Safe Landing

AVIATION WORKERS
FOR A SUSTAINABLE FUTURE

This is Safe Landing's response to the second UK Sustainable Aviation Fuels (SAF) Mandate Consultation which closes on 22nd July 2023.

SUMMARY

We advocate for the UK Government aviation fuel policy to involve:

- A focus on capping and reducing total jet fuel consumption as a priority, in order to drive down fossil jet fuel use. Any proposed "SAF" mandate is of secondary importance to this.
- Applying an emissions price to all aviation emissions in order to raise revenue for loss & damage funds and cross-economy decarbonisation.
- Performing a cross-economy assessment and prioritisation of available non-fossil fuel feedstocks, i.e. biomass and renewable energy, before assuming any for aviation.
- Prioritising non-fossil fuel feedstocks for applications which produce the greatest emissions savings, social utility, and distributed benefits across the population.

We conclude that the UK Government should therefore:

- Introduce a carbon budget for UK aviation consistent with 1.5°C and allocate that budget.
- Perform a cross-economy assessment of available non-fossil fuel feedstocks and allocate.
- Remove financial support for all aviation biofuels and remove biofuel 'SAF' mandate targets.
- Prioritise biomass for other uses: mostly fertiliser production, heating, and Bioenergy Carbon Capture and Storage (BECCS) plants. Prioritise waste oil/fat for 'HVO' biodiesel production, with relatively small quantities of 'HEFA' biofuel co-produced during this process.
- Remove financial support for electro-fuel (e-fuel) and e-fuel mandate targets in the near-term.
- Prioritise renewable electricity for other uses: mostly grid, building and ground transport decarbonisation.
- Focus financial support on grid decarbonisation, Green Hydrogen (H2) production and Direct Air Capture (DAC). Prioritise Green H2 produced for displacing Grey H2 and within aviation for hydrotreating kerosene. Prioritise DAC for carbon capture and storage (DACCS).
- Minimise fuel supply chains in order to reduce transport emissions of the feedstock and fuel. This will mean primarily utilising domestic feedstock supplies.

The global aviation industry is about to undergo a huge transformation across aerospace manufacturing, airline operations and aircraft/airport configurations. We believe that government support should primarily be targeted here, rather than squandered on further financing the fuels industry, particularly for fuel pathways with questionable sustainability.

BACKGROUND

Safe Landing is a group of aviation workers campaigning for long-term employment. We do this by challenging leaders to conform with climate science and reject dangerous growth. We believe that it's in workers' best interests to critique and challenge sustainability strategies of our business and political leaders in order to ensure that plans are robust and realistic.

Our group prefers to avoid use of the term 'Sustainable Aviation Fuel' or 'SAF' as it implies that any such fuel is by definition 'sustainable'. That is, we can produce and burn large quantities indefinitely without incurring any environmental or social impacts. We believe an honest assessment of most so-called 'SAF' pathways reveals that this often isn't the case.

As such, we prefer to use the term 'alternative jet fuel' to refer to any drop-in alternative to conventional jet fuel, i.e., fossil fuel kerosene. This includes biofuels produced from biomass, and power-to-liquid electro-fuels (e-fuels) which are produced using electricity.

THE CHALLENGE AND THE RISKS

It is well understood that there are no technological solutions available to decarbonise the aviation sector within the timescales necessary to comply with the Paris Agreement. It is highly likely that we'll blow the carbon budget for 1.5°C within the next 10 years, and will run an increasing risk of runaway global warming, climate breakdown and ecological collapse.

Within this timeframe, alternative 'zero emissions' aircraft such as electric and hydrogen cannot be designed, developed, certified and scaled. Equally, there isn't enough time to develop radical new jet engine powered aircraft.

As such, business leaders running aerospace manufacturing, airlines and airports are keen to report to their shareholders that air traffic growth is still possible using existing aircraft designs. Therefore, the idea that we can continue as planned with business-as-usual growth (a return to the pre-pandemic doubling of air traffic every 15 years) and simply power these aircraft with an alternative 'sustainable' fuel to meet our decarbonisation targets, is understandably alluring. It's an equally compelling story for fossil fuel company executives to tell, as a means for locking-in fossil fuel reliant aircraft and airport infrastructure. This is why we need to be cautious of the claims, and assess them critically.

IATA have recently estimated that in order to transition all aviation fuel use from fossil kerosene to alternative jet fuel would cost in the order of **$5 trillion**. For the UK aviation sector, costs would likely be in the multiples of £100bn. A jet fuel tax could raise £10bn/year, but this might not even cover it.

There is a lot at stake here and a lot we can get seriously wrong if we aren't careful:

- We run the risk of wasting significant time and money in both the private and public sector. If we develop the wrong technology, it'll leave us with stranded assets and loss of investment. In this scenario, workers will always be the first to suffer via redundancies and pay cuts etc.
- That time and money could have been spent on other types of fuel production, but also on other decarbonisation efforts within aviation, or indeed in other sectors.
- Within aviation, it could have been spent upgrading the efficiency of aircraft regardless of fuel type, and we could lose the UK position as an aviation leader if we sidetrack this effort.
- We may prolong fossil fuel use in the UK, as any non-fossil energy diverted to "SAF" could have been used for displacing fossil fuels elsewhere. This will be bad for energy security and put consumers at risk of price rises from the volatility of fossil fuels as experienced this year.

- By backing the wrong fuel technology, we may have to import fuel into the UK from other countries who choose more wisely where to incentivise fuel production.
- For fuel production facilities we build, we could also become reliant on imported biomass/renewable feedstock from other countries and then become at risk of them raising prices or (justifiably) diverting the use of that resource for decarbonising their own sectors.

So how do we approach this problem to mitigate risks and give us the best chance of picking the right winners?

APPROACH

We suggest that there needs to be an underlying logical framework that guides which technologies and fuels governments should incentivise, subsidise, and mandate etc.

