SUSTAINABLE AVIATION

NET ZERO CARBON ROAD-MAP

SUMMARY REPORT

Enabling delivery of a UK-led zero carbon aviation revolution

SUSTAINABLE AVIATION
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ABOUT SUSTAINABLE AVIATION

Sustainable Aviation (SA) is a unique and growing alliance of the UK's airlines, airports, aerospace manufacturers, air navigation service providers and innovation companies in Sustainable Aviation Fuel (SAF) and carbon removals. Established in 2005 it is the first alliance of its kind in the world and has 43 members at the date of publication.

MEMBERS

DISCLAIMER

Sustainable Aviation (SA) believes the data forecasts and analysis in this report to be correct as at the date of publication. The opinions contained in this report, except where specifically attributed to, are those of SA, and based upon the information that was available to us at the time of publication. We are always pleased to receive updated information and opinions about any of the contents.

All statements in this report (other than statements of historical facts) that address future market developments, government actions and events, may be deemed 'forward-looking statements'. Although SA believes that the outcomes expressed in such forward-looking statements are based on reasonable assumptions, such statements are not guarantees of future performance: actual results or developments may differ materially, e.g. due to the emergence of new technologies and applications, changes to regulations, and unforeseen general economic, market or business conditions.

FOREWORD

BY SUSTAINABLE AVIATION CHAIR

For many people in the UK, 2022 was the year the climate crisis came home. Record temperatures across the country and extreme weather around the world gave an all too real insight into the kinds of events scientists are clear will happen more often, and with greater intensity, unless we reduce greenhouse gas emissions urgently.

That makes climate change an existential risk to us all. The UN Secretary General has described dangerous climate change as "economy-destroying". For aviation, a sector that is an integral part of the global economy, that makes climate change the most significant mid- to long-term risk we face.

As an industry, we are under no illusions that we too must change. We need to act decisively to reduce our climate impact. That's why this new Net Zero Carbon Road-Map is so important. It shows that we can take the carbon out of flying even as we grow, protecting the amazing benefits of international air travel for future generations. Decarbonising aviation also creates an opportunity to establish Britain as the home of the green aviation industry – creating thousands of jobs and attracting billions in inward investment.

In 2020, the UK aviation industry was the first anywhere in the world to commit to net zero 2050, when we published our previous Road-Map. Since then, global airlines, and global governments through International Civil Aviation Organisation (ICAO), have committed to the same goal. The global net zero transition for aviation is underway. We have many of the tools already – our collective challenge now, alongside Government, is to deliver at scale and at speed. This Road-Map strengthens the case for optimism that the power to decarbonise aviation is in our hands.

In the last three years, our confidence in the opportunity to cut emissions through the use of Sustainable Aviation Fuel (SAF) has increased. This Road-Map shows the potential for SAF to provide 75% of UK jet fuel needs by 2050. The last three years have also seen the first flight of a plane powered by hydrogen, increasing our confidence on the potential for zero carbon emission flight for shorter journeys too.

Some of the measures to cut emissions – like modernising airspace or using more fuel-efficient aircraft – not only cut carbon but reduce cost too. With some new low-carbon technology like SAF or hydrogen or carbon removals, there's a "green premium" in the early days before the market scales and prices fall. Increased costs for industry and consumers could have some impact on future demand for air travel, but our work shows that significant ongoing growth can be achieved at the same time as decarbonising aviation. That's the goal the sector has set itself: to protect the benefits for the UK of growing international connectivity, by achieving net zero carbon aviation by 2050.

The challenge, made even clearer by this Road-Map, is fundamentally one of economics, political action and cross-sector collaboration. Other countries have stepped up in the race to capitalise on these technologies, to produce and supply sustainable fuels, to design and sell zero carbon emission aircraft, to develop carbon capture technology, renewable electricity and hydrogen. We should be leading the pack, not just towards a more sustainable future, but a more prosperous one as well. The UK aviation industry stands ready to achieve net zero, and calls on the Government to work in partnership with us to deliver our Road-Map, so this critical decade is remembered as a real turning point to a permanently sustainable future for flight.

Matthew Gorman, MBE

EXECUTIVE SUMMARY

Climate change is a clear and pressing issue for people, businesses, and governments across the world. Net zero carbon emissions by 2050 is now a committed goal for the entire global aviation industry and UK Government. Focus must now be on accelerating delivery of the opportunities set out in this Road-Map to maximise the benefits this offers to the people across the UK.

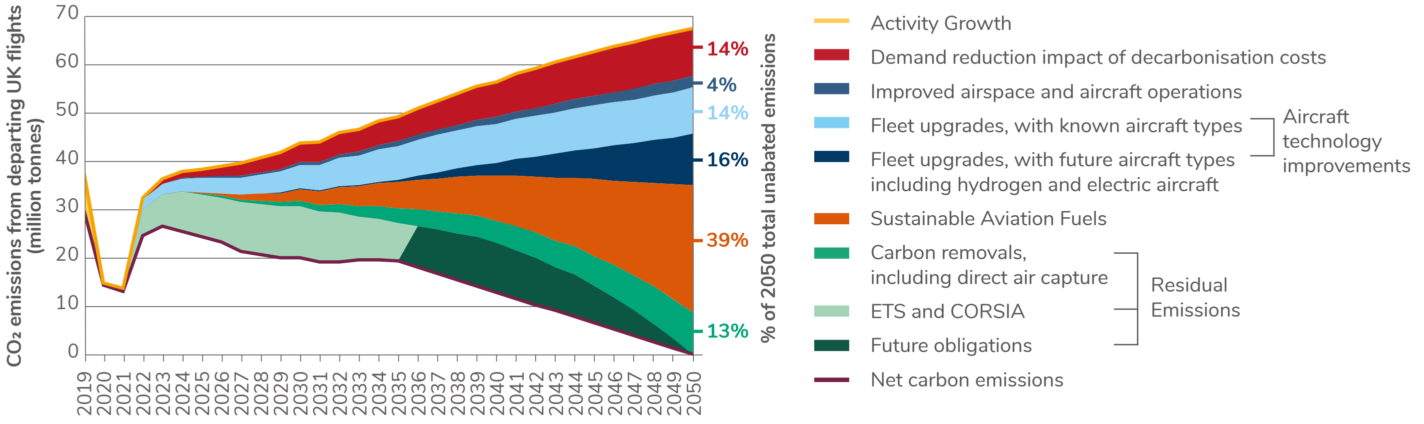
By 2050, the UK aviation industry can deliver net zero carbon emissions through the following initiatives compared with a scenario of growth at today's efficiency:

- 9.6 Million Tonnes of carbon dioxide ($MtCO_2$) saving due to decarbonisation cost impact on demand;
- 2.5 $MtCO_2$ saving from better air traffic management and operating procedures;
- 9.5 $MtCO_2$ saving from introduction of known and new, more efficient aircraft;
- 10.6 $MtCO_2$ saving from introduction of future, more efficient aircraft types including electric and hydrogen aircraft;
- 26.4 $MtCO_2$ saving from sustainable aviation fuels;
- 8.8 $MtCO_2$ saving from permanent carbon removals.

Our Road-Map draws on expertise from all corners of the UK aviation industry, including airlines, airports, aerospace manufacturers, air navigation service providers and wider supply chain and innovation organisations. It is based on a thorough review of the opportunities to cut aviation carbon emissions through smarter flight operations, new aircraft and engine technology, modernising our airspace, the use of sustainable aviation fuels and significant investment in carbon reductions through effective carbon market-based policy measures and greenhouse gas removals (GGRs).

With these actions, the UK will be able to accommodate significant growth in passengers through to 2050 whilst reducing emission levels from just under 40 million tonnes of CO_2 per year down to zero. Doing this can also support many new jobs in the UK renewable and low carbon economy.

Sustainable Aviation Net Zero Carbon Road-Map



- Following positive technological developments, UK aviation has updated its detailed plan on how we will reach net zero aviation by 2050.
- Analysis shows the vital role of upscaling sustainable aviation fuels (SAF) and how the UK has feedstocks (that use zero UK farmland) for a UK SAF industry that could create thousands of skilled jobs and help meet the 10% SAF mandate by 2030 – if Government takes crucial action on SAF plants now.
- The Road-Map highlights exciting progress developing zero-carbon emission flight including key advances in hydrogen-powered aircraft, and carbon removals technologies.
- The Road-Map identifies historic opportunity for the UK to lead the worldwide zero carbon aviation revolution which will create thousands of jobs, investment and help to secure the many benefits of flying for decades to come.

EXECUTIVE SUMMARY

Industry commitments

- We remain committed to cutting carbon emissions from UK aviation to net zero by 2050.
- We are supporting many initiatives today across operations, technology, sustainable fuels and carbon removal, to make our commitment a reality.
- We will continually review this Road-Map to ensure it remains in line with the latest scientific advice on meeting the UK and ICAO related aviation climate goals.
- Whilst non-CO_2 impacts are not addressed in this Road-Map we will be carrying out further work this year to determine the best way to manage these issues going forwards, working in collaboration with the Jet Zero Council and UK Government.
- A full technical report of this Road-Map, with more detailed data, will be published later this year.

Key messages

Achieving net zero carbon for aviation will be harder than for most sectors but it is achievable. However, it can only be delivered through an international approach, with substantial investment from industry and development of smart low carbon policies by the UK Government, working in partnership with the sector.

We ask the UK Government to support this road-map in the following ways:

- **Maximising short-term operational efficiencies** by accelerating the UK airspace modernisation programme and completing by the end of the decade.
- **Delivering commercial UK SAF production at scale this decade** by providing a price stability mechanism, alongside a SAF mandate and by prioritising access to UK sustainable feedstocks.
- **Investing in zero-emission flight technology** by uplifting matched funding levels to the Aerospace Technology Institute (ATI) programme through to 2031 - to drive efficiency improvements and the development of zero carbon emission technologies, alongside investing in the UK hydrogen supply and airport infrastructure.
- **Addressing residual aviation emissions** by accelerating the rollout of carbon removals, including them in the UK Emissions Trading Scheme (ETS) and ensuring aviation's fair share.

Delivering accelerated progress towards a UK-wide net zero CO_2 emission future requires aligning all of Government on a strategic plan, to ensure sufficient low carbon electrical and hydrogen generation is in place, to meet the increased energy demands with UK aviation receiving its fair share alongside other industries. Sustainable Aviation forecasts that UK aviation will require a maximum of an additional 147 TWh in additional renewable energy by 2050.

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE OF THIS NET ZERO CARBON ROAD-MAP

This Road-Map sets out Sustainable Aviation's view of how, with the application of a series of measures, the expected growth in UK aviation activity can be consistent with reaching net zero carbon emissions over the period to 2050. It is based on the latest information available to us at the time of writing.

The Road-Map's purpose is to inform debate, to highlight the efforts being taken by the aviation industry to reduce its carbon emissions, to assess the likely effectiveness of those efforts in the specific context of UK aviation, and to identify areas where Industry and Government can do more.

As with our previous CO_2 Road-Maps, we interpret "UK aviation" to mean "flights which depart from UK airports". This is consistent with the accounting convention used by the UK to assess emissions from UK aviation. Due to the intrinsic global nature of aviation, the UK aviation industry knows that approaches to decarbonise aviation must be addressed as an international endeavour to maximise emissions reductions and minimise competitive distortion. UK policy measures to address UK aviation emissions alone (which account for less than 4% of global aviation emissions), will do little to mitigate worldwide climate change impacts. However, aligning UK policy on aviation emissions with both EU and global polices can make real step changes. A demonstration of this was seen with the global commitment to net zero carbon emissions announced at the 41st International Civil Aviation Organisation (ICAO), General Assembly, in October 2022.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE OF THIS NET ZERO CARBON ROAD-MAP (CONTINUED)

COVID impact and recovery assumptions

The COVID pandemic had a very significant impact on UK aviation, but 2022 saw a strong recovery to 75% of 2019 annual airport terminal passenger numbers as reported by the Civil Aviation Authority (CAA). Latest forecasts for 2023 expect a recovery almost, but not quite back to 2019 levels. This latest result and forecast have been used as the basis for this Road-Map.

Scope of emissions

Carbon dioxide (CO_2) is the only emission modelled in this Road-Map. Besides CO_2, emissions from aviation also include oxides of nitrogen (NOx), water vapour, particulates, carbon monoxide, unburned hydrocarbons, soot, and oxides of sulphur (SOx). Two UK led scientific reports into non-CO_2 impacts from aviation were published in 2018 and 2021. These clarified the current state of scientific understanding of the non-CO_2 effects of aviation on the climate.

This is clearly an important and substantial issue that must also be addressed. There are uncertainties around the size, nature, duration, and permanency of these impacts which currently make them challenging to address in the same format as this carbon Road-Map. Sustainable Aviation members are already taking action on non-CO_2 emissions impacts, based on the latest scientific understanding. Sustainable Aviation will work with the Government, Jet Zero Council, and others to conduct further work on this topic.

Taking this into account, this Road-Map focuses purely on CO_2 emissions from departing UK flights.

1.2 UK AVIATION CO_2 EMISSIONS PERFORMANCE

Prior to the COVID pandemic, UK aviation emissions made up about 8% of total UK carbon emissions[1], not accounting for any voluntary or compulsory carbon trading and offsetting. In 2019 the gross emissions from flights departing the UK were 38 Million tonnes (Mt CO_2). As a result of carbon trading and offsetting in 2019 there has been a net reduction in UK aviation emissions of 8 Mt CO_2 resulting in net emissions from UK aviation of 30 Mt CO_2. During the COVID pandemic emissions fell significantly as air travel was restricted.

1 Derived from the UK 2019 Final Greenhouse Gas statistics, incorporating both domestic and international aviation emissions.

1. INTRODUCTION

1.2 UK AVIATION CO_2 EMISSIONS PERFORMANCE (CONTINUED)

Annual changes in UK aviation emissions

Between 1990 and 2019 emissions from flights departing the UK have more than doubled. However, since 2005 gross UK aviation emissions have stabilised, with only a 1% increase in emissions, despite a 30% growth in passengers (Pax) carried. This has been achieved mainly by the replacement of older aircraft with more efficient ones.

