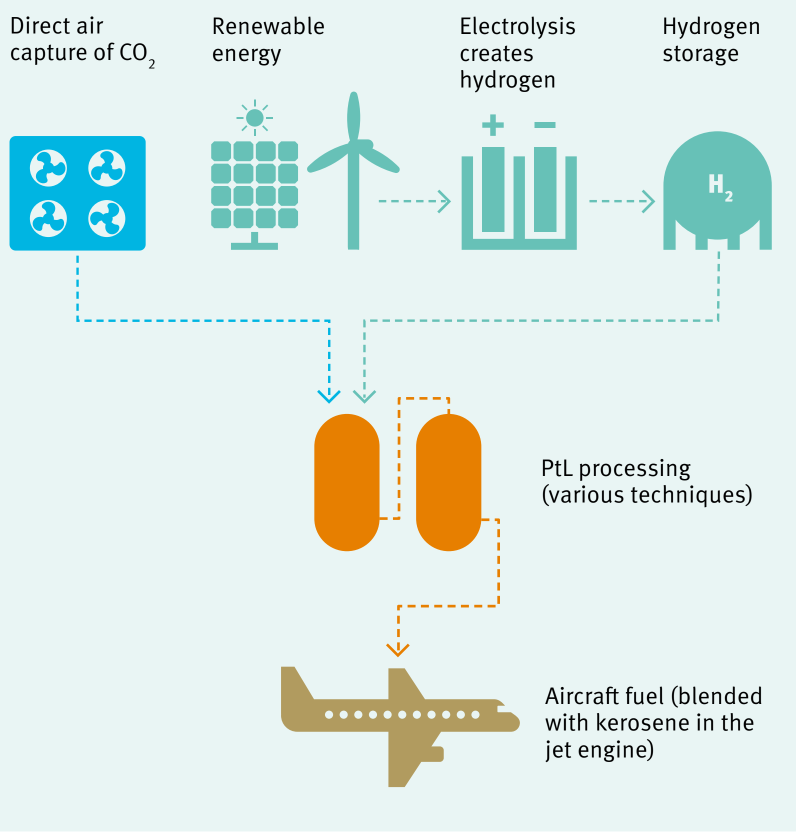
The analysis below shows that PtL fuel, in particular, has clear environmental benefits that other types of SAF being considered by DfT cannot deliver. (For more detail on this analysis, see annex one on page 31).

	Power-to-liquid fuel	**Waste-based biofuel**	**Recycled carbon fuel**
Emissions reductions			
Environmental impacts			
Costs			
Scalability			

Power-to-liquid fuel in focus

Power-to-liquid-fuel (also known as synthetic fuel or ekerosene) is created with electrical energy. Like other SAF types this can be used in existing aircraft engines without modification to engine infrastructure or fuelling processes, since it is chemically the same as the fossil fuel kerosene used in aircraft.

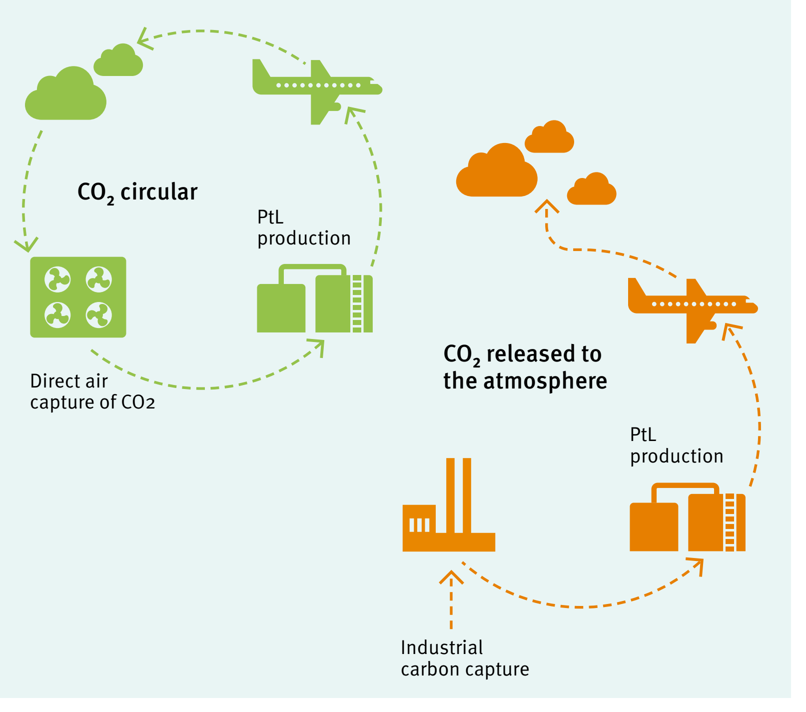
How PtL is made



As we have discussed, PtL is the only net zero carbon option fuel for flying, when it is derived using green hydrogen and direct air capture.