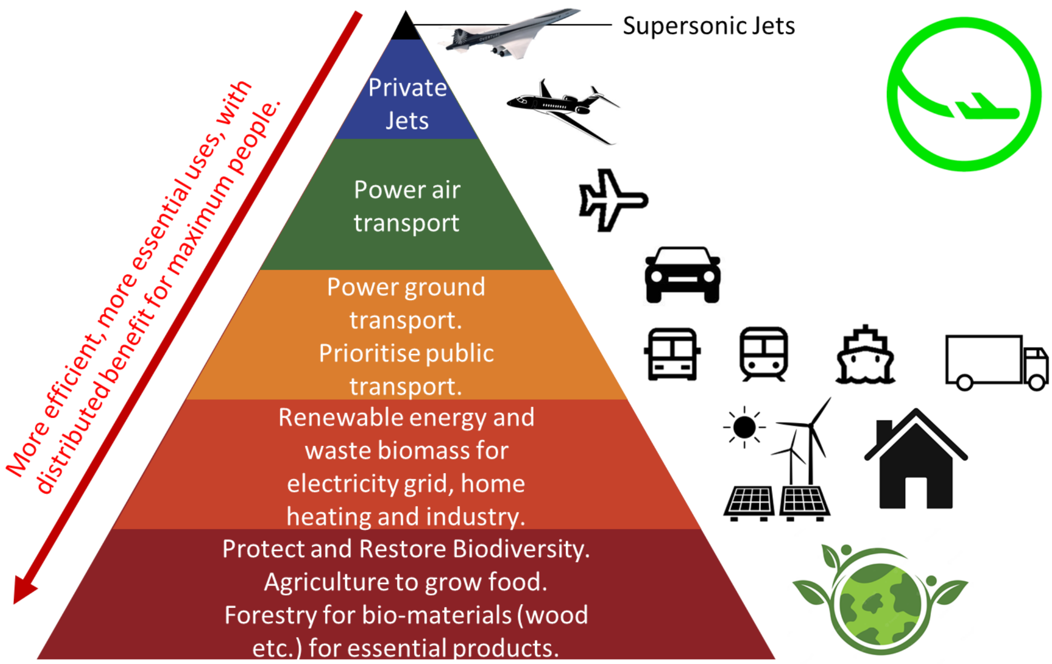
The standard practice of "Life Cycle Assessments" (LCAs) doesn't seem to work if we apply siloed thinking, treat aviation in isolation, and don't think of the problem holistically across our economy.

For instance, powering a supersonic airliner with e-fuel could theoretically provide close to 100% LCA emissions savings versus burning fossil jet fuel. However, the same e-fuel could have been used to transport 5 times the number of passengers an equal distance in a subsonic airliner. Similarly, the renewable electricity used to produce the e-fuel could have instead powered heat pumps in hundreds of homes, displacing gas boilers and providing multiple times more emissions savings again.

Therefore, there's an **opportunity cost** of using any given resource for one use over another.

In addition, there are also the issues of social utility and distribution. For instance, it's likely that most people would consider our ability to grow food, travel to work/school, and heat or cool homes as more essential to survival than air travel. Agriculture, grid electricity and public transport are also all more likely to benefit a wider distribution of people than, for example, private jets.

With this criteria in mind. we'd expect a hierarchy of resource use to look broadly like this:



Safe Landing diagram illustrating an assumed hierarchy for land/energy/resource use

When choosing where best to prioritise resources and direct government money, we need to bear these considerations in mind. Not only from a moral perspective but also a practical one. Because, within the severely limited time available to respond to the climate emergency, we need to get maximum 'bang-for-buck' with everything that we do. We can't afford to fritter away time and energy on inefficient efforts. Equally, air travel is no use on a dead planet, and tourism won't achieve sustainable development goals if people lack food, water and energy security.

Let's now apply this approach to fossil fuel, biomass and renewable electricity resources.

FOCUS ON FOSSIL FUEL

The climate crisis is caused by digging up fossil carbon and emitting it into the atmosphere where it accumulates. This is causing global warming that has already destroyed ecosystems, and may end up killing most life on earth. Heathrow states that: *"Climate is an existential threat to aviation, to us all"*.

We therefore need to focus on urgently **reducing fossil jet fuel use** and implementing the policies that will ensure this. Without this, frankly anything else is a distraction.

For instance, in the UK we currently burn about 12 million tonnes (Mt) of fossil kerosene per year. So even if we scale "SAF" to e.g. 1 Mt by 2030, that is essentially irrelevant if we are burning 13 Mt of jet fuel in total, so still burning 12 Mt of fossil kerosene. (The additional 1 Mt of "SAF" will also have associated carbon emissions, even with the most optimistic life cycle analysis).

We really need the UK Government (and others) to:
- Introduce a carbon budget for UK aviation consistent with a 1.5°C pathway.
- Be mindful of the fact that even other apparently less 'hard-to-abate' sectors are off track with decarbonisation efforts and therefore don't have any excess budget that aviation can use.
- Be mindful of the fact that lack of near-term mitigation policies for aviation non-CO2 emissions will reduce the UK aviation carbon-equivalent budget further.
- Spread the UK aviation budget across the coming decade to produce annual budgets.
- Allocate the annual UK aviation budget between UK airports.
- This budget will dictate how much fossil jet fuel can be consumed by airlines operating from each airport that year.

Note: another approach can be used, but this is fundamentally a budgeting problem, so we need to set annual UK aviation budgets and not exceed these. Let us be crystal clear: using 'SAF' to distract from this necessity amounts to solution denialism, and is a danger to aviation and aviation workers.

Financial measures can also be used to provide a price signal to travellers, drive down fossil jet fuel use and encourage airlines to operate as efficiently as possible within the given budget.

Applying emissions pricing to all aviation emissions can raise government revenue for loss & damage funds and cross-economy decarbonisation. This could be applied as:
- a kerosene tax to target carbon emissions
- an emissions price to target other emissions
- a frequent flyer levy to distribute financial burden to highest-emitters

Such policies would be socially progressive, as they predominantly target a minority of high-emitters, particularly if funds are used for activities with wide distributed benefits across the population. They also fit the "polluter pays" principle subscribed to by the UK Government's "Jet Zero" strategy.

This might seem like an unusual thing for aviation workers to advocate for, but we know higher prices are coming for kerosene, as burning any fossil fuel will soon require DACCS (more on this later), and any alternative fuel will remain at multiple times higher cost until 2050. We'd rather see those prices phased in more gradually through early design, rather than late disaster, and a sudden cliff edge jump in prices that, due to the timescales involved in aviation, our industry won't be able to respond to.

The next question is then where best to utilise government funds in order to maximise rapid decarbonisation?

BIOFUEL

Biomass (plants and vegetation) are fundamentally a very inefficient way of turning energy from sunlight into stored energy. For reference:

- Solar panels have a solar-to-electrical energy conversion efficiency of 20% or higher
- Biomass has a solar-to-bioenergy conversion efficiency of about 1 to 2%

Hence, use of land to grow biomass for energy (bioenergy/biofuel) should be minimised from an energy-efficiency perspective. We should prioritise land for growing food to feed people, protecting/restoring biodiversity to prevent ecological collapse, and for renewable energy.

Biofuel from Crops

There are other reasons to minimise the production of bioenergy / biofuel crops:

- They compete with food production and increase the cost of food.
- Cultivating energy crops in large monoculture fields destroys biodiversity and deepens the dependency of synthetic fertilisers, pesticides and herbicides.
- They can lead to land-use change emissions that are worse than fossil fuels.
- They can also result in humanitarian impacts e.g. land conflicts, rising food prices, water scarcity, and pollution that affects neighbouring communities.

The most cost effective and least energy-intensive way to produce biofuel is to grow oil crops such as palm, soy, rapeseed, sunflower etc. This is because oil is energy dense and easy to process. Even then, the Royal Society estimated that meeting existing UK aviation demand entirely with bioenergy crops would require around half of UK agricultural land. This makes biofuel-from-crops unsustainable.