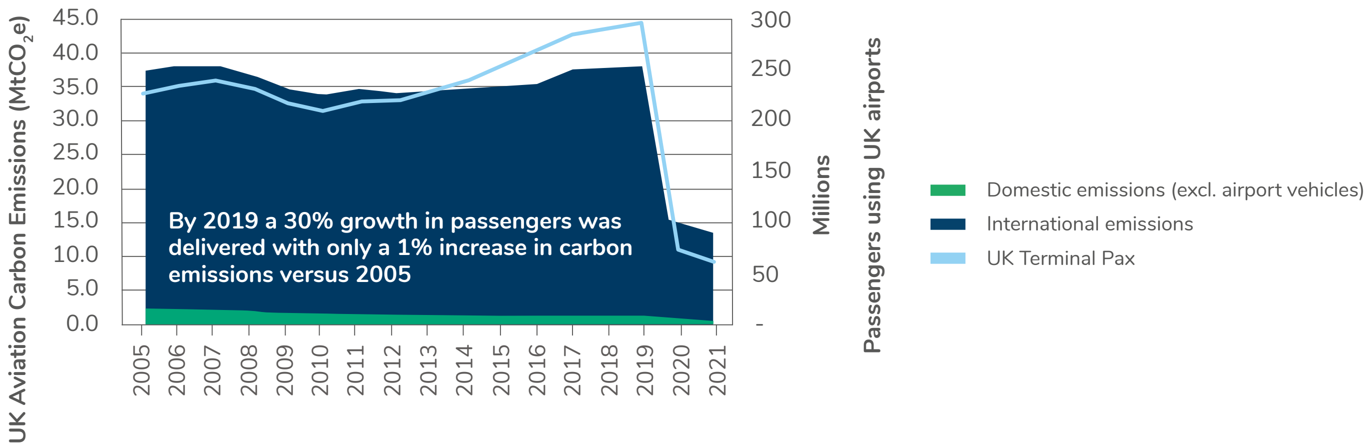


Figure 1: Changes in UK aviation carbon emissions and passengers since 2005.

Source: Data from UK Government Greenhosue Gas statistics.

1.3 INDEPENDENT ANALYSIS SUPPORTING THIS WORK

In addition to gathering the collective expert views from across the aviation industry, Sustainable Aviation has also sought independent support from ICF regarding the UK sustainable aviation fuel potential and from Foresight Transitions with regard to the evolving greenhouse gas removal market.

1.4 NEXT STEPS

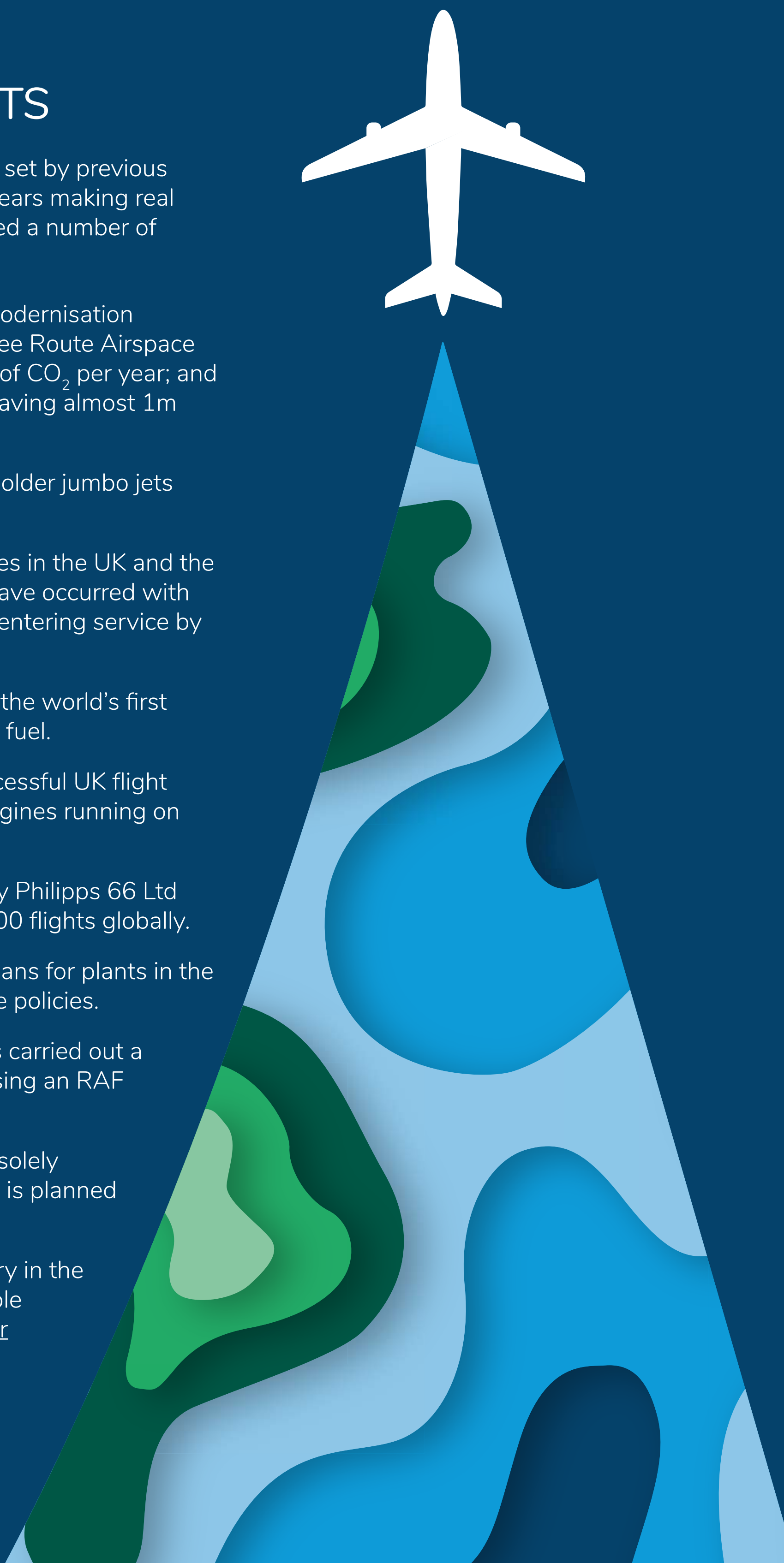
The following chapters summarise the results of the UK aviation industry's review of measures to deliver net zero carbon emissions by 2050. They present the central case scenario for each measure. A further technical report will be published in due course that provides more detailed analysis for each measure's potential and where appropriate additional scenario related outcomes. This further technical report will also look at the cumulative emissions from each measure and consider wider issues such as how these measures could develop beyond 2050.

2. THE SUSTAINABLE AVIATION NET ZERO CARBON ROAD-MAP

2.1 INDUSTRY ACHIEVEMENTS

The UK aviation sector is continuing to deliver on goals set by previous issues of this Road-Map with achievements in recent years making real progress on CO_2 reductions. SA members have delivered a number of world firsts, including:

- Since 2021, NATS has implemented nine airspace modernisation changes including the first UK implementations of Free Route Airspace and systemisation, saving more than 60,000 tonnes of CO_2 per year; and made changes to the North Atlantic track structure saving almost 1m tonnes of CO_2 per year.
- The COVID pandemic saw the earlier phasing out of older jumbo jets replaced by newer, more efficient aircraft.
- Hydrogen fuel cell aircraft are now in test flight phases in the UK and the testing of engines running on 100% hydrogen fuel have occurred with the ambition for hydrogen powered aircraft to begin entering service by the end of this decade.
    - Last November Rolls-Royce and easyJet achieved the world's first operation of a modern aircraft engine on hydrogen fuel.
    - In January 2023, ZeroAvia conducted the first successful UK flight of a 19-seater Dornier 228 with one of the two engines running on hydrogen fuel cells.
- UK SAF started production in 2022 in the Humber by Philipps 66 Ltd and SAF blends have now been used on over 450,000 flights globally.
    - At least 8 more SAF producers have announced plans for plants in the UK, subject to the requested Government incentive policies.
    - In November 2022, the RAF and industry partners carried out a world-first 100% sustainable aviation fuel flight using an RAF Voyager military transporter aircraft.
    - The world's first net zero transatlantic flight using solely sustainable aviation fuel from London to New York is planned in 2023.
- Greenhouse gas removals are now a growing industry in the UK, supported by the UK Government and Sustainable Aviation members, including through the Coalition for Negative Emissions.



2. THE SUSTAINABLE AVIATION NET ZERO CARBON ROAD-MAP

2.2 INDUSTRY COMMITMENTS

Reflecting the latest UK aviation industry analysis:

- We remain committed to cutting carbon emissions from UK aviation to net zero by 2050.
- We will continue to support many initiatives across operations, technology, sustainable aviation fuels and carbon removal, to make our commitment a reality.
- We will continually review this Road-Map to ensure it remains in line with the latest scientific advice on meeting the UK and ICAO related aviation climate goals.
- Whilst non-CO_2 impacts are not addressed in this Road-Map we will be carrying out further work this year to determine the best way to manage these emissions going forwards.
- A full technical report of this Road-Map, with more detailed data, will be published later this year.

2.3 KEY MESSAGES FOR GOVERNMENT

The Sustainable Aviation Net Zero Carbon Road-Map illustrates a path for the UK aviation sector to achieve net zero carbon emissions by 2050, by delivering on the following key actions:

- **Maximising short-term operational efficiencies** including accelerating the UK airspace modernisation programme and completing it by the end of this decade.
- **Investing in next generation and zero-carbon flight technology** by committing to an increase in matched funding levels to the ATI programme through to 2031. This will drive continued efficiency improvements and accelerate the development of next generation zero emission technologies.
- **Investing in a hydrogen supply infrastructure** including adequate production and distribution whilst ensuring aviation's estimated requirement is secured.
- **Supporting the development and implementation of regulation** that enables the roll out and use of hydrogen at airports.
- **Delivering commercial UK Sustainable Aviation Fuel (SAF) production at scale this decade** by legislating for a price stability mechanism alongside a SAF mandate by second quarter 2024, to deliver at least five UK SAF plants under construction by 2025.
- **Secure access to UK sustainable feedstock for aviation** to maximise the potential for a UK SAF industry (without using any UK farmland).
- **Addressing residual aviation emissions** by accelerating the development of Greenhouse Gas Removals (GGRs) positioning the UK as a global leader and forward planning for aviation's requirement.

Delivering accelerated progress towards a UK-wide net zero CO_2 emission future requires aligning all of Government on a strategic plan, to ensure **sufficient low carbon electrical and hydrogen generation** is in place, to meet the increased energy demands with UK aviation receiving its fair share alongside other industries. Sustainable Aviation forecasts that UK aviation will require a maximum of 147 TWh in additional renewable energy need, set out as follows:

Topic	2050 Forecast UK aviation renewable energy demand to deliver net zero carbon emissions
Hydrogen and electric aircraft	63 TWh
Power to liquid SAF	50 TWh
Carbon removals	34 TWh
Maximum additional renewable energy need	147 TWh

2. THE SUSTAINABLE AVIATION NET ZERO CARBON ROAD-MAP

2.4 SUMMARY OF THE ROAD-MAP CHART

As in previous editions, the Road-Map quantifies the contribution of each pillar of aviation decarbonisation in achieving a reduction of net CO_2 emissions to zero by 2050. The top line of the chart shows CO_2 emissions in a hypothetical "no-improvements" scenario in which emissions simply follow growth in aviation activity with no decarbonisation measures adopted, and in which growth in activity is not affected by decarbonisation costs. The first illustrated 'wedge' shows the expected reduction of projected aviation activity due to the increased costs incurred in achieving net zero carbon emissions, causing flight ticket prices to rise. This issue of the Road-Map considers how the costs of carbon credits, SAF and greenhouse gas removals, and are likely to reduce aviation activity growth.

The next three illustrated wedges represent efficiency gains and therefore a reduction in the amount of jet fuel needed and CO_2 emitted to achieve the expected aviation activity. These efficiencies are incorporated in the fleet by:

- Improvements in airspace management and aircraft operations,
- Fleet replacement to latest generation aircraft with known technologies and products, and
- Introduction of next generation aircraft with future technologies, including hydrogen aircraft.

Mandatory obligation schemes include the UK ETS, CORSIA and a notional future scheme will address residual emissions. A hypothetical notional future scheme is assumed to commence at the end of the currently defined CORSIA scheme in 2035 to mandate a linear trajectory of net emissions to zero by 2050. These obligation schemes define the position of the lowest line in the Road-Map chart which indicates the net residual emissions from UK aviation throughout the timeline. Strategies to mitigate the quantity of CO_2 as illustrated in the Road-Map chart include: utilising fuel with lower carbon lifecycle emissions (SAF); purchasing greenhouse gas removals (GGRs); and purchasing carbon credits within obligation scheme structures to achieve net reductions of the carbon emissions. Although purchasing of GGRs may occur as part of compliance with carbon offsetting schemes, SA has specifically illustrated their ramp up. This is because as carbon removals are a very different category of carbon credit from what are currently thought of as carbon offsets. Carbon removals will be influential to achieving a low cost carbon transition for the aviation sector, and therefore specific engagement with durable and scalable GGRs is identified.