The best way to create PtL is through a circular process (ie a closed CO_2 system, which reduces lifecycle emissions to zero) with direct air capture (DAC). To ensure CO_2 circularity when producing PtL, the carbon used to manufacture the fuel must not come from bioderived or fossil fuel sources, but from existing carbon already emitted into the atmosphere. When PtL is burned in the jet it emits an equal amount of carbon as was used to make it. By contrast, when PtL is produced using CO_2 from fossil fuel or bioderived sources, the CO_2 is still released to the atmosphere.

Why power-to-liquid fuel made using direct air capture is carbon neutral



Options for PtL uptake

To test the viability of increasing the amount of PtL in a jet fuel blend, we analysed three scenarios to 2050 with different targets for uptake (see below). These show the range of possible savings and the infrastructure that would be needed to achieve them which, in some cases, will be a limiting factor.

> “Our medium ambition scenario offers a 50 per cent decrease in CO_2 emissions compared to the low ambition scenario.”

Three scenarios for PtL

Low ambition

Targets	2030	2050
SAF	2.1%	25%
PtL	None	8.1%

This projection is based on the Climate Change Committee’s (CCC’s) central, ‘balanced pathway’ projection in its sixth carbon budget report.[10]

Medium ambition

Targets	2030	2050
SAF	5%	63%
PtL	0.7%	28%

The European Commission set these targets, under its ReFuelEU initiative, to accelerate the uptake of sustainable fuels.[11] We have applied the same targets to the UK. This scenario largely aligns with the CCC’s ‘widespread innovation’ scenario.

High ambition

Targets	2030	2050
SAF	10%	75%
PtL	2%	50%

This scenario combines Germany’s domestic PtL uptake targets, which are the most ambitious in Europe, with the UK’s ten per cent SAF by 2030 target.

While these three scenarios represent levels of SAF and PtL that the government could set, unplanned externalities could cause a deviation from expectations. For example, Microsoft recently introduced a corporate obligation that its own carbon price will increase by 600 per cent, to discourage polluting business travel. Initiatives like this could lead airlines and fuel suppliers to accelerate the uptake of SAF to secure lucrative business partnerships.

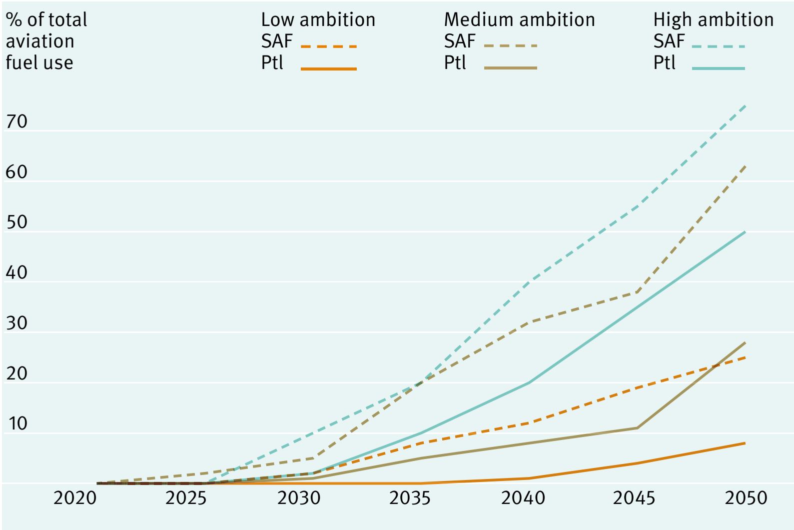
Our medium ambition scenario offers a 50 per cent decrease in CO_2 emissions compared to the low ambition scenario, while the high ambition scenario offers a 67 per cent reduction. Both pathways offer more emissions reductions than DfT’s own ‘high ambition’ scenario, but not as much as their ‘high ambition with breakthrough on SAF’ scenario, which relies on 100 per cent SAF by 2050. It is not clear what level of PtL would be used in DfT’s scenarios.