Biofuel from Waste

The land-use calculation above was for a dedicated energetic oily crop. Producing energy from 'waste' biomass, e.g. discarded crop stalks, stems, sheaves, bark or leaves will be far more difficult. These are the woody, protective, structural or functional parts of the plant - they aren't energy-dense and they are difficult to break down into energy. This makes them difficult to collect, transport and to process - without expending excess energy doing so.

As per the ***reduce-reuse-recycle*** hierarchy known to any keen environmentalist: we should clearly **reduce** the production of biomass waste as a priority, primarily by wasting less food and transforming agriculture. We can also **reuse** the functional properties of biomass for useful products such as timber for buildings/furniture, rice husks into cups, and wool or saw dust into insulation. And we can **recycle** the nutrients within biomass, via the action of microbial bacteria, by composting it.

Removing too much farm or forestry waste can also reduce the carbon content and fertility of soil and remove habitat for wildlife and biodiversity, so we need to be careful about targets and policies which maximise ruthlessly harvesting and collecting biomass 'waste'.

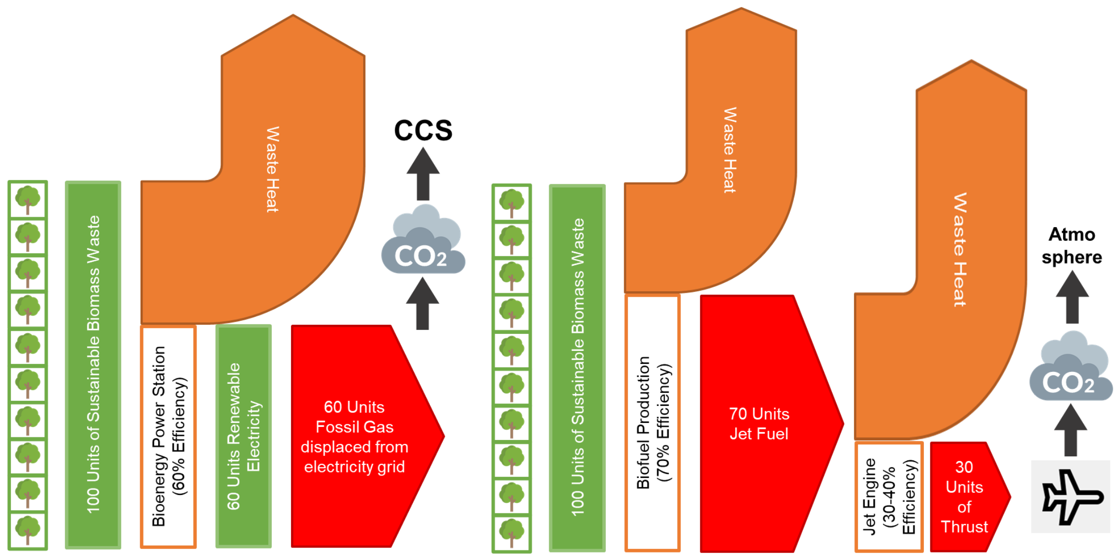
Let's imagine we somehow have a plentiful supply of sustainably harvested and collected agricultural, forestry or household/municipal biomass waste though. Where should we prioritise it?

Firstly, we should compost it. We currently use massive amounts of fossil fuels to produce grey hydrogen (H2) which is turned into ammonia (NH3) for agricultural fertiliser. This industry produces more greenhouse gas emissions than aviation and shipping combined. We can compost food, garden, farm and forestry waste into biogenic fertiliser which can displace fossil fuel fertiliser. Appropriating this waste for aviation will deprive agriculture of non-fossil fuel fertiliser to decarbonise and would presumably push up the prices of global food production which would remain reliant on fossil gas.

Next, we should use it for ground power. If biomass waste is sent to an anaerobic digester (AD), fertiliser is produced, alongside biogas. This biogas can be used for heating or grid decarbonisation via a Bioenergy with Carbon Capture and Storage (BECCS) power plant (a gas turbine running on bioenergy with CCS equipment filtering the exhaust) to produce negative emissions.

There are a number of reasons why waste biomass should be prioritised for fertiliser, home heating and grid electricity over processing into a transportation fuel:

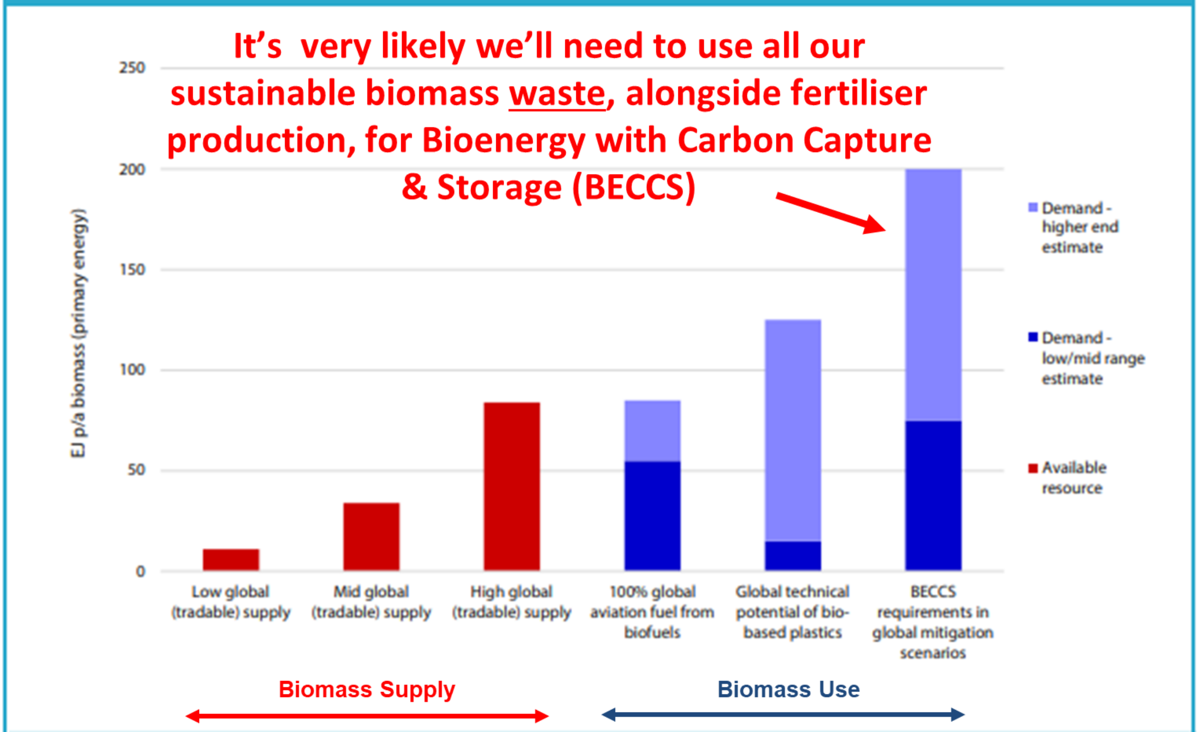
- Plants take nutrients from the soil and convert them into biomass using solar energy. Taking waste biomass and converting it into a fuel means burning those nutrients, rather than utilising the existing nutritional content of the biomass to grow more things.
- A co-product of anaerobic digesters is biogas which can be used to very efficiently displace fossil gas used for heating buildings, as we transition to heat pumps.
- Biogas/biofuel can also fuel combined cycle gas turbine (CCGT) power plants which are likely to remain an important part of grid electricity generation for decades. These can be ramped up and down quickly to stabilise and provide storage capability to an electricity grid with high amounts of variable renewable energy generation. However, these are reliant on fossil gas (methane) which can be displaced with biogas (bio-methane) or other biofuels.
- A CCGT power plant is about twice the efficiency of an aircraft gas turbine jet engine (about 60% vs. 30% efficiency), because a power plant on the ground can be optimised for higher thermodynamic efficiency without worrying about weight, size, complexity and failure mode issues on board an aircraft. It's even more efficient if accounting for jet fuel production losses.
- A CCGT power plant can install a carbon capture and storage (CCS) device on the exhaust to sequester and store carbon for 'negative emissions'. This isn't possible on board an aircraft.
- Using waste biomass to produce fertiliser and/or grid electricity is therefore inherently more efficient and will provide food/electricity which has a wider distributed benefit.