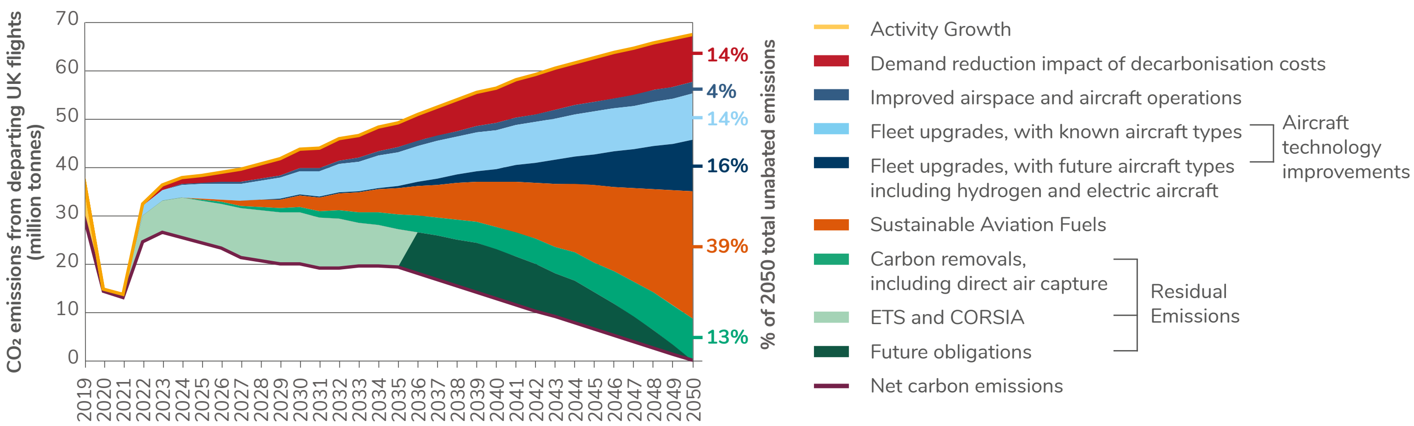


Figure 3: Sustainable Aviation Net Zero Carbon Road-Map

3. CARBON EMISSIONS: HYPOTHETICAL ‘NO-IMPROVEMENTS’ SCENARIO

3.1 KEY MESSAGES

- In a hypothetical ‘no improvement’ scenario, where no further decarbonisation measures were taken, growth in UK aviation activity would generate 67.5 Mt CO_2 by 2050.
- This would hypothetically, represent a 78% growth in aviation activity and emissions compared to the 2019 baseline.

3. CARBON EMISSIONS: HYPOTHETICAL NO-IMPROVEMENTS' SCENARIO

3.2 UK AVIATION DEMAND FORECAST

To determine future growth forecasts for CO_2 emissions from departing UK flights, Sustainable Aviation has always used UK Government forecasts. These forecasts are then compared to wider industry aviation forecasts. Many aviation industry forecasts look at global or regional demand growth, within which the UK demand is incorporated. They show global aviation growth forecasts of over 3% per annum. For the UK aviation market, forecasts are slightly lower at an average of 2.3% per annum, reflecting the maturity of the UK aviation market.

3.3 DEVELOPMENTS SINCE LAST ROAD-MAP

The previous full SA CO_2 Road-Map forecast took place in 2019, prior to the COVID pandemic, and was published in February 2020. It used the UK Government 2017 aviation forecasts with supplemental information from 2018 related to the 'Making Best Use' report. A COVID overlay CO_2 Road-Map was published in July 2021. This was a light touch forecast which used the 2019 forecast data, modifying it to reflect the forecast demand changes from the COVID pandemic.

COVID impact and recovery assumptions

The COVID pandemic had a very significant impact on UK aviation, but 2022 saw a strong recovery to 75% of 2019 passenger numbers. Using actual data and an estimate for post-COVID recovery, changes to forecast CO_2 emissions were made to reflect the pandemic's affect to UK aviation activity. A summary of these changes is detailed in the table.

Year/Scenario	SA 2021 COVID Overlay	Actual	SA 2023 Road-Map	2023 References
Unit	% of 2019 CO_2 emissions	% of 2019 CO_2 emissions	% of 2019 CO_2 emissions	
2020	30%	39%	39%	Using Actuals
2021	50%	N/A	36%	Based on Digestive UK Energy Statistics (DUKES) - showing lower fuel uptake than 2020
2022	85%	N/A	86%	Estimated COVID recovery pattern
2023	98%	N/A	96%	
2024	100%	N/A	100%	
Source	SA Derived	UK Govt GHG Statistics	SA Derived	

Table 1: Comparison of COVID pandemic recovery forecasts

UK Government aviation forecast

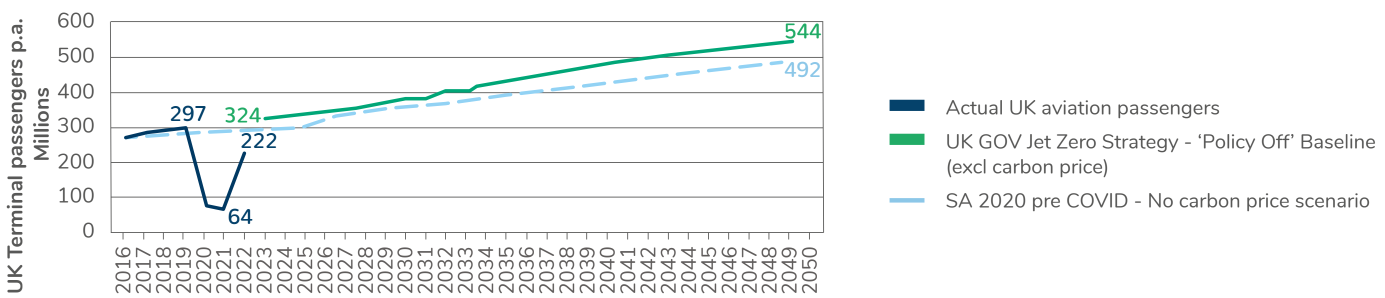
The UK Government updated their model and demand forecast for aviation as part of their work on the Jet Zero Strategy, published in 2022 in their further technical consultation. This produced a range of scenarios from a 'policy off' baseline to the 'high ambition' scenario, with the latter being adopted for the central Jet Zero Strategy case.

3. CARBON EMISSIONS: HYPOTHETICAL NO-IMPROVEMENTS' SCENARIO

3.4 SUMMARY OF ANALYSIS

SA has used the UK Government 'policy off' baseline forecast to develop the hypothetical 'no-improvements' CO_2 emissions forecast in this Road-Map. The latest demand forecast (excluding any decarbonisation cost effect on demand) shows an 83% increase in passenger demand by 2050 compared to 2019. This is delivered by a slightly smaller number of flights than previously forecast in SA's 2020 Road-Map, prior to the COVID pandemic.

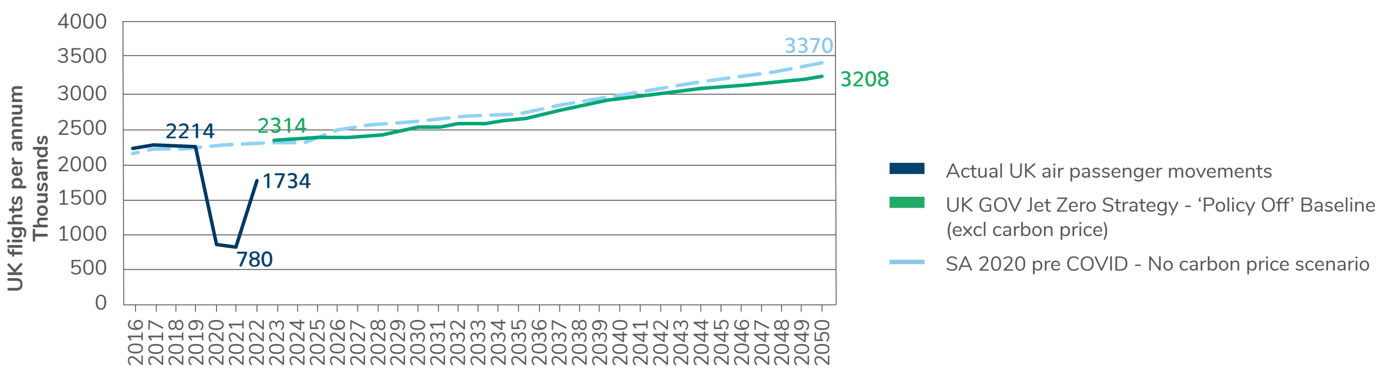
UK Aviation Terminal Passengers



In 2022 passenger numbers returned to 75% of 2019 baseline. By 2050 passenger numbers are forecast to be 83% greater than the 2019 baseline.

Figure 4: UK Government 'Policy off' scenario growth forecast in UK aviation passengers

UK Aviation Air Transport Movements (ATM)



In 2022 air transport movements were 78% of the 2019 baseline. By 2050 air transport movements are forecast to be 45% greater than the 2019 baseline.

Figure 5: UK Government 'Policy off' scenario growth forecast in UK air transport movements

In addition to the passenger and air transport movement forecasts per annum, the Department for Transport (DfT) also provided SA with annual passenger kilometre forecast data. This is taken as the measure of UK aviation activity growth as it captures the distance flown by each passenger, as well as the total number of passengers carried.

3. CARBON EMISSIONS: HYPOTHETICAL NO-IMPROVEMENTS' SCENARIO

Method for calculating hypothetical 'no improvement' emissions from UK Aviation

Firstly, for this Road-Map a baseline year of 2019 was chosen, against which to compare future changes. This year was chosen as it reflects the latest year of normal aviation activity prior to the COVID pandemic.

To calculate the emissions from flights departing the UK, as well as passenger kilometre data, an assumption on the type of aircraft used is also required. To create a 'hypothetical no improvement' emission forecast, the mix of aircraft types and operating efficiencies are locked at their 2019 values.

In future years, any growth in demand is met using a growing number of aircraft conforming to the 2019 fleet mix, and their operating efficiencies. This method can be broken into a series of steps as summarised below:

Determine forecast changes to total distance flown per annum to 2050 in an unconstrained demand growth scenario (Provided by UK Government)

Set the baseline year for future changes to be measured

(2019 used for this Road-Map)

Determine UK aviation CO_2 emissions in the baseline year (using UK Government published data)

Determine the percentage change in passenger km for each future year compared to the previous year to 2050

From 2020 onwards, for each year multiply the UK aviation CO_2 emissions from the previous year by the percentage change determined in the previous step

Figure 6: Method for identifying hypothetical 'no improvement' scenario growth in CO_2 emissions

Hypothetical 'no improvement' emissions from UK Aviation

The Government forecasts available did not include the effect on aviation activity of the COVID pandemic. Therefore, the above method could only be applied from the year 2025. In the years 2019-2021 data on actual CO_2 emissions were used. In the years 2022-2024, estimations were made by SA using insights from the World Economic Forum on the rate of activity recovery following the pandemic, to define CO_2 emissions as a percentage of the 2019 baseline year.

The 2019 UK aviation CO_2 emissions for the baseline year of this Road-Map are detailed below:

Sector	Sub-sector	2019 (emissions in Mt CO_2)
UK Civil Aviation CO_2 emissions from all departing flights	Domestic	1.4
	International	36.4
	Total	37.8

Table 2: Baseline UK aviation CO_2 emissions

Source: Table 1.3 and 6.1: Civil Avaition CO_2 emissions - UK Final Greenhouse gas statistics

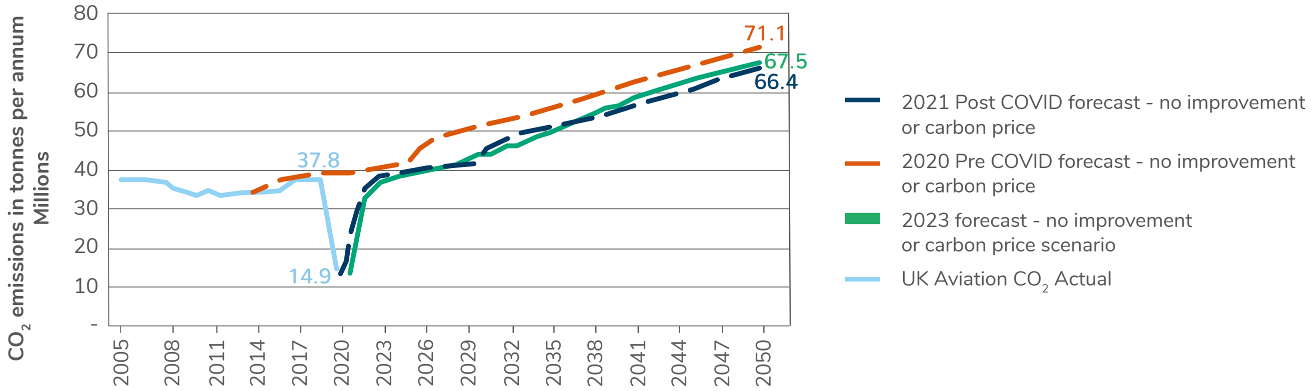
3. CARBON EMISSIONS: HYPOTHETICAL NO-IMPROVEMENTS' SCENARIO

Hypothetical 'no improvement' emissions from UK Aviation (continued)

This emission figure represents the aviation fuel used by all civil aviation flights departing the UK, converted into CO_2 emissions by the Government. This fuel usage therefore is a 'snapshot' of aviation operating efficiencies in 2019 resulting from the mix of aircraft used and any operational and air traffic management efficiencies being achieved at the time.

Following the method defined earlier, emissions from the unconstrained growth in UK aviation demand are forecast to grow to 67.5 Mt CO_2 by 2050 in a hypothetical 'no improvement' scenario. This is 1 Mt CO_2 greater than the SA 2021 COVID Overlay forecast but 3.6 Mt less than the SA 2020 pre COVID Road-Map forecast.

UK Aviation Hypothetical 'no improvement' CO_2 emissions (no carbon price)



Unabated UK aviation emissions are forecast to grow by 78% from 2019 to meet demand.

Figure 7: Forecast of hypothetical 'no improvement' CO_2 emissions

3.5 ASSUMPTIONS

Sustainable Aviation take the latest UK Government modelling of future UK aviation demand to 2050 as the basis of our Road-Map work.

The Government demand forecast assumes a series of air traffic movement and passenger capacities for UK airports.
The Government states that these assumptions do not represent any proposal for limits on future capacity growth at specific airports, nor do they indicate maximum appropriate levels of capacity growth at specific airports for the purpose of planning decision-making. Any figures do not represent expected passenger numbers, just the upper limit assumed for each airport as an input to the modelling process.