How Germany is getting ahead with PtL fuel

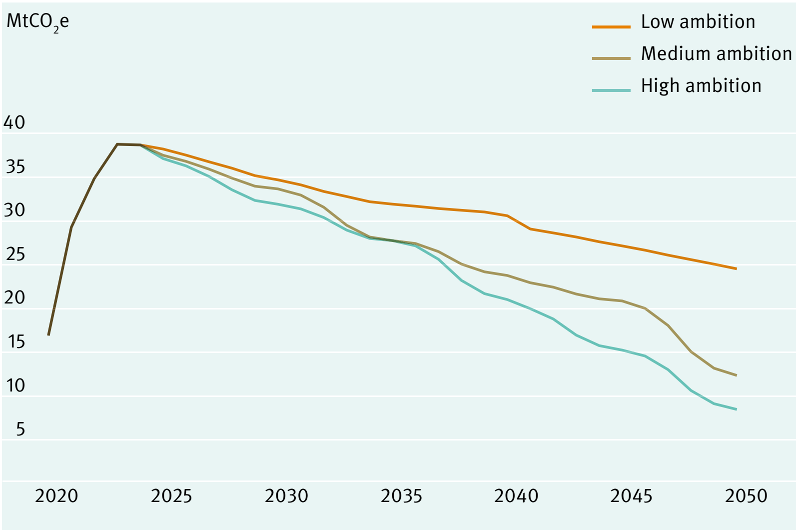
Germany has invested €1 billion in PtL: industrial production facilities will be constructed to make the largest possible quantity of this fuel at the lowest possible price. The aim is to manufacture 200,000 tonnes annually by 2030, accounting for two per cent of the overall fuel blend. Germany is the only place which has committed to a PtL target prior to 2030, aiming for 0.2 per cent by 2026. It will adopt regulatory frameworks and promotion schemes to help push the market into a commercial space.[12] Exclusive partnerships between fuel suppliers and buyers have already cropped up as a result, such as Atmosfair's initiative to provide Lufthansa Cargo and Kuehne+Nagel with synthetically produced, CO_2 neutral fuel.[13]

Progress under the three scenarios

Projected uptake of SAF and PtL



UK aviation emissions to 2050

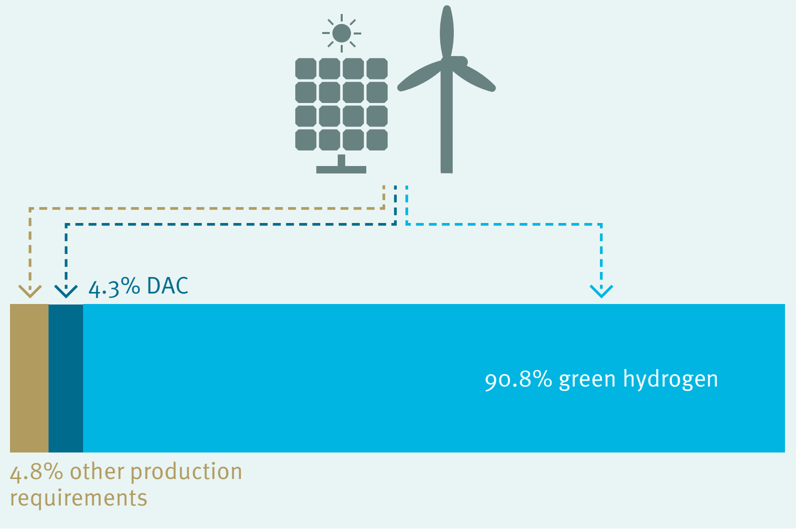


PtL and renewable energy

The biggest difficulty that PtL production is likely to face in the UK is renewable energy capacity to produce green hydrogen.

> **"The biggest difficulty that power-to-liquid production is likely to face in the UK is renewable energy capacity to produce green hydrogen."**

Green hydrogen is expected to use most of the electricity required for PtL production in 2050



Electricity also be required for DAC and during fuel synthesis.

According to the CCC, the production of PtL is one of the least efficient ways to use renewable energy, compared to its use in other sectors, because of the multiple stages in its production.[14]

Furthermore, it could be argued that aviation should not be a priority use of renewables as there are other options to cut carbon in the sector, such as managing the number of flights taken.

Predictions of PtL's demand for renewables should factor in how high its uptake should be in future.

“It is imperative that hydrogen, particularly green hydrogen, is directed to applications of highest value.”

Scaling up green hydrogen

A combination of electricity prices and capital costs of electrolysers are, amongst other things, preventing the wider adoption of green hydrogen in the UK and Europe, but several countries have ambitious targets. The UK government recently increased its goal to 10GW of low carbon hydrogen production by 2030, with at least half coming from electrolytic hydrogen created from water and electricity, rather than methane.[15]

Although ‘blue’ hydrogen (see below) is currently cheaper, this may not be the case beyond the 2020s, particularly given high gas prices. Green hydrogen also offers certainty of cost compared to blue hydrogen which depends on the volatile price of fossil fuels.