Safe Landing sketch with approximate numbers showing difference in activity and efficiency

On BECCS, the following chart from the [CCC's Biomass in a Low Carbon Economy] report shows that the low-mid range demand estimate for BECCS in global mitigation scenarios alone almost exceeds high estimates of global available biomass resource supply. Higher end estimates for demand may be more than double this. Higher end estimates for demand of bioplastics may also exceed supply:

Figure 5.1. Potential global demand for sustainable biomass by key end-use applications in 2050



Source: CCC analysis.

Annotated Figure 5.1 from the CCC's Biomass in a Low Carbon Economy report, page 114

For additional context, it's worth noting that the scale of biomass assumed in the Integrated Assessment Models (IAMs) used by the Intergovernmental Panel on Climate Change (IPCC) would require a land area for dedicated bioenergy crops typically one to two times the area of India. As such, scientific articles have concluded that "*the sustainability of large-scale BECCS is questionable given its extensive land, water, and energy requirements for feedstocks and the competing necessity of these resources for the provision of ecosystem services*" but noted "*BECCS on a more limited scale, however, could have more benign impacts if feedstocks were restricted to wastes and residues.*" So given that all government plans currently rely on significant levels of BECCS, it would be high risk to assume that significant quantities of biomass waste can be directed towards transport fuel production.

Finally, even if there is some biomass waste that for whatever reason can't be used for fertiliser, biogas heating, BECCS, or indeed bioplastic or steel production etc., and can instead be made into transport biofuel - it needs to be remembered that a large proportion of ground transport will still use liquid hydrocarbon fuels for many years, if not decades, during the transition to electric vehicles (EVs). This includes cars in the nearer-term and ships, trucks, construction vehicles and agricultural vehicles etc. in the longer-term. These will compete for transport biofuels, are a more efficient use of resources than air travel, and tend to have wider distributed benefits across the population.

In summary: from a hierarchy of best use approach, we don't believe that Biofuel-from-Crops or Biofuel-from-Waste can scale sustainably when the requirements from other sectors are considered.

Biofuel from Waste Oil/Fat
The Hydrogenated esters and fatty acids (HEFA) aviation fuel produced from waste oil/fat is currently the only commercialised 'SAF' pathway and is being relied upon for all near term 'SAF' targets. While this could also be used for BECCS or fertiliser, this feedstock is already energy-dense and requires little additional energy to collect and process into transport fuels. This makes sense.

However, this is not a fuel pathway that can be scaled beyond 1-2% of existing jet fuel use. As the ICCT put it: "*waste oils are highly resource-constrained and are already largely consumed by the road sector. High near-term targets for SAF blending may only incentivize the diversion of waste oils from existing uses*". We therefore view it as a distraction.

In addition to volume constraints, there is competition with other sectors and waste oils are already utilised to produce e.g., animal feed and road transport biofuels. The UK Government acknowledged within the previous UK 'SAF' Consultation in 2021 (Para 4.28) that:

> "*Relying on this fuel could also divert used cooking oil (the feedstock primarily used to produce HEFA) away from the renewable diesel (HVO) production process. When plants increase the product slate of HEFA over HVO, their* ***overall fuel yield decreases and production costs increase****. This means pivoting this feedstock away from use in road transport at this stage will make* ***economy-wide decarbonisation more expensive***".

Therefore, this demonstrates that limited waste oil feedstocks are better utilised in the ground transport (cars, trucks and shipping) sector on both an environmental and economic basis. Scaling aviation 'HEFA' would only result in shifting of emissions savings from one sector to another, whilst reducing total emissions saved, and increasing government spending and tax payer costs.

We've illustrated the reason for this with the following diagram/sketch:

Headline: if we maximise jet fuel (HEFA) output, the process is less efficient and less overall fuel is produced, leading to less fossil fuel displaced.

Safe Landing sketch with approximate numbers showing difference in fuel production efficiency if optimising the process for more jet fuel (HEFA) and less biodiesel (HVO)

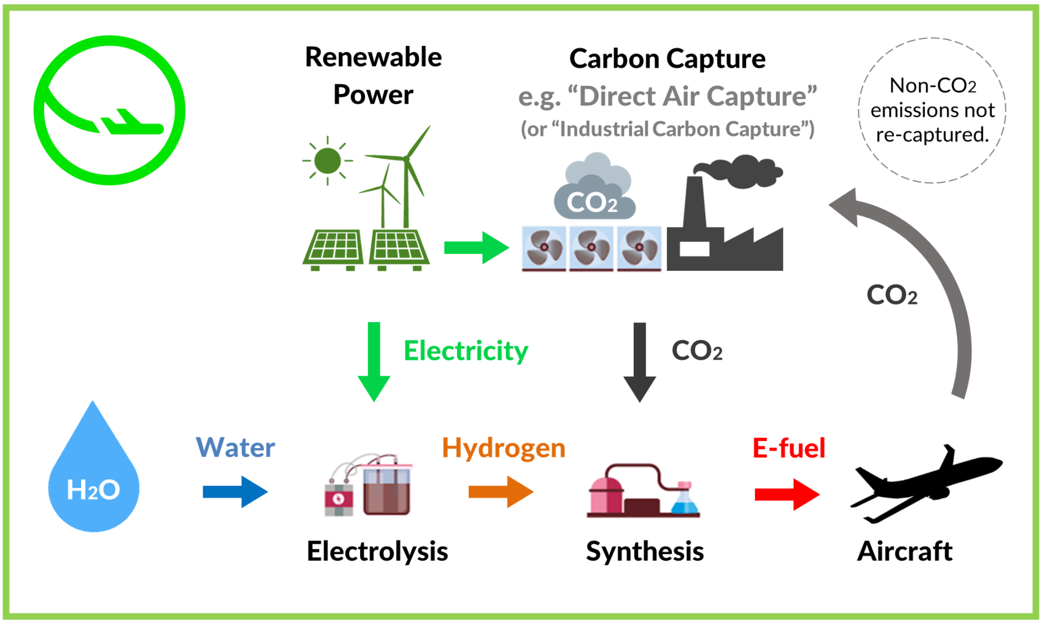
In addition, there are severe supply risks from relying on large quantities of waste fat/oil. We need to reduce global animal agriculture and oil use. There is a high risk of fraud within feedstock supply chains. We already import a large quantity from South East Asia, where it should be used locally.