All fuel efficiency improvements achieved prior to 2019, from operational and air traffic management improvements and replacement of older aircraft with newer ones, are assumed to continue to be delivered as the aviation activity grows from 2020 to 2050. Any new fuel efficiency improvements, made after 2019, will be captured in the topic wedges of this CO_2 Road-Map.

3.6 KEY FINDINGS

- In a hypothetical 'no-improvement' scenario, growth in UK aviation demand is forecast to generate 67.5 Mt CO_2 by 2050. This is one mega tonne greater than the SA 2021 COVID Overlay forecast but 3.6 mega tonnes less than the SA 2020 pre COVID Road-Map forecast.
- This means that by 2050, in a hypothetical 'no improvement' scenario, unabated UK aviation emissions could grow by 78% to meet demand compared to the 2019 level.

4. DEMAND REDUCTION DUE TO THE IMPACT OF DECARBONISATION COSTS

4.1 KEY MESSAGES

- Reduction in projected aviation activity of 14.3% is expected in 2050 because of the costs of decarbonisation associated with the purchase of carbon credits, greenhouse gas removals (GGRs) & Sustainable Aviation Fuel (SAF).
- Obligation schemes e.g. the UK ETS should recognise the CO_2 emissions mitigated by using SAF and purchasing GGRs as this will aid delivery of the net zero transition as modelled.
- Efforts should be taken to minimise the impact on aviation activity by supporting the rapid development and scaling of the decarbonisation tools required. This could be particularly effective in the reduction in cost to the aviation sector associated with SAF, which is a favoured mitigation technique due to having a relatively high technology readiness level (TRL), and it is recognised as an in-sector solution.

4. DEMAND REDUCTION DUE TO THE IMPACT OF DECARBONISATION COSTS

4.2 SUMMARY OF ANALYSIS

Measures taken by the aviation sector to achieve decarbonised operations incur additional costs when compared to business as usual. For this issue of the Road-Map, Sustainable Aviation have taken a step forward in the modelling to provide a fuller estimate of these costs and to assess their likely effect on aviation demand growth due to the resultant increase of flight ticket prices.

Operational costs included in the assessment:

- Purchasing of carbon credits within the UK Emissions Trading Scheme (UK ETS) and the global Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), plus an anticipated future obligation scheme which comes into effect after the current defined CORSIA scheme ends in 2035.
- Purchasing of greenhouse gas removals (GGRs) as a method to achieve net zero carbon operations – with GGRs assumed to be the only viable carbon credit by 2050.
- The additional cost of SAF. The cost of SAF considered is the portion above the cost of Jet A-1 which would otherwise be used on the equivalent flights.

One-off costs such as the cost of infrastructure are not currently included in the analysis. The basis of the analysis is the identification of the level of obligation to offset emitted CO_2 which is defined by current (UK ETS & CORSIA) and future schemes. This effectively defines the lowest line in the CO_2 Road-Map, or the net residual emissions from aviation during the timeline to 2050. Figure 8 illustrates how the CO_2 reduction obligation acts on all aircraft emissions, so is measured from the top of the 'SAF wedge'.

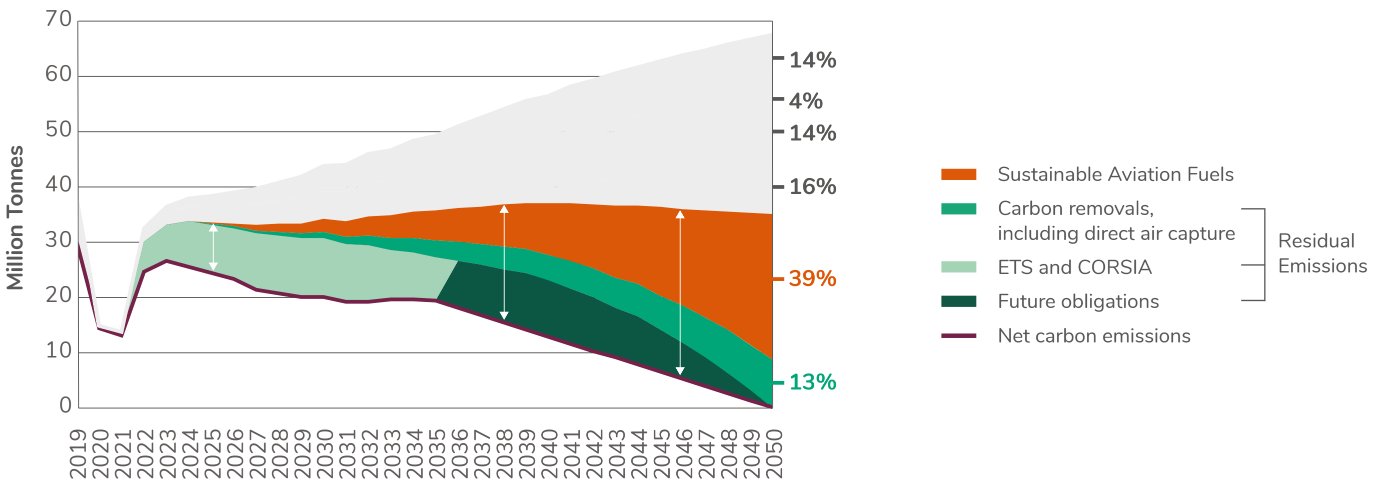


Figure 8: Pictural representation of the activities generating a decarbonisation cost

The aviation sector can address this obligation, which ultimately leads to net zero carbon by 2050, by:

- Utilising fuels with lower lifecycle carbon emissions (SAF),
- Purchasing verified carbon credits in established schemes,
- Purchasing GGRs and more specifically transitioning to engineered GGRs.

4. DEMAND REDUCTION DUE TO THE IMPACT OF DECARBONISATION COSTS

4.2 SUMMARY OF ANALYSIS (CONTINUED)

UK aviation currently relies on carbon off-setting to compensate for residual emissions. Reflecting the commitment of SA members, this Road-Map assumes a managed transition away from carbon off-setting towards engineered carbon removals with high durability. This transition would support the least cost pathway to net zero carbon emissions for the sector, therefore SA advocates for stimulation of the GGRs sector to produce a timely and therefore affordable scale up. This would ensure sufficient removals are available to meet projected aviation needs in 2050. Implicit in the modelling is the assumption that the purchase of GGRs will be eligible for the obligations within the mandatory scheme structures. The calculation of overall costs therefore accounts for the reduction in obligation achieved by purchasing GGRs. Similarly, the obligation to purchase carbon credits in mandatory schemes is also assumed to be reduced by the utilisation of SAF, in accordance with the level of lifecycle CO_2 savings achieved rather than the mass of SAF used.

The overall costs of decarbonisation are therefore calculated as: £ GGRs + £ SAF (premium over fossil fuel) + £ *remaining* obligation

This cost is divided into individual aircraft seats and therefore an effect on an individual ticket price. The translation of the full decarbonisation costs to ticket prices is ultimately a commercial decision for airlines, but the assumption made in this analysis is that all cost is transferred to the passenger. DfT published estimates for price elasticity for flights by destination region have been used to estimate the percentage impact on aviation demand due to the increased costs. Use of alternative data for price elasticity would produce different results but the use of the DfT data is consistent with the use of government forecasts for activity growth.

4.3 ASSUMPTIONS

Carbon Credit Obligations - ETS & CORSIA

The baseline fleet activity patterns have been analysed to attribute costs between the currently defined UK ETS (for flights within the UK and departing to the EU) and CORSIA (for all departing flights beyond the UK and Europe) schemes depending on the geographic location of the destination airport. For the portion falling under the UK ETS which runs until 2040, the continual reduction of the cap and the airline free allowances retiring to zero in 2027, are accounted for. For the portion falling under CORSIA which runs to 2035, obligations are calculated based on the no growth baseline rules and an assumption of charges aligned to the IATA global growth factor. Between 2033 and 2035 growth calculations are proportioned: 85% Global and 15% UK, to determine the overall CO_2 obligation and associated costs. A notional future obligation scheme is defined simply to begin in 2035 when the current CORSIA scheme ends and chart a linear trajectory of net CO_2 emissions to zero by 2050. The National Grid carbon prices have been used as the most recent authoritative estimation for the cost to purchase credits in all three schemes.

GGRs

Sustainable Aviation has conducted research and interviews to establish an estimated cost profile for GGRs per year, taking into account the predicted proportions of different technologies contributing to the total available volume.

SAF

ICF have conducted a study for Sustainable Aviation to advise the cost profile of different types of SAF including UK produced hydro processed esters and fatty acids (HEFA) / co-processing SAF, UK produced waste based SAF, UK produced power to liquid SAF, and imported SAF. UK produced SAF is assumed to be available to UK departing flights at the 'cost of production' which includes a 15% return on investment for producers. This assumes suitable policy including a price support mechanism is in place to enable the emergence of a UK SAF production industry.

The cost of imported SAF is initially buoyed by the US market where elevated prices are expected due to a stack of supportive policy – this is because it is assumed that a US SAF producer if choosing to export, would expect a competitive price from a UK buyer who would not be benefiting from the US-aligned policies. It is not assumed that this policy will operate indefinitely, and so between 2040 – 2050 the cost of imported SAF is assumed to converge with the UK cost of production. The cost of SAF considered is the premium which is additional to the cost of Jet A-1 which would otherwise be used on the equivalent flights.

4. DEMAND REDUCTION DUE TO THE IMPACT OF DECARBONISATION COSTS

4.4 KEY FINDINGS

Figure 9 & 10 illustrates the cost of the different decarbonisation measures per tonne of CO_2 which is mitigated over the timeline to 2050.

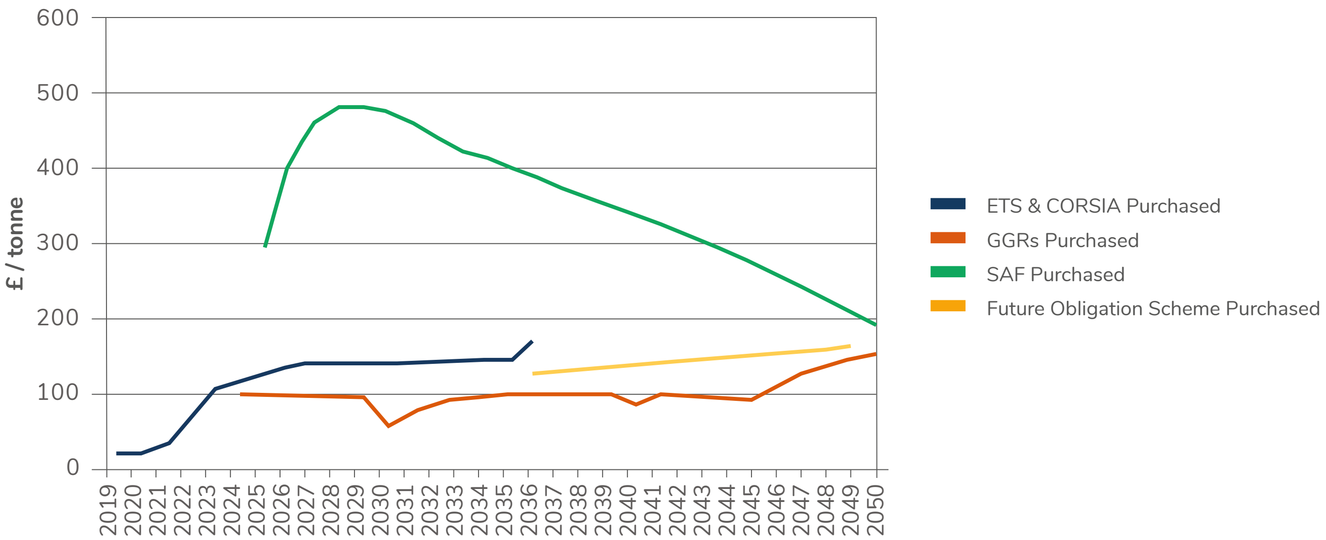


Figure 9: Cost per tonne of CO_2 mitigated in the SA Road-Map model

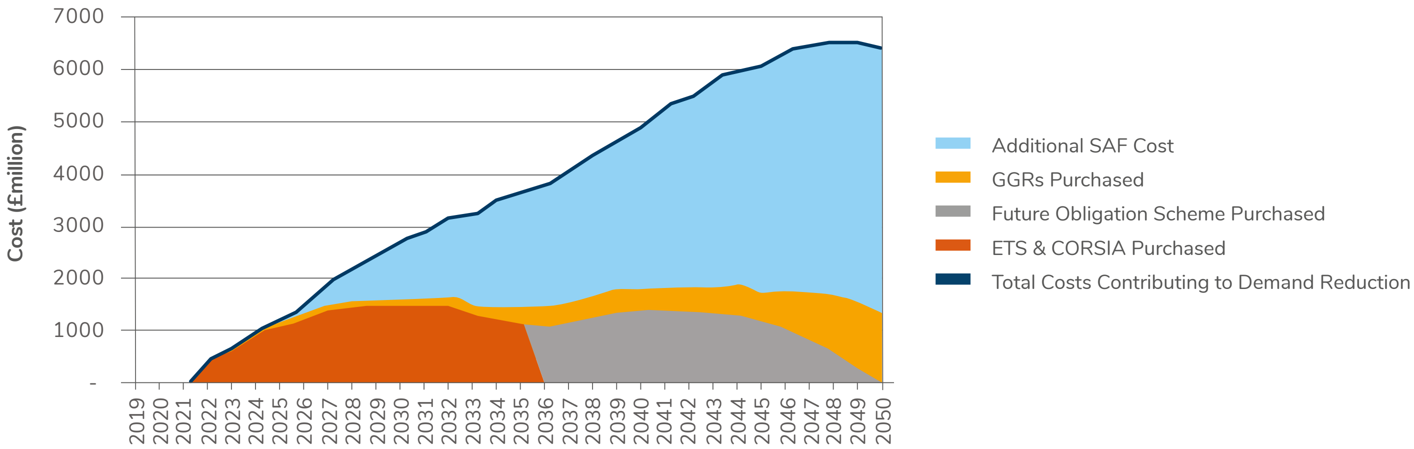


Figure 10: Breakdown of annual costs for each decarbonisation measure

4. DEMAND REDUCTION DUE TO THE IMPACT OF DECARBONISATION COSTS

4.4 KEY FINDINGS (CONTINUED)

The price of SAF slightly reduces over time, which when coupled with the assumed incremental increase in carbon savings (to 100% in 2050), results in the cost per tonne of mitigated CO_2 reducing significantly, eventually aligning with the other decarbonisation measures. However, SAF is the most expensive mitigation method in the intervening years. The obligation schemes are shown to increase in cost as carbon prices are expected to rise. Within ETS schemes, UK airlines pay for two types of allowances based on their CO_2 emissions in-scope: those allowances which are auctioned, and those allowances which are bought from other sectors. Only the latter counts towards CO_2 mitigation, and the volume of the latter is determined by the ETS cap. During the time period when credits are being purchased within the ETS, the cost per tonne of CO_2 mitigated is higher than the unit cost per tonne of CO_2 (based on the National Grid high estimate). Whilst the GGRs used initially are likely to include a higher percentage of lower cost nature based solutions, there will be a transition to more expensive but more durable GGRs, such as Direct Air Capture (DAC) towards 2050. The scale-up of these more expensive GGRs is expected to see their cost decrease over the same time frame.