Our analysis shows that, in 2030, over ten per cent of total UK hydrogen produced would be needed for PtL in our medium ambition scenario. This is a lot but might be preferable to some uses proposed, for instance, in the gas grid, where it risks slowing the transition from gas boilers to more efficient heat pumps.

However, by 2050, this scenario would require over 50 per cent of the green hydrogen the CCC thinks will be available under its ‘balanced pathway’. This would not be tenable, given all the other uses for hydrogen and renewable energy, unless there are major technological breakthroughs.

The government’s current approach to hydrogen focuses on ensuring supply and gives relatively little consideration to end uses. It is imperative that hydrogen, particularly green hydrogen, is directed to applications of highest value, where electrification is not currently an option, such as for aviation uses.

Why not blue hydrogen?

Blue hydrogen is generated from the steam reformation of natural gas with capture and storage of the resulting carbon dioxide emissions. Although it could have a role in some applications in the next couple of decades, avoiding limitations on the availability of green hydrogen, it has higher associated emissions and risks locking in the continued use of fossil fuels. It is worth noting that DfT does not currently consider it suitable for SAF production as the resulting fuel would still be too emissions intensive.

Direct air capture

There are currently only 19 operational DAC plants in the world, none of which are in the UK. Ultimately, to meet global needs to cut carbon, many more DAC plants will be required. To make DAC worthwhile, its energy requirements must be met by the lowest carbon supply possible.

> "Direct air capture's limited availability could hold back power-to-liquid fuel production."

Renewable energy requirements for DAC are marginal compared to green hydrogen production. For the lowest possible emissions for the purposes of aviation fuel production, DAC should be powered exclusively by renewable energy.

The CCC predicts aviation will be a driving force in scaling up greenhouse gas removals, like this technology, paving the way for more cost effective carbon storage. This is expected to be essential in avoiding the worst impacts of climate change and is one of the additional benefits of developing SAFs. But government policy in this area is still largely focused on R&D so it is likely that DAC's limited availability could hold back PtL fuel production. There is funding allocated, in part, for DAC through the '£1 billion net zero innovation portfolio' in the prime minister's 2020 *Ten point plan for a green industrial revolution*.[16]

Commercialising direct air capture for aviation fuel

Winners of DfT's Green Fuel Green Skies competition, Carbon Engineering, were awarded £350,000 to support the development of a DAC facility to capture atmospheric CO_2. In partnership with LanzaTech UK Ltd, this will produce more than 100 million litres of jet fuel a year.

DAC technology is a fundamental component of PtL production. Carbon Engineering are leading the commercialisation by capturing carbon dioxide directly out of the atmosphere at megatonne-scale and using the pure CO_2 captured to produce efuels.

By repurposing existing industrial equipment when constructing DAC plants, the company has minimised waste throughout its operations.

Economic benefits of developing PtL

Growth in demand for green hydrogen and DAC in the UK will create new, skilled jobs.

Each DAC plant employs approximately 300 permanent staff, with a further 3,000 jobs in the wider supply chain.[17]

The UK hydrogen strategy suggests that developing a successful hydrogen sector could lead to 9,000 UK jobs by 2030 and up to 100,000 by 2050.

> **"Measures to scale up PtL will decrease reliance on foreign imports and increase energy and price security in future."**

Yet the largest increase in jobs for PtL will stem from the growth in renewables. National Grid predicts that, to reach net zero by 2050, the energy workforce will need to grow by 400,000 jobs, with over 110,000 created by 2030, and some of these will relate to the growth needed for PtL production.[18]

The UK is one of the largest aviation fuel importers in the OECD, importing more than half of its fuel.[19] This will have associated emissions from long distance transportation. The opportunity to increase domestic supply and reduce transport emissions through PtL is huge, as all the required industries can be scaled up in the UK. The war in Ukraine, and the consequent spotlight on the level of UK fuel imports, has highlighted this further. Measures to scale up PtL will decrease reliance on foreign imports and increase energy and price security in future.

The non-CO2 climate impacts of aviation

Using PtL fuels will not eliminate all greenhouse gas emissions associated with the aviation sector. Emissions from aviation, besides CO_2, are substantial and this is still the case when burning PtL. Aircraft exhausts produce other emissions which still contribute to global warming, such as nitrogen oxides, particulate matter and water vapour.

Nitrogen oxide (NOx) emissions produced from PtL combustion are at a similar level to those from fossil fuel kerosene.[20] However, compared to conventional fuel, PtL fuels have reduced volumes of aromatics, which are a source of particulate emissions.