In summary: it makes sense to use waste oil/fat feedstock to produce transport fuel, but the amount of HEFA produced should correspond to the production output which will maximise fossil fuel displacement and emissions savings. This means maximising the output for biodiesel production which can be used for cars in the near-term and for ships, trucks etc. in the longer term. Relatively small quantities of HEFA jet fuel will be produced as a co-product - but this is already happening and requires no additional investment or subsidy. We'd prefer to direct government finance elsewhere.

We're concerned that our current industry strategy is to lobby for HEFA incentives which is distracting time, money and attention this decade from other more scalable options with lower sustainability risk.

ELECTRO-FUEL (E-fuel)

E-fuel is produced by synthesising 'green H2' with 'green carbon' from DAC to produce a jet fuel:



Safe Landing diagram illustrating the e-fuel production process

The following quote and diagram is taken from the UK Climate Change Committee (CCC)'s Sector Summary for Electricity Generation, pages 10-11:

> "*Electrification represents a key abatement option to reduce emissions in other sectors.*
>
> *Given potential limits to the pace of deployment of low-carbon capacity, it will be **important to focus on sectors which have the most efficient use of low-carbon electricity** (Figure M5.4).*
>
> *Across our scenarios new demands therefore come primarily from the electrification of transport, heat, and industry.*
>
> *Hydrogen production, Direct Air Capture, and synthetic fuels are **relatively inefficient uses of electricity and should be lower priority** than direct use of electricity for decarbonisation.*"

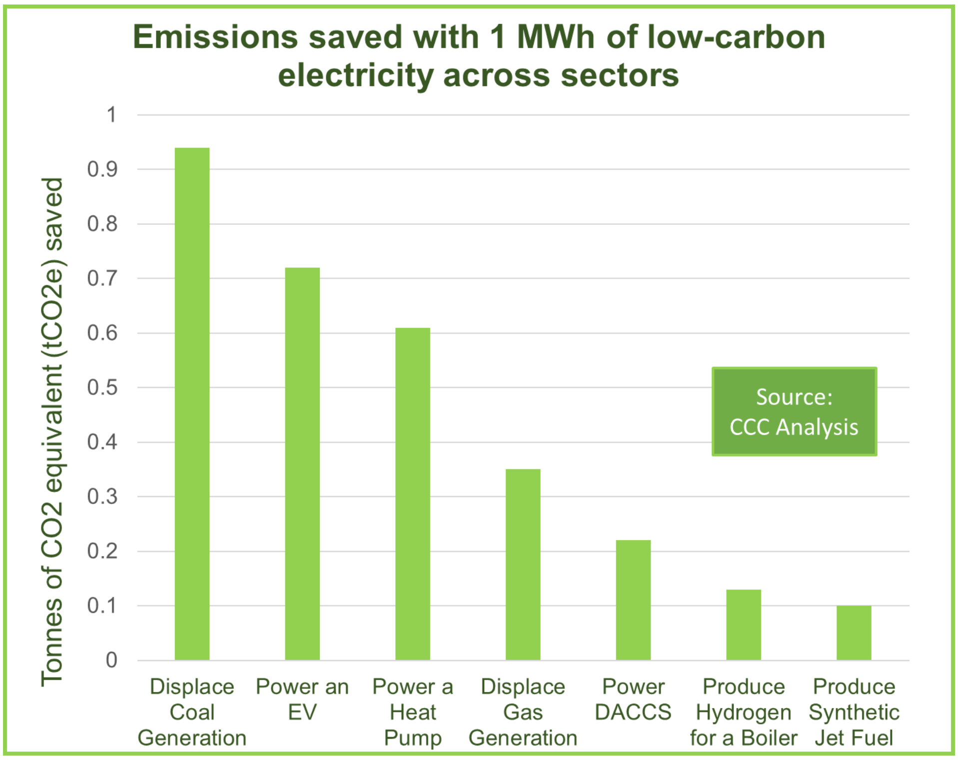
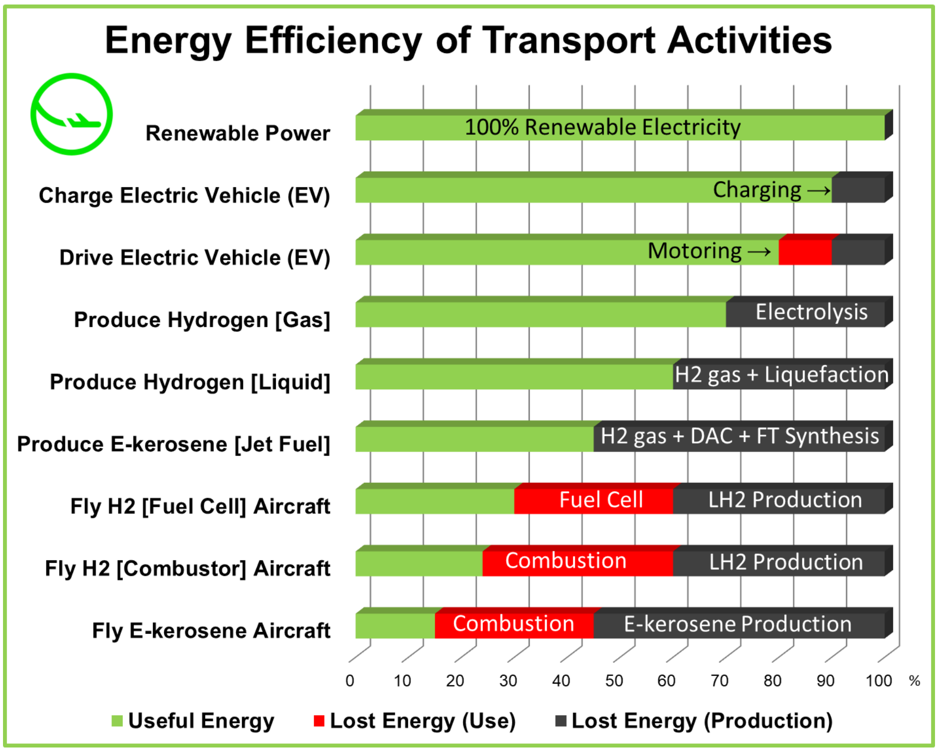


Figure M5.4 from the [CCC's Sector Summary for Electricity Generation], page 11

From this quote and diagram, it should be immediately obvious that the government should favour direct use of electricity for decarbonising the grid, ground transport and buildings - before any is used to power DACCS, produce green hydrogen or produce synthetic jet fuel (e-fuel), which is the most wasteful use of green electricity on their chart. This is because e-fuel production is very inefficient primarily due to the production of green H2, running DAC, and the Fischer-Tropsch (FT) synthesis process to produce the hydrocarbon jet fuel:



Safe Landing chart illustrating the losses from fuel production and use for various activities

We can perform some basic calculations to demonstrate the electricity requirement for powering UK aviation with 100% e-fuel, if we use a reasonable power-to-liquid (PtL) efficiency estimate of 45%.