The demand reduction is based on an average ticket price of £150 estimated for all UK departures in the baseline year of 2019, and the weighted DfT price elasticity figures. Demand reduction peaks at 15% in 2047 and reduces to 14.3% in 2050 as the costs of the various decarbonisation measures continue to reduce.

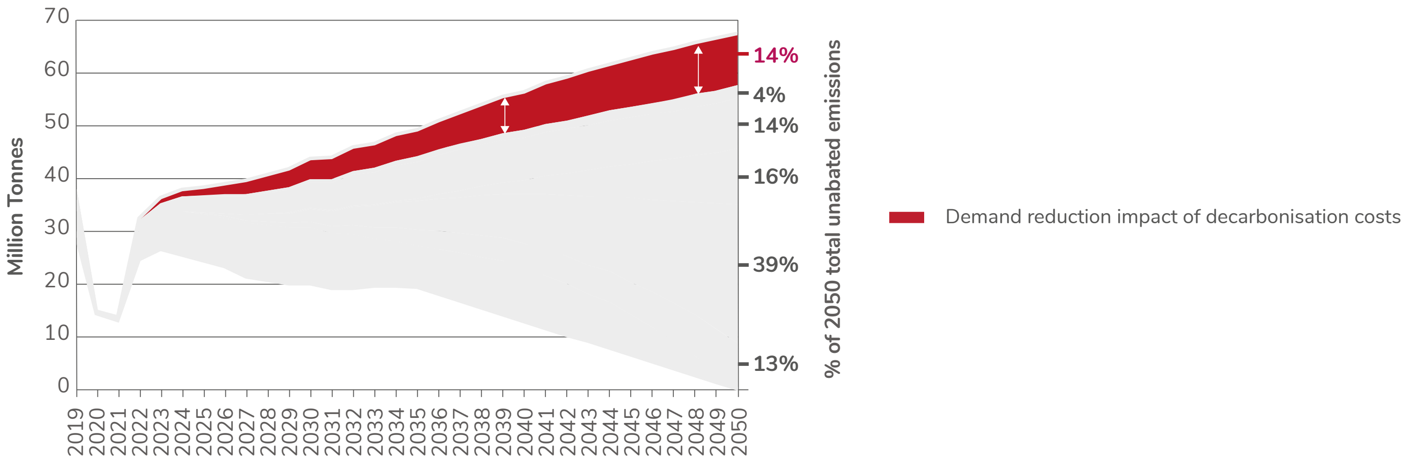
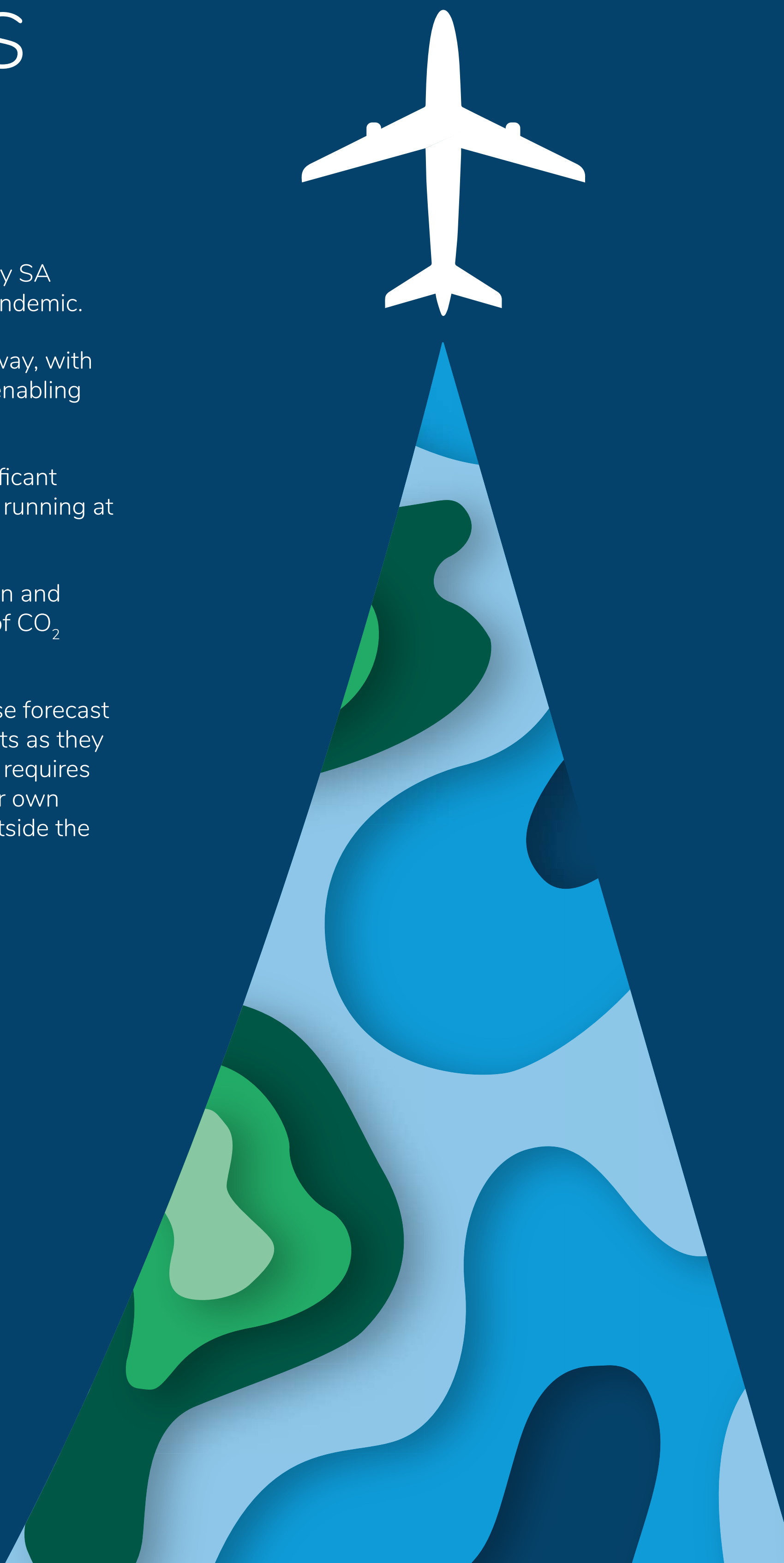


Figure 11: Overall demand reduction due to costs of decarbonisation measures

4.5 RECOMMENDATIONS

- It is imperative that obligation schemes recognise carbon savings associated with SAF and GGRs. This recognition will aid the delivery of the net zero carbon transition as modelled.
- Efforts should be taken to minimise the impact on future demand for aviation by supporting the development and scaling of the decarbonisation tools required. This is particularly relevant to the reduction in cost to the aviation sector associated with SAF, which is a favoured mitigation technique due to having a high TRL, and it is recognised as an in-sector solution.

5. AIRSPACE AND AIRCRAFT OPERATIONAL IMPROVEMENTS



5.1 KEY MESSAGES

- Many efficiency improvements have been delivered by SA members in the last few years, despite the COVID pandemic.
- UK airspace modernisation at network level is underway, with changes delivered over the past three years already enabling greater than 1 million tonnes of CO_2 savings a year.
- Lower level UK airspace modernisation requires significant cooperation between airports which post-COVID are running at different speeds on their plans.
- Overall efficiency savings from airspace modernisation and aircraft operational improvements can enable 2.5Mt of CO_2 reductions per year by 2050.
- Even greater airspace efficiency savings, beyond those forecast here, are possible for international UK-departing flights as they fly through airspace beyond the UK's control, but this requires government bodies beyond the UK to modernise their own airspace and air traffic management, and thus lies outside the scope of this Road-Map.

5. AIRSPACE AND AIRCRAFT OPERATIONAL IMPROVEMENTS

5.2 DEVELOPMENTS SINCE LAST ROAD-MAP

Despite the pandemic, improvements in air traffic management (ATM) and operations have continued. Highlights include:

- Introduction of free route airspace in Scotland in December 2021 and the West Airspace Deployment over southwest England and Wales, in March 2023. These changes are each expected to reduce CO_2 emissions by c12,000 tonnes per year, equivalent to the power used by 3,500 homes.
- Delivery of the Operational Service Enhancements Project, a series of six high-level changes which collectively are contributing annual CO_2 savings of 30,000+ tonnes; some of these are within UK airspace, others improve UK-Europe interfaces.
- Introduction of Space-Based ADS-B surveillance over the North Atlantic in 2019; this is expected to deliver a reduction in CO_2 emissions of up to 2 tonnes per transatlantic flight. With more than 1,000 transatlantic flights every day, this adds up to a potential of almost 1Mt CO_2 per annum.
- Repeat of the 'Perfect Flight' in September 2021 led by British Airways, NATS, Heathrow and Glasgow airports reduced CO_2 emissions by 62% (16% due to airspace and aircraft operations) compared to the original Perfect Flight more than a decade ago. Flights like this prove operational improvement opportunities to deliver across the fleet.
- UK ATM environmental performance metric made available for all. NATS created a metric more than 10 years ago which is now embedded in its regulatory performance scheme and has enabled savings of c7Mt CO_2 since 2012. The metric is still unique in the scope of its measurement and NATS has made it available free of charge to aviation stakeholders around the world.
- Introduction of ever smarter IT and data support systems to enable more efficient flights. Examples include:
  - Airbus and easyJet A320 descent profile optimisation.
  - Virgin Atlantic and Signol - Pilots have saved the equivalent of 1,000 tonnes of fuel in under six months.
  - Flight deck tools like OptiClimb combine machine learning predictive performance models with 4D weather forecasts, to recommend customised speed changes at different altitudes and issue recommended climb speeds to pilots ahead of each flight. Emissions savings of up to 5% are possible for each flight using OptiClimb.
  - Airbus fello'fly Wake Energy Retrieval seeks to mirror the 'V' shaped formations birds fly in. A single test flight in 2021 across the Atlantic generated a saving of 6 tonnes of CO_2 and demonstrated the potential for efficiency gains of up to 10% on long haul flights.

Despite these developments, aircraft flights globally are nowhere near as efficient as they could be. The addition of traffic into the global network drives inefficiency. Air traffic management improvements are designed to address these growth related inefficiencies and deliver reductions in CO_2 over and above maintaining the current fleet management efficiency with a bigger fleet in the network.

5. AIRSPACE AND AIRCRAFT OPERATIONAL IMPROVEMENTS

5.2 PROGRESS SINCE LAST ROAD-MAP (CONTINUED)

European Aviation and Global Aviation CO_2 Road-Maps have reviewed these issues since the last SA CO_2 Road-Map was published. Their airspace and aircraft operational efficiency savings are summarised below:

Airspace and aircraft operational efficiency scenarios	Global industry Waypoint 2050 report	
Criteria	Compound annual growth rate (CAGR)	2050 Overall Saving
Worst case	0% per annum	0%
Central case	0.1% per annum	3%+
Best case	0.2% per annum	6%+

Table 3: Waypoint 2050 summary of operational & ATM modelled savings

Airspace and aircraft operational efficiency scenarios	European industry Destination 2050 report			
Criteria	Intra-EU	Non-EU	Overall Saving	Note
2030	5% / 5 Mt CO_2	5% / 6 Mt CO_2	5% / 11 Mt CO_2	Most measures partially or fully implemented
2050	7% / 8 Mt CO_2	6% / 10 Mt CO_2	6% / 18 Mt CO_2	

Table 4: Destination 2050 summary of operational & ATM modelled savings

5.3 SUMMARY OF ANALYSIS

In this Road-Map, based on the latest information on airspace and aircraft operational improvement opportunities, and the delays to UK airport level airspace modernisation, the following rates of CO_2 savings have been modelled.