Current estimates indicate that PtL fuels could reduce aviation's total climate impacts by 30 to 60 per cent and cut contrail cirrus by ten to 40 per cent.[21]

It is vital that messages around SAF and PtL highlight that, largely, only the CO_2 emissions are being addressed. A starting place to manage non-CO_2 effects is through changes to the UK Emissions Trading Scheme (ETS), which does not currently account for non-CO_2 climate impacts.[22]

Paying for power-to-liquid fuel development

> “The introduction of a PtL sub-mandate could stimulate the investment needed in green hydrogen and direct air capture.”

Typically, fuel is an airline’s single largest operating cost. Although there is a level of uncertainty in stimating the future costs of PtL, due to external and unknown market forces, it is predicted to be roughly three times more than the price of current jet fuel, even when produced at scale.[23]

Given the high upfront cost of investing in production, there are two challenges: to support the scale up of a new industry and then ensure an ongoing market.

Existing funding

In 2021, DfT announced the winners of its Green Fuels Green Skies competition.[24] Only one, Lanzatech UK Ltd and Carbon Engineering (see page 21), focuses on PtL. This project plans to produce 100 million litres of fuel a year by 2030 which is only 0.7 per cent of the UK’s current annual aviation fuel consumption.[25]

One study estimates that “first-of-a-kind commercial plants could cost between £600m-£700m”.[26] DfT states that costs for one plant could exceed £1 billion. Funding from the government, announced in the net zero strategy, is only £180 million, so there is a large gap in plans sufficient to build them and no clarity on who will fund them.

Projected costs

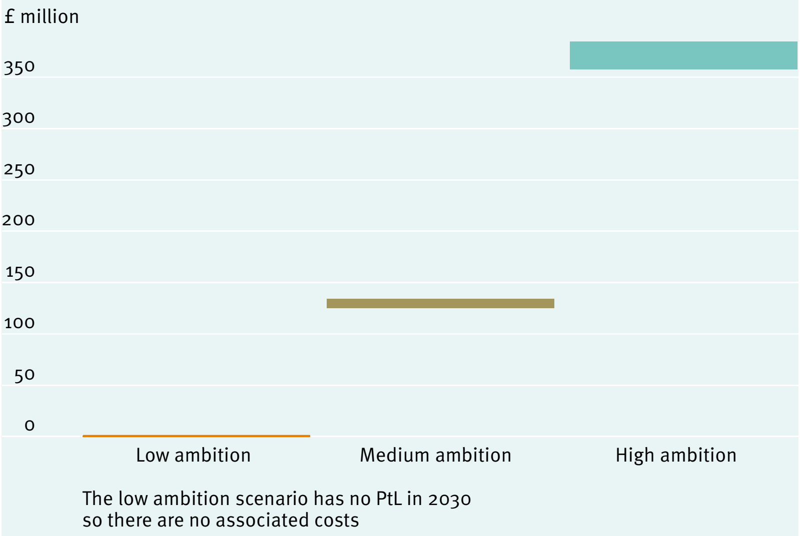
Uncertainty over future PtL costs is due to the range of potential different technologies involved. Green hydrogen is by far the largest cost component of PtL production, with McKinsey estimating it will be responsible for 73 per cent of total PtL costs in 2030.[27] But, given the price is expected to drop significantly in the coming years, it would be a sound investment now to encourage green hydrogen expansion, for aviation fuel and other sectors. Increased investment in DAC technology could also bring operating costs down significantly.

However, even in 2050, the cost of producing fossil fuel kerosene is still expected to be cheaper than any other type of fuel. A major reason is its exemption from tax.

The graph below shows an estimated range of costs for PtL in 2050 using Carbon Engineering's DAC cost projections and estimates from the World Economic Forum for future hydrogen and processing costs (note that this does not take into account the potential price reductions from economies of scale).[28,29]

> **"Even in 2050, the cost of producing fossil fuel kerosene is still expected to be cheaper than any other type of fuel."**

Annual cost range for PtL production in 2030 under our three scenarios



Affording cleaner, greener aviation

The introduction of a PtL sub-mandate, within an overall SAF mandate, could stimulate the investment needed in green hydrogen and DAC. But, unlike the equivalent zero emission vehicles mandate for cars, this technology is not already available to scale up at a comparable price to the fuel it is replacing and the infrastructure does not yet exist to produce it. Accompanying tax measures could support the development of a domestic PtL supply chain.

Aviation tax reform

Reforming aviation taxes would offer a source of income to help finance the transition to PtL production, if the revenue was hypothecated. Although domestic and European Economic Area flights are included in the UK's Emissions Trading Scheme, airlines are given millions of free emissions allowances and there is no tax on aviation fuel.[30] Airline tickets are also subject to reduced VAT. This means that aviation is not operating under the polluter pays principle and is effectively subsidised to the tune of many billions of pounds. Road vehicle fuel, by comparison, is subject to fuel duty taxes and 20 per cent VAT.