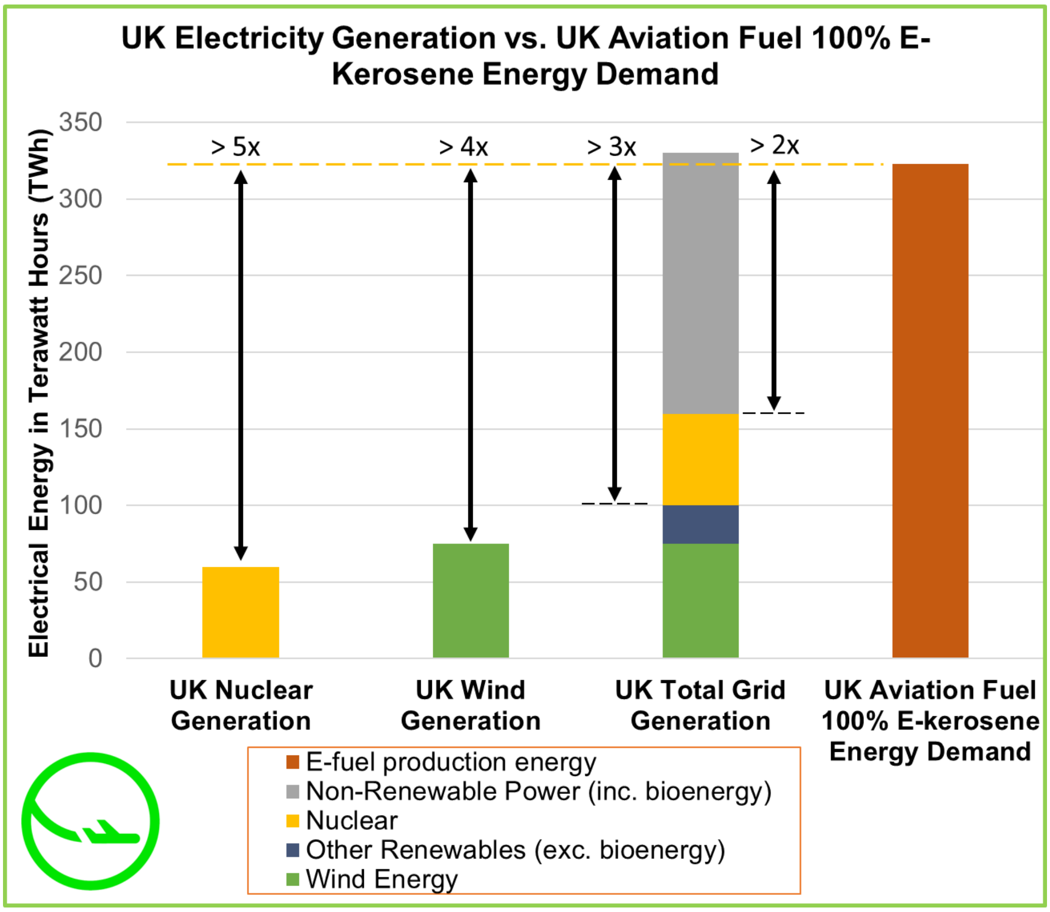
- UK civil aviation emissions in 2018 = 38.2 $MtCO_2$ [source, page 6]
- 1kg fuel = 3.15kg CO_2 [source, page 17]
- UK jet fuel consumption = 38.2Mt/3.15 = 12.1 million tonnes of jet fuel.
- Energy conversion for jet fuel = 12kWh/kg [source, page 14] = 12,000 kWh/tonne
- 12,100,000 tonnes jet fuel x 12,000 kWh/tonne = about 145 TWh of jet fuel
- 100% E-fuel: 145 TWh of e-fuel (@ 45% PtL efficiency) requires about **323 TWh** of electricity.

Total UK electricity demand in 2020 was **330 TWh** [source], but only:

- 135 TWh was from 'renewables' (includes bioenergy)
- 97 TWh from wind/wave/solar/hydro combined (excludes bioenergy)
- 75 TWh from wind
- 50-60 TWh from nuclear

Therefore, UK aviation from 100% e-fuel would require either:

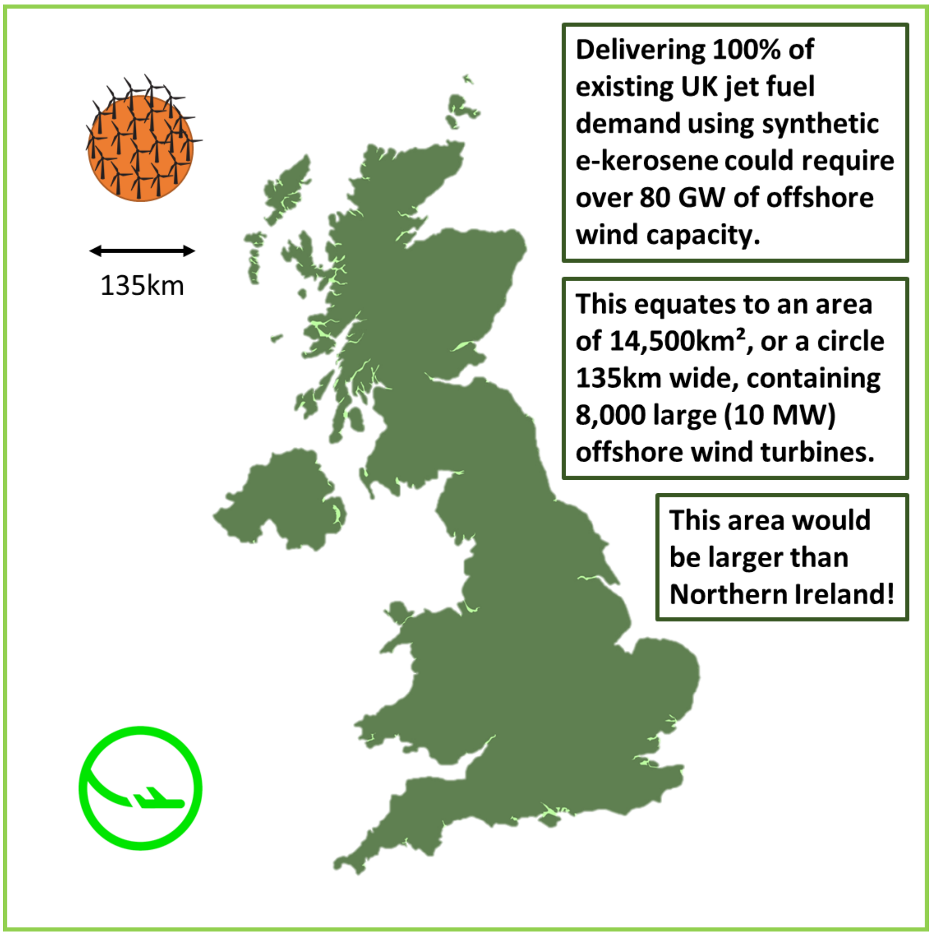
- a similar quantity of energy to the **entire** UK electricity generation today
- > 2x current 'low-carbon' electricity generation (if we include nuclear in this)
- > 3x current renewable generation (wind, wave, solar and hydro power)
- > 4x current wind energy generation
- > 5x current nuclear energy generation