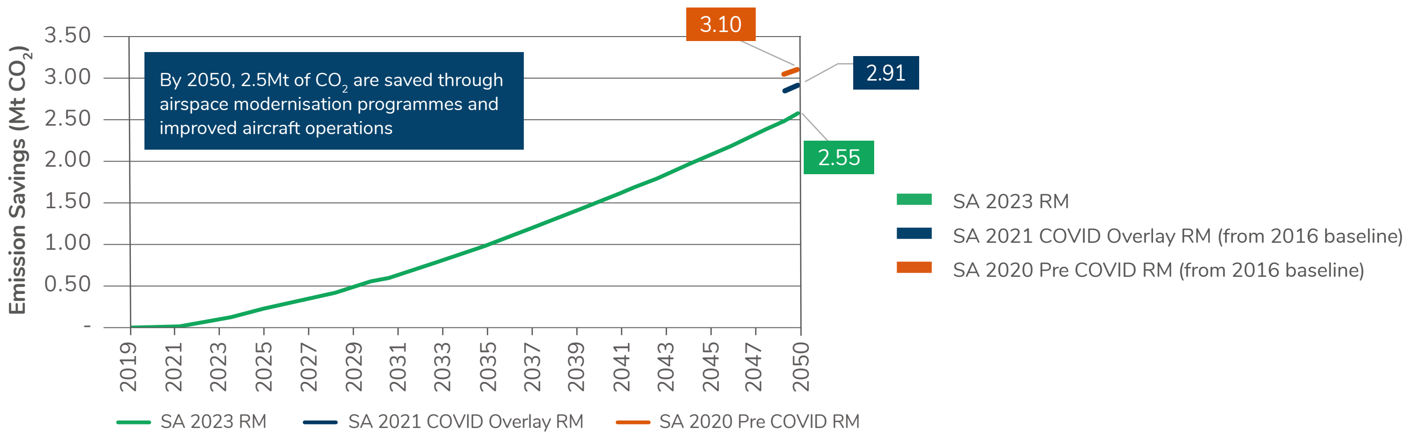


Figure 12: Airspace and aircraft operations CO_2 saving forecast from previous Road-Maps

5. AIRSPACE AND AIRCRAFT OPERATIONAL IMPROVEMENTS

5.3 SUMMARY OF ANALYSIS (CONTINUED)

Putting this into context with previous SA CO_2 Road-Maps, the ongoing savings from operations and ATM are reducing. This is because many of the easier efficiency improvements were already been achieved by 2019 and as traffic increases, airspace efficiency delivery is eroded. A breakdown of where the forecast CO_2 savings come from is provided in the table below, along with a comparison for how this has changed since 2012.

Category	Forecast % CO_2 savings			
	2023 Road-Map	2020 Road-Map	2016 Road-Map	2012 Road-Map
Efficient air traffic management	2.8	4.7 (significantly delivered pre 2020)	6.3	6.5
Improvements to airport ground operations	0.3	0.3	0.3	0.3
Airline improvements to aircraft operations	1.3	2.1	2.1	2.1
Total	4.4	7.1 (4.4 from activity after baseline year)	8.7	9.0

Table 5: Forecast CO_2 savings from operations & air traffic management included in previous SA Road-Maps

5.4 ASSUMPTIONS

In determining forecast CO_2 savings from airspace and aircraft operations the following assumptions have been made:

- Only additional airspace and aircraft operational initiatives above those already in place in 2019, are counted as CO_2 savings in this section.
- The United Nations Framework Convention on Climate Change (UNFCCC) scope of operational improvements and ATM applies to all flights which depart from UK airports. This means that the UK portion of the emissions benefits reflected in the Road-Map is relatively small, as most of the CO_2 emissions are generated during flight activity to destinations outside of UK airspace. This activity is therefore out of SA's ability to control, however, this impact is included in this Road-Map analysis.
- The analysis of potential ATM efficiency improvements outside of UK airspace found limited evidence of planned improvements, hence the relatively modest airspace benefit (2.8%) assumed in the Road-Map. It is estimated that a 1.3% emissions saving will come from improved aircraft operations and a further 0.3% from improvements to operations on the ground, e.g. aircraft taxiing. Therefore air traffic management and operations reported in line with UNFCCC requirements will deliver a 4.4% emissions reduction by 2050.
- As noted above, the global and European decarbonisation roadmaps expect between 3% and 6% emissions benefits from operations and airspace by 2050, setting the UK decarbonisation Road-Map within the range identified by other roadmaps.
- Within UK airspace we anticipate that airspace specific emissions savings closer to 5% will be delivered by 2030. This equates to around 1Mt CO_2. Additionally, the progressive delivery of airspace change may well generate compound benefits above what we can estimate currently.

5. AIRSPACE AND AIRCRAFT OPERATIONAL IMPROVEMENTS

5.4 ASSUMPTIONS (CONTINUED)

- Clearly, if States globally push to deliver airspace modernisation in line with the expectations of global and European roadmaps, the 4.4% assumed in this Road-Map could be improved. Further work to define this opportunity will be explored in our Technical Report. For now SA notes the view from Airlines for Europe, that enabling airlines to fly the most efficient routes can unlock significant CO_2 savings of up to 10%.
- UK network airspace modernisation is assumed to be complete by 2030; however, delays to lower level airspace modernisation risk missing this completion date.
- CO_2 savings from airline operational efficiencies are generated from a wide range of solutions. Information provided by SA airline members indicates a potential for c15% fuel efficiency saving, if all airspace and operational efficiencies could be achieved. This has been evidenced by the "Perfect Flight" trials. However, air traffic operates in an environment where various factors compromise efficiency, e.g. weather and the presence of other commercial traffic. Aircraft operational improvements alone are forecast to deliver around 2% efficiency improvements for flights within the UK and Europe and just under 1% for flights beyond the UK and Europe. The net result gives an average of 1.3% efficiency improvements in aircraft operations from the UK aviation activity mix in the baseline year.

5.5 KEY FINDINGS

- Many efficiency improvements have been delivered by SA members in the last few years despite the COVID pandemic.
- UK airspace modernisation at network level is underway, with changes delivered over the past three years already enabling c60,000 tonnes of CO_2 savings a year.
- Lower level UK airspace modernisation requires significant cooperation between airports.
- Overall cumulative emissions savings from airspace modernisation and aircraft operational improvements over the period 2019 to 2050 are forecast to be over 32Mt CO_2.
- Even greater airspace efficiency savings, beyond those forecast, are possible for departing UK flights as they fly through airspace beyond the UK's control, but this requires government bodies beyond the UK to modernise their own airspace and air traffic management, and thus lies outside the scope of this Road-Map.
    - Most UK departing flights operate to destinations outside UK airspace where their operational efficiency is beyond the control of UK operators or the UK Government. Significant additional opportunities to improve efficiencies exist in these non-UK airspace areas but are reliant on actions by non-UK organisations. SA members are actively working with these stakeholders to encourage progress.
    - Analysis of potential air traffic management efficiency improvements outside of UK airspace found limited evidence of improvements planned, hence the modest airspace benefit (2.8%) assumed in the Road-Map. If States globally push to deliver airline and airport operational improvements and airspace modernisation in line with the expectations of global and European roadmaps, the emissions reductions could be significantly higher.

5.6 RECOMMENDATIONS

- Maximise short-term operational efficiencies by accelerating the UK airspace modernisation programme and completing it by the end of the decade.
- Champion the UK's work by SA members in progressing airspace modernisation and urge similar programmes beyond the UK.
- Continue to work with States globally and through ICAO to encourage airline and airport operational improvements and airspace modernisation in line with the expectations of global and European roadmaps.

6. AIRCRAFT AND ENGINE TECHNOLOGY

6.1 KEY MESSAGES

- Technology-driven gains in efficiency deliver sustained benefit and lessen the financial burden of other decarbonisation measures – the development and introduction of new technologies to the fleet are modelled to mitigate 29.8% of CO_2 emissions in 2050, or 20.1Mt CO_2.
- Transformational technology development is now required to deliver the next generation of conventionally fuelled architectures, and hydrogen aircraft concepts – further investment in aerospace research & development is required to support this delivery.
- The UK is well positioned to take advantage of the decarbonisation opportunity presented by hydrogen powered narrow body aircraft.
- **Adjacent sector support** is a fundamental building block to deliver the modelled improvements, including:
  - Low carbon energy capacity
  - Green hydrogen production capacity
  - Hydrogen infrastructure

6. AIRCRAFT AND ENGINE TECHNOLOGY

6.2 DEVELOPMENTS SINCE LAST ROAD-MAP

Historic investments in aerospace technology research and development are delivering significant efficiency improvements and mitigation of CO_2 emissions in the UK fleet in the present day. The recent industry shock of the COVID pandemic has served to accelerate the retirement of some older, less efficient aircraft such as the 747-400s. This has brought forward some efficiency improvements which were previously expected to take place over a longer time span.

Furthermore, aerospace manufacturers are currently engaged in a heightened phase of innovation with several exciting technological advances under development. These will support the next generation of products to contribute efficiency gains for UK aviation activity. So far in 2023:

- Rolls-Royce and easyJet have tested an engine on 100% gaseous hydrogen fuel.
- Airbus have announced ambition to produce the world's first zero-carbon commercial aircraft by 2035 in their ZEROe programme.
- Boeing have announced a truss-braced wing demonstrator programme in collaboration with NASA.
- ZeroAvia have flight tested a hydrogen fuel cell powered Dornier 228 19-seat aircraft.
- In addition, momentum is gaining in supporting activities such as the investigation of hydrogen infrastructure by projects such as NAPKIN, HyNet and by the Connected Places Catapult.

6.3 SUMMARY OF ANALYSIS

The Technology Wedge models the CO_2 emission reductions which can be achieved through the introduction of improved aircraft and engine technology to the UK fleet. This contribution to the Road-Map is split into two sections: Generation 1 upgrades constituting baseline fleet renewal to known products, and Generation 2 upgrades involving fleet replacements with future products which are not yet in production.

Proportion of CO_2 emissions from departing UK aircraft in 2019

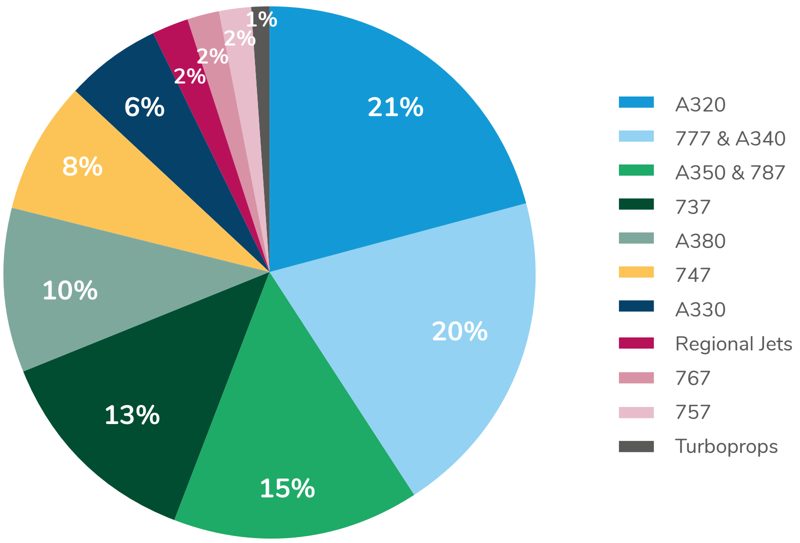


Figure 13: Materiality within UK aviation of baseline year (2019) CO_2 emissions by each aircraft category

6. AIRCRAFT AND ENGINE TECHNOLOGY

6.3 SUMMARY OF ANALYSIS (CONTINUED)

Analysis of the fleet in the baseline year of 2019 provides the UK aviation sector activity. This includes delivered Available Seat Kilometres (ASKs) and the materiality of CO_2 emissions by all UK departures, distributed by operator, destination region, flight distance, aircraft type and size.

A bottom up methodology is used to model the evolution of this baseline activity to new products, in line with expected fleet renewal rates and technology availability. Novel future products including electrical, and hydrogen powered aircraft are introduced to portions of the fleet, which deliver activity expected to fall within the capability and deployment scope of the future technologies.

6.4 ASSUMPTIONS

Electric Aircraft

It is assumed that future electric aircraft remain limited to 19 seats and an 800nm range. In the previous Road-Map, within-range flights delivered by larger aircraft were upgraded to small electric aircraft, multiplying the number of flights as required. For this Road-Map only a multiple of at most 2 is accepted when replacing baseline activity with electric aircraft. The entry into service date is expected to be 2028. When technology capability is considered, electric aircraft partially replace the Turboprop and Regional Jet categories.

Hydrogen Aircraft

Two notional types of future hydrogen aircraft have been utilised to create the bottom up scenarios for fleet category replacement, based on the expected capability of the aircraft. In all cases it is not specified whether the products are new airframes or retrofit solutions, or whether the propulsion techniques involve hydrogen combustion or fuel cell technology. A regional hydrogen aircraft is assumed to have 70 seats and 800nm range capability, with first availability from 2028. A narrow body hydrogen aircraft is assumed to have 180 seats and 2,400nm range capability with an entry into service date of 2035. In line with the approach to electric aircraft, where multiple flights would be required to deliver the replaced baseline activity due to reduced seat numbers, only a multiple of at most 2 is accepted. When technology capability is considered, the regional hydrogen aircraft partially replaces the Turboprop and Regional Jet categories, and the narrow body hydrogen aircraft partially replaces the Narrow Body (A320 family & 737s) and Large Narrow Body (757s) categories. A wide body hydrogen aircraft is not envisioned pre-2050.

Infrastructure Considerations for Hydrogen

Consideration has been made that hydrogen infrastructure will be required in the destination regions for flights to make them eligible to be upgraded to these products. It is assumed that the necessary infrastructure will develop in the required timeframe within: the UK; in North, South & West Europe; and in the USA & Canada. All other global regions are conservatively assumed not to sufficiently develop the infrastructure and therefore represent activity which cannot upgrade to a hydrogen product. It is also not assumed that all airports in eligible regions will have supporting infrastructure in place when hydrogen aircraft first enter service. An extended fleet refresh time is applied to categories which are partially replaced by hydrogen to account for this additional enabling development. The earliest hydrogen aircraft delivered would likely be assigned to major hub city pairs or specific airports which have targeted hydrogen readiness. It is assumed that around 20 years will elapse before as much as half of the narrow body fleet has been replaced by a hydrogen powered aircraft, which would require more widespread infrastructure readiness. The development of new regulations to manage hydrogen aircraft and their supporting infrastructure is also a prerequisite to these fleet upgrades.

CO_2 Mitigation from Electric and Hydrogen Aircraft

Electric and hydrogen aircraft are assumed to produce zero emissions of CO_2 during operation, resulting in a 100% CO_2 saving on those flights relative to their conventionally fuelled predecessors. This means that availability of renewable energy has been assumed for charging electric aircraft, and to produce green hydrogen fuel. It is estimated that 970kt green hydrogen will be needed in the year 2050 and an associated 63 TWh low carbon electricity required to produce this. A further 0.4 TWh electricity is estimated to be required to charge the electric aircraft which are introduced in the fleet upgrade model developed by SA.