> **"Aviation is not operating under the polluter pays principle."**

Prior to the pandemic, aviation had consistently enjoyed high revenues and profits. Although the industry is now in recovery mode, it should be responsible for shouldering the bulk of the cost of the transition to sustainable flying.

A levy that increases as more flights are taken within a year, such as a frequent flyer levy, would be a fair and progressive approach to addressing the climate impacts of flying, given just ten per cent of people take half of all flights, placing some of the financial burden on those who fly more.[31]

A hypothecated kerosene tax could pay for first of a kind commercial PtL plants in the UK. It would also narrow the price difference between SAF, assuming it is not taxed, and conventional fuel. The European Commission is proposing to remove kerosene's EU tax exemption, if the UK does not do the same it may distort the market.

If the UK applied the European Commission's proposal to tax flights at €0.33 per litre, it would raise €7.3 billion per year (£6.1 billion). If those costs were passed on to ticket prices, it is estimated that could lead to a drop in passenger numbers and, therefore, of CO_2 emissions, of up to 12 per cent.[32]

Analysis conducted by the World Economic Forum predicts that, assuming an increasing CO_2 tax on fossil fuel kerosene, SAF could reach price parity with conventional aviation kerosene between 2035 and 2040.[33]

Recommendations

> **The UK should introduce a PtL sub-mandate as part of the wider SAF mandate.”**

Using PtL, blended in aviation fuel, would cut emissions significantly, compared to other types of SAF. Our medium ambition scenario would cut CO_2 emissions in 2050 by 50 per cent compared to the low ambition scenario.

The UK imports over 70 per cent of its jet fuel.[34] Moving to a domestic SAF industry, especially PtL which relies on technologies which are not yet scaled up outside the UK, is an industrial opportunity which will help bring down infrastructure costs, create jobs and promote UK leadership in more sustainable aviation.

The government has made it clear that it is relying heavily on SAF to cut carbon emissions from flying. But, unless costs are brought closer to those of conventional aviation fuel, PtL production particularly will not increase by the amount needed.

Our recommendations below will maximise the potential of PtL fuels for the UK, alongside a broader aviation decarbonisation strategy:

1. Introduce a PtL fuel target

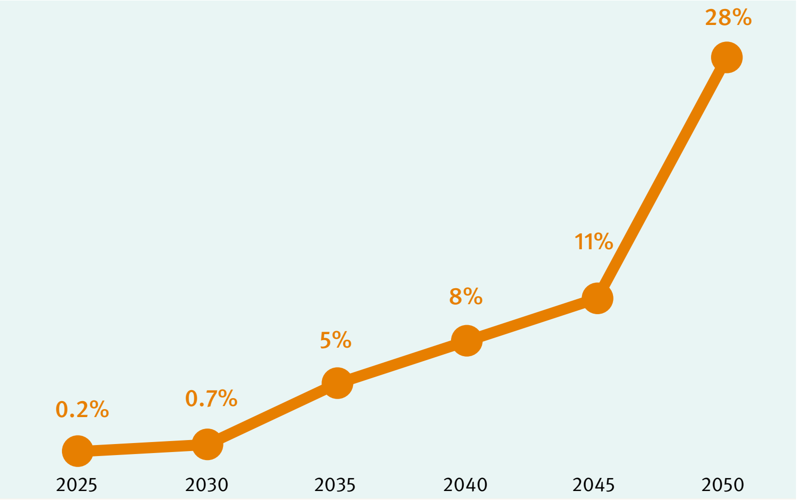
The UK should introduce a PtL sub-mandate as part of the wider SAF mandate. There are two ways this could work:

- **A volume based mandate**
  This is being introduced in the EU so would be easier for fuel suppliers and airlines operating on international routes.
- **A greenhouse gas emission intensity mandate**
  This would reduce emissions and offer more incentive for airlines to buy PtL because of its lower lifecycle emissions.

We recommend a mandate which incorporates both approaches. A wider SAF mandate should be introduced under a greenhouse gas intensity scheme, which obliges suppliers to reduce the emissions intensity of fuels by a minimum of ten per cent. Alongside this, we recommend the introduction of a sub-mandate for PtL, obliging fuel suppliers to sell fuel with a certain percentage of PtL in the mix, increasing over time.[35]

Based on our analysis, our high ambition scenario is not achievable without rapid deployment of renewables and DAC. This is unlikely to happen under current government plans. Doing so without much higher renewables capacity could restrict the amount of low carbon electricity available for other sectors.

Our recommended uptake rate of PtL, 2025 to 2050



We recommend that a sub-mandate for PtL follows our medium ambition scenario, with a 2025 start date to ensure early adoption.