Safe Landing chart comparing UK e-kerosene electricity use with existing generation capacity

Note: The other important caveat of PtL e-fuel production is that only around 50% of e-fuels produced in a PtL plant can be used as jet fuel (i.e. e-kerosene), while the remaining 50% would be by-products (e.g. e-diesel). In our calculation of aviation's renewable electricity needs, we included only the share of electricity corresponding to the share of e-kerosene in the PtL product slate. In practice, the PtL plant will require about double that amount of electricity to produce the jet fuel and other by-products. This means that almost twice the amount of electricity would be required to produce all the renewable jet fuel necessary for the UK. The by-products obtained in the process would need to be used by other sectors so as not to be wasted, but in most cases direct electrification or other alternative fuels are more efficient solutions for decarbonisation. This means that producing PtL for aviation comes with an additional penalty in terms of renewable electricity [source, page 33-34] and we'd actually need about **645 TWh which would be > 8x current wind energy generation**.

Ignoring this and just focusing on the electricity for the e-kerosene: current offshore wind installed capacity is 10.4 GW. This generates 40.7 TWh electricity per year [source]. So the 323 TWh required to produce 100% e-fuel, would need 323/40.7 = 8x more capacity = 82.5 GW. This represents **87% of the 95 GW of offshore wind installed by 2050** in the CCC's Balanced Pathway scenario they have recommended to the UK Government [source, page 97]. Assuming 175 km² per GW of offshore wind, this would require 14,500 km² of sea bed, **an area larger than Northern Ireland**, and equating to a circle with a diameter across of about 135 km. For eye-boggling context, we've created an illustration of how much new offshore wind generation we'd need to build for e-kerosene alone:



Safe Landing illustration showing UK offshore wind area required for e-kerosene production

Taking into account the note above about unavoidable e-kerosene by-products, we'd actually need about **175% of the CCC's estimate** of UK offshore wind installed by 2050, or an area **twice the size of Northern Ireland**.

We think this would be very unrealistic within the next couple of decades, given CCC estimates for offshore wind capacity and given competition for renewable electricity from other sectors.

Various NGOs propose that only "additional" renewable electricity [source, page 60] should be used for aviation e-fuel or green H2.

However, it feels inconceivable that such a quantity of renewables could be built without impacting the build and market cost of renewable electricity for others. This is due to economics if energy demand far outstrips supply. And even if we believe the supply of renewables can be infinite without serious ecological and environmental impact - we still need to accept the very real human constraints of scoping, planning, funding, building and commissioning projects. For the coming decades, it's clear that renewable electricity supply will be constrained. With total human energy demand currently far exceeding renewable supply (about 160,000 TWh demand vs. 7,000 TWh renewable supply), if we don't rapidly reduce energy demand, **we will prolong fossil fuels, regardless of renewable supply**.

There is certainly an argument that aviation can be harnessed as a force for good to increase the supply of renewables, and production capacity of green H2 and DAC which are necessary elements for economy-wide decarbonisation. However, the assertion that we should therefore maximise e-fuel use is not a logical next step, as the calculations, diagrams and rationale above hopefully make clear.

It would, to us, seem much more logical to prioritise driving down fossil jet fuel use within aviation via a mixture of capacity limits, kerosene tax, emissions pricing and/or frequent flyer levies. Those revenues could then be used (in addition to e.g. loss & damage payments) to fund renewable energy, green H2 and DAC capacity. As with any new technology, the early stage of deployment will feature high costs and low supply. Increasing supply and decreasing costs is therefore essential. Such technologies, once scaled and saturated elsewhere, are then likely to prove vital for aviation in future decades.

However, it doesn't make sense to direct their output to aviation fuels during the immediate decades, as there are other uses that will provide significantly greater emissions savings (see Figure M5.4 from the CCC, above).

Let's now take a look at how we could put these outputs to better use.

Renewable Electricity

As seen in Figure M5.4 from the CCC, above, renewable electricity will provide the maximum emissions savings if utilised for grid, road transport, and building heat decarbonisation. Not shown on the chart, but expected to provide higher emissions savings too, are decarbonising trucks, shipping, agriculture and industry/manufacturing, particularly steel, cement, fertiliser and chemical production. Using renewable electricity to decarbonise these sectors will provide greater emissions savings than producing aviation fuel in the near-term and benefit a wider distribution of the population.

Green Hydrogen (Green H2)

Due to the inherent inefficiency of Green H2 production and the difficulties transporting and storing it. It makes sense to minimise Green H2 production wherever possible in favour of direct electrification.

Currently in the UK, and globally, hydrogen is overwhelmingly produced from fossil-fuel intensive processes - so called "Grey Hydrogen". Grey H2 globally accounts for 2% of carbon emissions.

As such, Green H2 produced from renewable electricity should be prioritised for displacing existing uses of Grey H2 produced from fossil fuels i.e. fertiliser production and chemicals processing. This is likely to take at least two decades.

In addition, hydrogen has important potential future uses as:

- a means of energy storage; and
- a source of power for energy intensive industries like steel, glass and mineral production.

Green H2 production is likely to be best suited to applications or places which are adjacent to, or accessible to, hydrogen users, such as industrial clusters i.e. fertiliser, chemicals or steel production.

The upshot of all of this, is that Green H2 production should either take place near industrial clusters, or industrial clusters should be moved to regions of high renewable energy supply, but low demand. With this in mind, airports that are particularly large and located near urban centres are not great candidates for early Green H2 use.

Green H2 for Cleaner Kerosene

Where it would make sense for aviation to make immediate use of Green H2, albeit in relatively small quantities, is to reduce the aromatic, naphthalene and sulphur (ANS) content of fossil jet fuel supply.

Aromatics are a class of hydrocarbons present in jet fuels that produce more soot than other classes of hydrocarbons when burned. Naphthalene is the aromatic molecule that can produce the most soot. Jet fuels also contain small quantities of sulphur (less than 0.1%) that produce SO2 and sulphate particles when burned. Reducing these compounds is expected to reduce soot when the jet fuel is burned: which should improve air quality at airports and reduce the climate impact of contrails. Recent flight tests with 'SAF' have confirmed that reducing ANS content can significantly reduce contrail-cirrus by reducing soot emissions.