6. AIRCRAFT AND ENGINE TECHNOLOGY

6.4 ASSUMPTIONS (CONTINUED)

Conventionally Fuelled Next Generation Aircraft

Upcoming designs in research and development including novel engines such as ultra-high bypass, water-enhanced turbofan and hybrid electric architectures, and novel airframes such as truss-braced wing or folding wing concepts, offer significant potential for the next generation of products. It is assumed that the next generation of narrow body class products will be available from 2035 offering a 20% efficiency improvement. In the wide body class there is a 20% improvement with availability from 2040. These improvements are lower than the 25% estimated in the previous Road-Map, which reflects the view that historic gains in technology efficiency improvements cannot be indefinitely sustained. Optimums are reached in the execution of traditional hydrocarbon fuelled designs, including computational modelling sophistication, manufacturing methods and theoretical limits of combustion efficiency.

6.5 KEY FINDINGS

- Fleet renewal to known latest generation products will continue to deliver sustained efficiency improvements to UK aviation. An 11.3% reduction in fleet-wide CO_2 emissions will be achieved by these products by 2030, and by 2050 this will increase to a 14.1% reduction.
- Generation 2 upgrades to future products will collectively deliver a fleet-wide CO_2 emissions reduction of 15.7% by 2050. Half of this contribution is delivered by the projected transition of the narrow body aircraft classes to hydrogen aircraft.
- The total contribution from the technology wedges by 2050 is a 29.8% reduction in CO_2 emissions, with this projected to grow beyond 2050, as fleet renewal continues for a further 10 years before all eligible routes have been upgraded to the latest technology.
- To deliver the improvements in CO_2 emissions as modelled, the UK aviation sector will require 13kT of green hydrogen fuel in 2030 and 970kT of green hydrogen fuel in 2050.
- Figure 14 shows the full fleet upgrade model including which technology transitions occur, what overall efficiency gain is achieved and the duration for the fleet renewal. The improvements are achieved fully at the end of the indicated lines, with gains accounted linearly from the baseline year or start date.

Fleet Upgrade Model

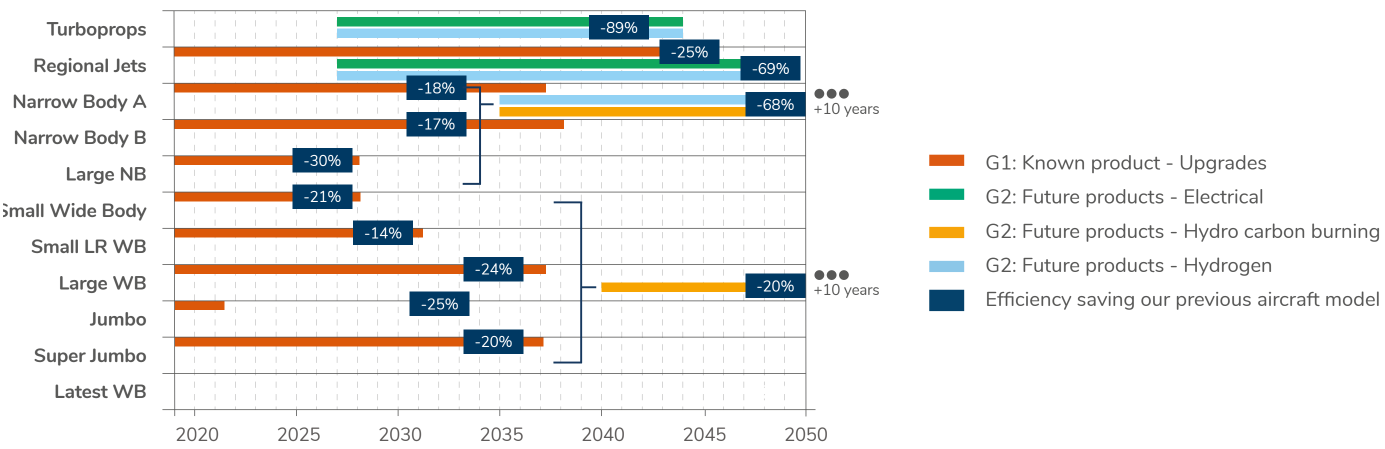


Figure 14: Pictorial representation of the fleet upgrade model

6. AIRCRAFT AND ENGINE TECHNOLOGY

6.6 RECOMMENDATIONS

Historic investments in aerospace technology research and development are delivering significant improvements in the UK aviation sector's carbon footprint today. These gains are sustained and growing incrementally as the current fleet is being replaced by known products. Likewise, continued investment will be necessary to support the sector's ability to deliver required aviation activity while converging on net zero carbon operations in 2050. Investment today in more efficient technology will ensure that beyond 2050, the sector can continue to deliver further transitions at reducing cost, by lessening the potential financial burden of other decarbonisation measures. The low carbon energy sector and green hydrogen production and infrastructure scaling must be supported and expedited, as this is a fundamental building block to delivering the modelled carbon savings.

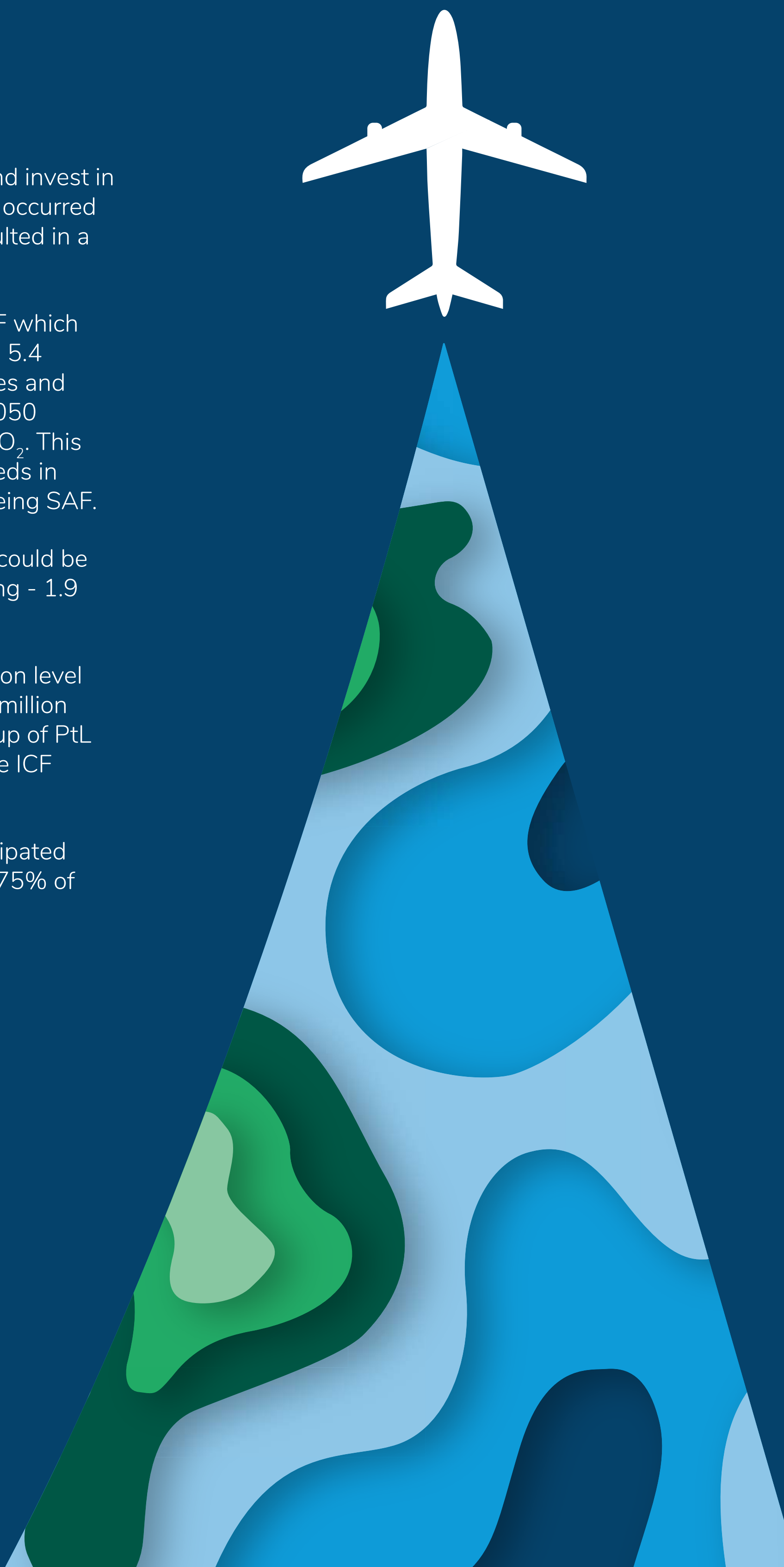
The UK is well positioned to take advantage of the large opportunity presented by improvements modelled in the narrow body class transition to hydrogen aircraft, with a large proportion of UK aviation activity in this class, flying routes within the expected technology capability, and to regions likely to develop the required supporting infrastructure. Significant engineering advancements will be required of aerospace manufacturers to deliver the transformational technologies required for both the next generation of conventionally fuelled aircraft, and hydrogen aircraft. The government should facilitate accelerated technology development by increasing investment in aerospace research. This would capitalise on the size of the opportunity presented to maintain a cost effective and productive aviation sector in the energy transitioned world.

Therefore, investment in zero carbon emission flight technology is recommended, by uplifting matched funding levels to the ATI programme through to 2031 - to drive efficiency improvements and the development of zero carbon emission technologies, alongside investing in the UK hydrogen supply and airport infrastructure.

7. SUSTAINABLE AVIATION FUELS

7.1 KEY MESSAGES

- Rapid policy progress on a global basis to promote and invest in new sustainable aviation fuel (SAF) technologies has occurred since the last Road-Map publication and this has resulted in a higher potential for SAF in this Road-Map.
- SA has commissioned an independent study from ICF which has identified that the UK could domestically produce 5.4 million tonnes of SAF sourced from sustainable wastes and residues and power to liquids (PtL) technologies in 2050 providing a CO_2 saving of over 17 million tonnes of CO_2. This represents two thirds of the UK's anticipated SAF needs in 2050[1] based on 75% of aviation fuel used in 2050 being SAF.
- This central estimate projects that 3.5 million tonnes could be produced from sustainable biomass with the remaining - 1.9 million tonnes - from PtL technology.
- Imports are also needed to meet the UK's high ambition level for a 2050 SAF mandate which is approximately 8.4 million tonnes of SAF in 2050. Although a more rapid scale up of PtL SAF could satisfy all UK SAF needs in 2050 under the ICF study's high scenario.
- The SAF Road-Map estimates are based on the anticipated trajectory required to meet an assumed mandate for 75% of aviation fuel used in 2050 to be SAF.



1 Based on the UK SAF consultation "Early SAF Breakthrough Scenario" published 2021.

7. SUSTAINABLE AVIATION FUELS

7.1 SUMMARY (CONTINUED)

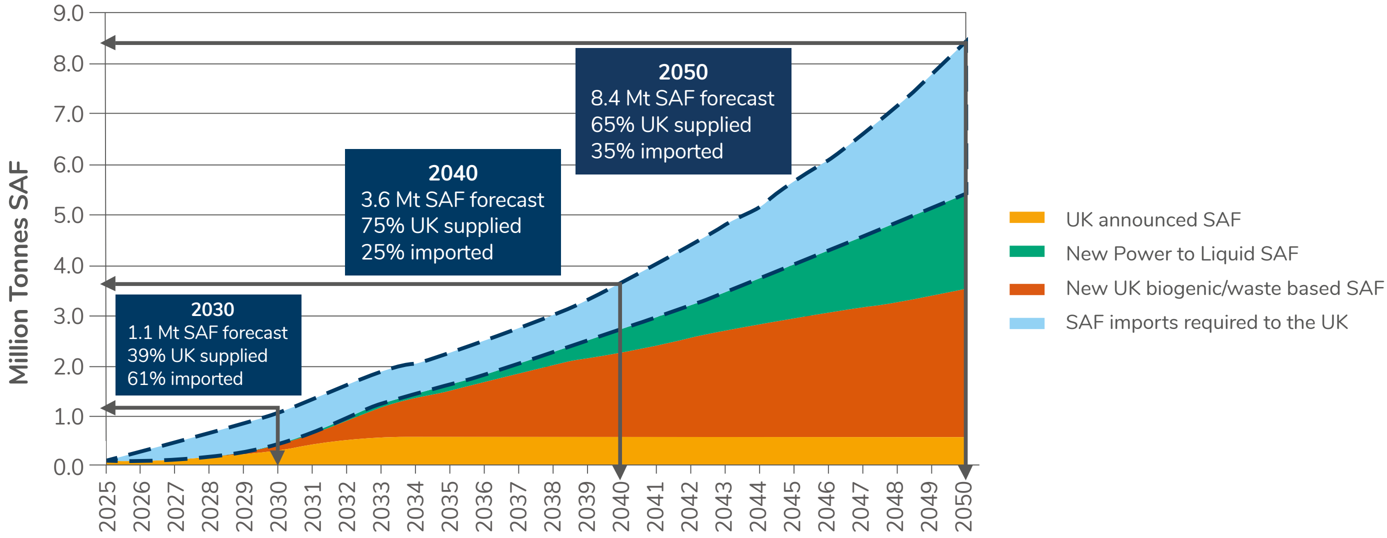


Figure 15: SA forecast SAF supply for the UK

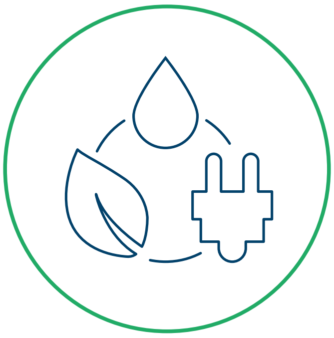
- With 75% of aviation fuel use in 2050 mandated to be SAF, 39% of the total CO_2 mitigation in 2050 would be achieved.
- Action now to boost and support a UK SAF sector will reduce the UK's reliance on SAF imports, which will be needed to meet the UK's announced 10% mandate in 2030 and further mandated quantities.
- Global demand currently exceeds supply for the period to 2030, with most SAF in this period coming from waste oils, fats and greases – the availability of these feedstocks is constrained. ICF estimates there is likely to be a shortage of SAF available in this timeframe unless there is a rapid increase in production capacity in the near term.
- UK SAF production would create over 10,300 jobs and generate nearly £1.8bn of GVA to the UK by 2030. In 2050 these figures rise to 60,000 jobs and support over £10bn of GVA.
- The Inflation Reduction Act in the USA and the EU's Fit for 55 packages are moving ahead rapidly, providing support for new technologies, incentives for producers and mechanisms to reduce SAF costs for airlines.
- Urgent action is required to remove barriers to realising this potential. The most urgent being the implementation of a price support mechanism for UK producers of SAF, that more closely matches the support provided outside the UK, to incentivise private investment in the UK production of SAF.