Enforcing this requires considerable scaling up of the infrastructure for both DAC and green hydrogen, beyond the CCC's 'balanced pathway', corresponding instead more closely with its more ambitious 'widespread innovation' pathway. A new funding model will be needed to pay for earlier development of green hydrogen which will require ten per cent of the UK's 1GW green hydrogen supply in 2025.

Please see annex two on page 32 for more detail on the feedstock requirements for PtL production under our medium ambition scenario.

2. Reform aviation taxes

Allowing continued untaxed, unabated emissions from the aviation sector is not compatible with the government's net zero commitments. Urgent action is needed in the 2020s to ensure the 2050 goal is met. DfT and the Treasury should collaborate to create a new tax environment that supports the scale up of SAF and PtL and starts to manage passenger numbers. We recommend introducing a kerosene tax and considering a frequent flyer levy. These taxes, if hypothecated, could provide a substantial pool of funds to scale up and deploy PtL quickly.

"Allowing continued untaxed, unabated emissions from the aviation sector is not compatible with the government's net zero commitments."

3. Prioritise uses of green hydrogen

The UK's hydrogen strategy does not specify which modes of transport will use the limited hydrogen available. The government should reserve hydrogen for sectors which do not have alternative options to decarbonise. This will reduce the need to unnecessarily increase renewable energy demand; a scenario in which efuels are dominant in the transport system could result in almost 50 per cent more renewable electricity being needed in 2050, compared to a scenario in which hydrogen is used primarily for aviation and shipping.[36]

4. Consider new measures to manage passenger growth

SAF, even PtL, is not the silver bullet for aviation decarbonisation, in part due to the non-CO_2 effects of aviation and (see page 23) because the cost and infrastructure requirements of scaling up PtL production mean it cannot meet 100 per cent of fuel demand.

Any residual emissions in 2050, when the UK is expected to be at net zero, will have to be offset in some way. Previous Green Alliance research recommends that, because the global capacity to remove and store carbon from the atmosphere is limited, the UK should maximise efforts to reduce absolute emissions from aviation.[37] To make this possible, the residual emissions level anticipated in 2050 should be reduced, which SAF deployment alone will not be able to achieve.

DfT's projection of a 74 per cent increase in passenger numbers by 2050 depends on a breakthrough in SAF technology, which has not yet occurred. There is a risk that, without this breakthrough, aviation will drastically overshoot its climate targets. We recommend that DfT considers how best to manage demand. At a minimum, DfT should follow the CCC's 'balanced pathway' for target passenger numbers, but with the aim of being even more ambitious than this until significant emissions reductions from advanced fuel technology can be proven.

Annex one
Sustainable aviation fuels compared

	Power-to-liquid fuel	Waste-based biofuel	Recycled carbon fuel
Emissions reductions	99 per cent (100 per cent if the supply chain is fully decarbonised)[38]	70-90 per cent[39]	As this displaces emissions from fossil fuel waste, there are no emissions reductions in overall lifecycle (unless mixed with biogenic material)
Environmental impacts	Water and power use, some small land use required for DAC plants and electrolysers	If sourced incorrectly, can cause land degradation and harm to biodiversity. Also requires high land use[40]	May continue to prop up the fossil fuel market into the future, undermining decarbonisation efforts in other sectors[41]
Costs	Highly variable costs (renewable electricity) and high first of a kind costs for new power plants	Most cost effective fuel for near term carbon abatement (cooking oil derived)	There is a marginal additional cost of obtaining feedstock, but with diminishing returns in future as fossil fuels are phased out
Scalability	No scalability limit but dependent on availability of renewable energy, hydrogen and DAC	Limited availability for jet fuel as it is currently used in road transport	Only scalable if the fossil fuel industry scales up

Annex two
Production requirements for power to liquid fuel

Feedstock requirements for power-to-liquid fuel production under our medium ambition scenario

	2030	**2050**
Electricity supply	**Required:** 1.4 TWh **Available:** 361 TWh 0.4% of availability	**Required:** 54.1 TWh **Available:** 612 TWh 8.8% of availability
Hydrogen	**Required:** 1.3 TWh **Available:** 13.6 TWh 10% of availability	**Required:** 51.2 TWh **Available:** 97.2 TWh 53% of availability
Direct air capture	**Required:** 0.2 $MtCO_2e$ **Supplied:** n/a*	**Required:** 6.5 $MtCO_2e$ **Supplied:** 5 $MtCO_2e$ an additional 1.5Mt CO_2e would be required
Cost	£125 – 134 million	£3.9 – 4.4 billion

Notes

'Required': projected as necessary under the proposed mandate

'Available': CCC balanced pathway recommendation

* the CCC balanced pathway does not project DAC capacity in 2030

Since our recommended uptake rates are higher than the CCC's projection in its 'balanced pathway' scenario, it follows that the feedstock requirements will also be higher. This is broadly aligned with the CCC's 'widespread innovation' scenario. We recommend that the government aims to achieve innovation, as set out in the CCC's scenario, to ensure that the right level of renewable energy, hydrogen and DAC will be available.