This can be achieved through a process called **hydrotreatment** (reaction with hydrogen), which is commonly used in refineries for other fuels e.g. diesel. Reducing jet-fuel aromatics is one of the measures that EASA has proposed to reduce soot/particulate emissions and contrail formation.

Reduced ANS would reduce air pollution by fine and ultrafine particles of soot and sulphate at airports (hydrotreating fuel implies hydrodesulfurization, which means that not only soot but also sulphate particles would be reduced). The likely consequence would be improved air quality and reduced health impacts for airport customers, workers and nearby communities.

There are strong grounds to act as soon as possible to reduce ANS in kerosene:

1. **Quick**: it could be implemented within a few years, rather than waiting decades for 'SAF'.
2. **Low Energy**: hydrotreating kerosene would use a tiny quantity of Green H2 versus 'SAF'.
3. **Cheap**: hydrotreating kerosene is very low cost (increases fuel price by only a few percent [pg. 57]) compared to 'SAF' (which is several times more expensive than kerosene).
4. **Nothing to lose**: improving the quality of kerosene is likely to have many benefits, but has essentially no downsides, other than the small incremental costs – which would result in more employment for workers.

In summary: the aviation sector already plans a massive use of Green H2 as a raw material to make alternative fuels: biofuels and e-fuels. But Green H2 will be in very short supply for decades. It would be more efficient to first use the available Green H2 to hydrotreat conventional fossil kerosene than using it to produce SAF. For the same small quantity of H2, the total climate impact and health impact of jet fuel could be reduced a lot more by hydrotreating the majority of kerosene rather than by producing limited quantities of "SAF" and blending it with non-hydrotreated kerosene.

Direct Air Capture (DAC)
As seen in Figure M5.4 from the CCC, above, renewable electricity will provide greater emissions savings (twice as much) if utilised for Direct Air Carbon Capture and Storage (DACCS), rather than combining 'green carbon' from DAC with Green H2 to produce a synthetic jet fuel.

As already identified above, Green H2 is inefficient to produce, has competition with more efficient decarbonisation pathways and will as such remain scarce for decades.

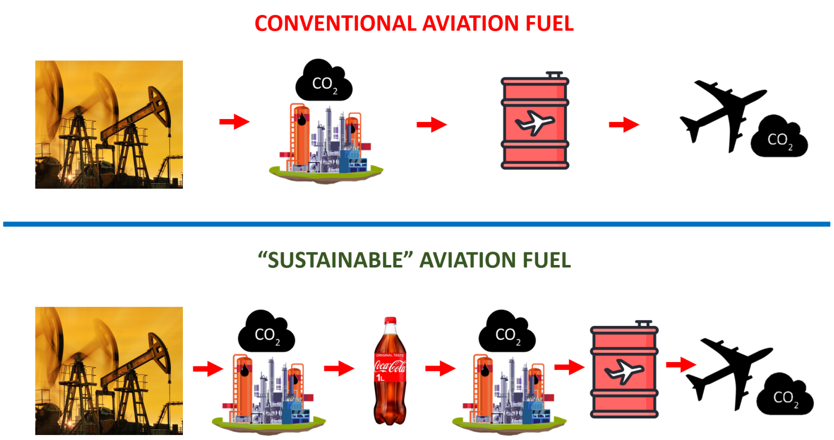
Therefore, in the near term, we advocate for aviation revenue and funding to be spent on DACCS rather than on e-fuel production. This also means we advocate for near term e-fuel mandates to be dropped.

The only argument we can see against this is to provide a more visual story of aviation decarbonising its own operations by producing a fuel that is going directly into aircraft. However, this is entirely superficial and illogical from an efficiency, energy and cost perspective if the references used here are correct. The goal has to be rapidly reducing emissions, and we need the most cost and time effective solutions to achieve this.

The only question is whether to hypothecate aviation revenue for DACCS ahead of e.g. renewable energy and direct electrification of the grid, ground transport, buildings and industry. There is an argument for that, and a balance will need to be struck as DACCS will be needed in all existing government decarbonisation plans. If aviation doesn't pay for it's early development, then it's not clear who will, other than general taxpayers and this would appear to be a socio-economic injustice.

Finally, we advocate for DACCS contracts to not be awarded to fossil fuel companies, as is currently common practice. If fossil fuel companies are to benefit from DACCS carbon removals in the future, then it will provide them with the perverse incentive to maximise the size of their future market, by prolonging the extraction and burning of fossil fuels today. Clearly this is highly problematic. We would rather see publically-owned DACCS projects in low-income countries who are experiencing the worst climate impacts, may be overly reliant on aviation/tourism or high-carbon industries for their economies and require economic investment in order to diversity, decarbonise and create jobs. This would appear to provide some socio-economic justice, at least in a small way, via being paid to clean up the mess that others have mostly created and profited from.

FUEL FROM RECYCLED CARBON
Utilising fossil carbon from plastic waste is surely misguided when reducing plastic or storing in landfill would prevent further greenhouse gas emissions:



Using carbon extracted from a fossil fuel power station or industrial process with CCS to produce a synthetic jet fuel also doesn't appear to offer any benefit vs. immediately storing the carbon, as per the e-fuel vs. DACCS argument, the production of Green H2 and the FT process for the synthetic fuel means that simply storing the carbon feels like a more efficient step.

COST OF ENERGY

Whatever fuel is used by our aviation industry in the future, one thing is clear: costs will increase. This will be true whether we:

- Continue to burn fossil kerosene and run DACCS alongside this, or;
- Scale alternative aviation biofuels and/or e-fuels such as e-kerosene or Green H2

This is driven by the fundamental inefficiency of these processes and the fundamental inefficiency of flying. Some of these inefficiencies and associated costs will be difficult if not impossible to reduce. Also the prediction that a carbon budget for fossil fuels and scarce global supply of non-fossil energy compared to total energy demand will drive up prices for alternative fuels.

There will no doubt be some that believe that resources shouldn't be ring-fenced for certain uses and market forces should be allowed to act and provide economically efficient outcomes. Even that perspective would have to admit that it still doesn't make sense for governments to actively subsidise the least efficient use of energy, with the majority of it being wasted due to thermodynamic losses.

Because of this, if allowed access to feedstocks (renewable electricity of biomass) we view it as likely that aviation fuel producers will have to pay a cost premium vs. other uses, rather than receive subsidies.

This is likely in turn, to drive a huge transformation across aerospace manufacturing, airline operations and aircraft/airport configurations. This in itself will cost trillions of dollars in investment. We believe that government support should primarily be targeted here, rather than squandered on further financing the fuels industry, particularly for fuel pathways with questionable sustainability.

In short: if the UK government spend £30bn subsidising 'SAF', they might waste all their money, and the same money could have been spent developing a medium-range hydrogen aircraft/engine or a next-generation jet fuel-powered aircraft e.g. blended wing body or truss-braced wing aircraft powered by open rotor engines, etc. Such technology and competency is a necessity, regardless of fuel availability - let's focus there instead.

We can be contacted at: info@safe-landing.org if anything in our response requires further detail.