Endnotes

1 Sustainable Aviation, 2020, *Sustainable aviation fuels roadmap*

2 Climate Change Committee (CCC), 2020, *The sixth carbon budget: aviation*

3 BBC, 14 September 2021, 'Boeing says air travel to return to pre-pandemic levels by 2024'

4 BBC, 14 July 2021, 'Carry on flying, says government green plan'

5 Department for Transport (DfT), 2022, *Jet Zero: further technical consultation*

6 Ibid

7 Climate Change Committee (CCC), 2020, *The sixth carbon budget*, 'charts and data in the report'

8 UK Petroleum Industry Association, 'Fuels', www.ukpia.com/downstream-policy/fuels/

9 Department for Transport (DfT), 30 June 2021, 'Jet Zero Council – third meeting'

10 Climate Change Committee (CCC), 2020, *The sixth carbon budget*

11 EUR-Lex, 2021, 'Proposal for a regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport'

12 Baker McKenzie, 23 August 2021, 'Sustainable aviation fuel (SAF) and the German PtL roadmap – another area of application for hydrogen technologies'

13 Kuehne+Nagel, 2021, 'Kuehne+Nagel and Lufthansa Cargo agree on exclusive partnership to promote CO_2-neutral power-to-liquid-fuel'

14 Climate Change Committee (CCC), 2020, *The sixth carbon budget*

15 Department for Business, Energy and Industrial Strategy (BEIS), 2022, 'British energy security strategy'

16 BEIS, 2020, *Ten point plan for a green industrial revolution*

17 Rhodium, 2020, *Capturing new jobs and new business: growth opportunities from direct air capture scale-up*

18 National Grid, 2020, *Building the net zero energy workforce*

19 Possible, 2022, *The right track for green jobs*

20 Ricardo, 2020, *Renewable electricity requirements to decarbonise transport in Europe with electric vehicles, hydrogen and electrofuels*

21 Fuel Cell and Hydrogen, 2020, *Hydrogen-powered aviation*

22 Ibid

23 Transport & Environment, 2022, *Roadmap to decarbonising European aviation*

24 The government's Green Fuels, Green Skies (GFGS) competition was launched in March 2021 to support the development of the emerging UK sector on its pathway to produce SAF at scale. The competition was for UK companies that pioneer new technologies to convert household rubbish, waste wood and excess electricity into SAF, with the chance to win a share of £15 million for the development of SAF production plants in the UK. Eight UK companies shared the prize.

25 LanzaTech, 2021, 'Carbon Engineering and LanzaTech partner to advance jet fuel made from air'

26 E4Tech, 2020, 'Designing a funding competition to deploy first of a kind commercial scale Sustainable Aviation Fuel plants in the UK'

27 World Economic Forum, 2020, *Clean skies tomorrow: sustainable aviation fuels as a pathway to net-zero aviation*

28 $163 per tonne of CO_2

29 McKinsey estimates the cost of DAC decreases between 2020 and 2030 (19 per cent decrease), with price stagnation from 2030 onwards, so using a constant value for DAC (from Carbon Engineering, see note 29) is appropriate, especially given we do not expect to see it commercially operational until 2030.

30 HM Government, 2021, 'UK ETS aviation allocation table'

31 *The Guardian*, 25 September 2019, '1% of English residents take one-fifth of overseas flights, survey shows'

32 Transport & Environment, 2019, 'Leaked study shows aviation in Europe undertaxed'

33 World Economic Forum, 2020, op cit

34 Sustainable Aviation, 2020, op cit

35 Fuel suppliers operating under an emissions intensity mandate would have to convert back to specific volumes of fuel to be sourced for use, meaning this application of both mandates is entirely feasible.

36 Transport & Environment, 2021, 'Efficient pathways to electrifying UK transport'

37 Green Alliance, 2020, *The flight path to net zero*

38 World Economic Forum, 2020, op cit

39 Sustainable Aviation, 2020, op cit

40 Transport & Environment, 2013, *Sustainable alternative for land-based biofuels in the European Union*

41 Zero Waste Europe, Bellona Europa and Rethink Plastic, 2020, 'Recycled carbon fuels in the renewable energy directive'

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