7. SUSTAINABLE AVIATION FUELS

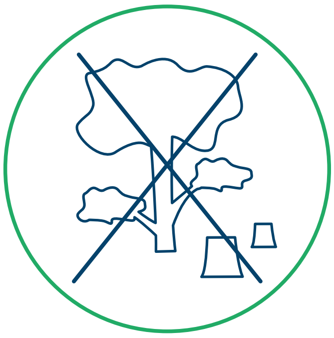
7.2 SUSTAINABLE AVIATION FUEL CRITERIA

SA only supports high quality SAF which does not have negative consequences for the environment or other sectors. Our acceptance criteria include that SAFs:

Are produced from biomass or recycled carbon

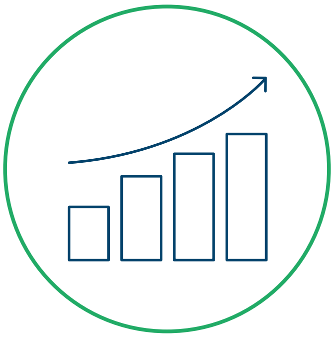


Meet stringent sustainability standards with respect to land, water, and energy use



Avoid Direct and Indirect Land Use Change (ILUC) impacts, for example, tropical deforestation

Do not displace or compete with food crops and will not use any UK farmland



Provide a positive socio-economic impact

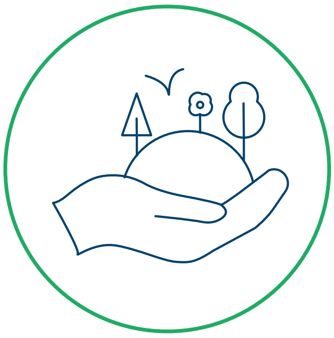


Exhibit minimal impact on biodiversity and conservation values

Have been assessed and certified by an appropriate sustainability standard

7. SUSTAINABLE AVIATION FUELS

7.3 DEVELOPMENTS SINCE LAST ROAD-MAP

Despite the pandemic, the development of SAF has progressed significantly, both globally and in the UK, since our last Road-Map in 2020. It has moved from concept, through commitment and now into small scale production, including in the UK.

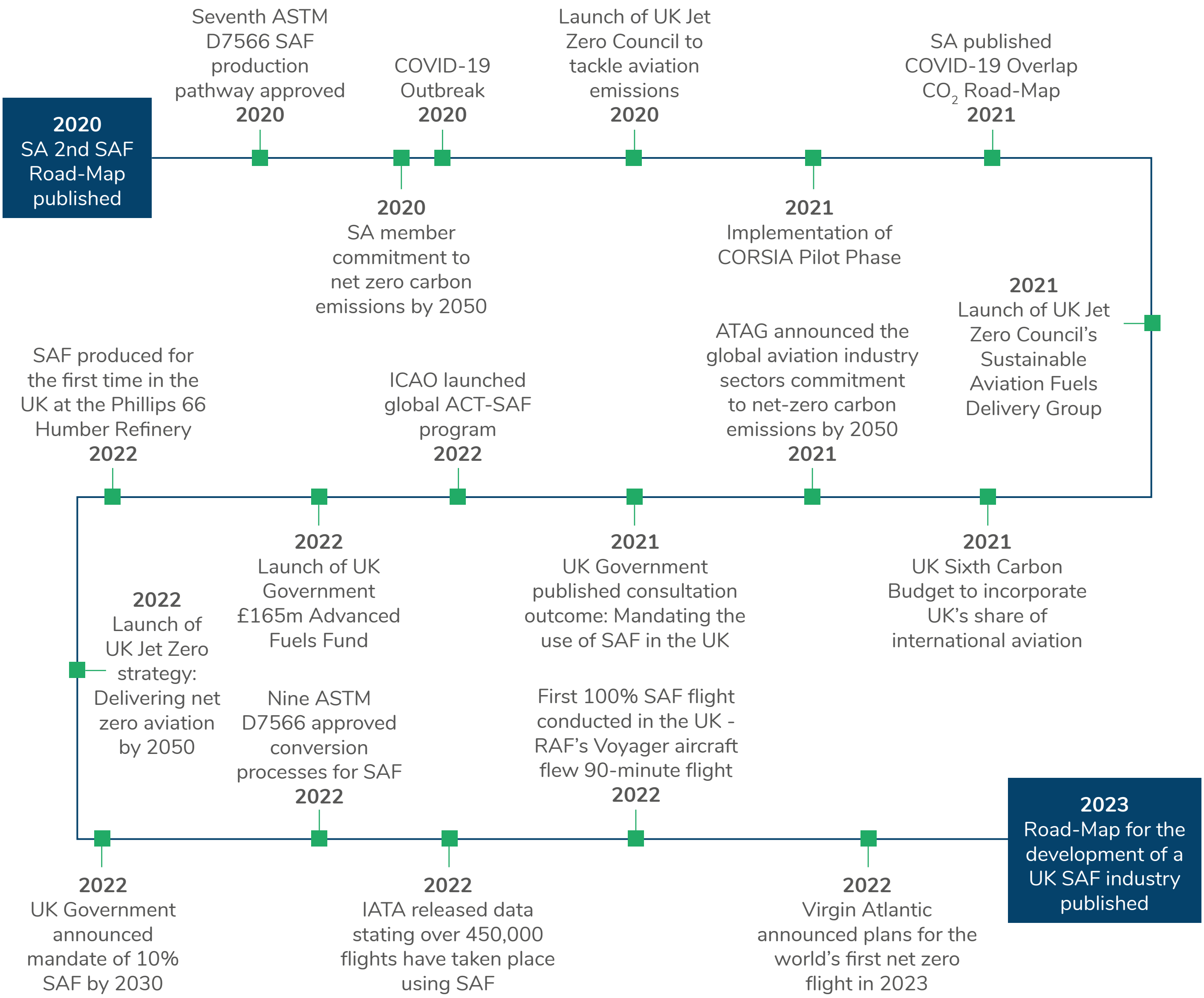


Figure 16: Progress in SAF development since 2019

7. SUSTAINABLE AVIATION FUELS

7.3 DEVELOPMENTS SINCE LAST ROAD-MAP (CONTINUED)

SAF production is currently being led in the US, supported by their Inflation Reduction Act (IRA), which is attracting over 70% of announced global SAF capacity to the US. The EU is also progressing with the 'Fit for 55' policy package, including several complementary supply and demand side mechanisms[3], funded through revenue from the ETS program.

In the UK, SA welcomes the support already provided by the UK Government including:

- Setting an ambition through the Jet Zero Strategy for at least five commercial SAF plants under construction in the UK by 2025;
- the £165 million Advanced Fuel Fund to support the development of advanced fuels plants in the UK for financial years 2022-25;
- Setting the obligation on fuel suppliers to reduce the carbon intensity of jet fuel, starting in 2025 and growing to reach the equivalent of at least 10% SAF use by 2030;
- £12 million to support fuel testing, including funding to establish a SAF clearing house for financial years 2022-25 and up to £1m to support the delivery of the first net zero carbon transatlantic flight fuelled on 100% SAF; and
- the £400 million partnership with Breakthrough Energy Catalyst to drive investment into the next generation of clean energy technologies, including SAF.

ICF have summarised the now extensive pathways for making SAF:

There are several SAF projects at different stages of development in the UK, mostly focussed on the Alcohol to Jet (AtJ) and Fischer Tropsch (FT) pathways

	Approved pathways				Under certification
	HEFA/Co-processing	AtJ	Gas+FT	PtL[3]	HTL
# of projects in the UK[1]	1	3	4	0	1
Projects developer(s)	Philips 66 (Co-processed HEFA)	1. Lanzatech 2. Carbon Engineering 3. Nova Pangaea[2]	1. ABSL 2. Alfanar 3. Fulcrum 4. Velocys	Note Ambitions: 1. ScottishPower and Storegga 2. Acorn Project	Green Fuels Research
Intermediate inputs	Waste lipids	Alcohols	Syngas	Hydrogen, Carbon	-
Example Feedstocks	Used cooking oil, inedible tallow, other waste fats, oils, and greases	Biogenic wastes, woody residues, industry flue gases, DAC, water (hydrogen)	MSW, residual waste and industrial waste	Renewable electricity	Sewage sludge

Notes: (1) Including GFGS competition winners (2) Nova Pangaea produce cellulosic ethanol which will be processed by LanzaJet. (3) PtL has been shown stand-alone, but would use the ASTM certified AtJ or FT-SPK pathways for SAF production. PtL may also use the methanol route, which is not yet certified. Sources: https://ee.ricardo.com/gfgs.

Table 6: Summary of pathways for producing Sustainable Aviation Fuel

These global and UK developments, whilst welcome, still need to be accelerated to scale up the use of SAF. In 2022, the global SAF market made up less than 0.1% of the jet fuel market, with just c240,000 tonnes of production[4].

3 Commission is calling for experts to advise on the new framework of the EU ETS Innovation Fund upcoming calls for proposals and new auction mechanism (europa.eu)
4 https://www.iata.org/en/pressroom/2022-releases/2022-12-07-01/

7. SUSTAINABLE AVIATION FUELS

7.4 SUMMARY OF ANALYSIS

Sustainable Aviation commissioned ICF to review the latest UK SAF market potential. The full detail of this analysis is available in a separate report.

Feedstock

The ICF study identified that the availability of sufficient feedstock was not a limiting factor in building a UK SAF industry. Biogenic feedstock availability is spread across multiple categories, with no single dominant source identified. Innovations for novel biological feedstocks and conversion processes can significantly increase bio-feedstock availability. In determining the availability of feedstock, inputs that would compete with food production were excluded and the availability of feedstock assessment assumed that existing uses of biomass would continue – hence ICF's estimates are conservative. These assumptions are in line with SA's definition for SAF that prioritises wastes and residues and avoids feedstock that is in competition with food production, so no UK farmland will be used for UK SAF production. The ICF study also considered for all biogenic feedstock sources, what proportion would be available to the aviation sector.

ICF assert that whilst renewable electricity availability is theoretically unlimited, the rate of deployment will constrain availability, with a base estimate that 50 TWh could be available for PtL (+7% total renewable electricity in 2050 assuming UK needs prior to considering aviation are 712TWh as estimated in the UK Net Zero Strategy). A recent report from the CCC[6] indicates that a halving of existing electricity prices could lead to a more rapid ramp up of renewable power for SAF. Given that aviation will need to use renewable electricity for hydrogen aircraft as well as for greenhouse gas removal technologies, this central estimate uses a more conservative value, rather than the high estimate for PtL.

SAF Modelling Output

ICF's central scenario has been used by SA. This is summarised below:

Scenario	SAF emissions reduction potential (percentage of life cycle CO_2 savings vs using fossil fuel)		UK SAF Production (Mt)		Imported SAF (Mt)	
	2030	2050	2030	2050	2030	2050
SA Central Case	70%	100%	0.4	5.4	0.7	3.0

Table 7: Central estimate forecast of SAF produced in the UK

The SA model estimates that 1.1 million tonnes of SAF will be required in 2030 to meet the UK 10% SAF mandate, of which the ICF study indicates that 0.4 million tonnes could be delivered through UK production and the remainder would be met by imports. Based on a 75% mandate level by 2050 this would increase to 8.4 million tonnes of SAF, of which the ICF study indicates that 5.4 million tonnes could be delivered through UK production and the remainder would be met by imports.

The reliance on imports highlights the consequence of the slower development of supportive policy for SAF in the UK. From the 2040s imports provide a much greater proportion of the SAF required by UK aviation, because the demand for SAF exceeds the ability to supply from UK produced SAF.

The latest central case forecast shows SAF has the potential to save around 26 Mt CO_2 for UK aviation by 2050, which is an 11.6 Mt CO_2 greater saving than previously forecast. This assumes that sufficient SAF supply will be available in the global SAF market by 2050 to top up UK production with imported SAF. The improved outlook for SAF emissions savings is driven by the faster than expected development of SAF plants with more rapid US expansion. It should be noted that much of the US expansion is based on HEFA and conversion of first generation alcohols which may not be eligible as a UK qualifying SAF. Significant government support such as the USA's IRA and the EU's response has led to early SAF plant development.

6 https://www.theccc.org.uk/publication/delivering-a-reliable-decarbonised-power-system/

7. SUSTAINABLE AVIATION FUELS

7.4 SUMMARY OF ANALYSIS (CONTINUED)

Economic benefits of a UK SAF Sector

Social and Economic potential: Independent analysis by ICF shows that building a SAF industry has significant potential to create jobs and economic growth. By 2030, this analysis estimates that a SAF industry could contribute £1.8 billion in Gross Value Added (GVA) for the UK, with much of this in the upstream activities. By 2050 this could increase to £10.1 billion, of which £1.8 billion is direct and the remainder across construction and upstream activities.

UK SAF Market Economic Potential	2030	2050
Combined jobs (direct, construction and upstream)	10,350	60,000
Combined GVA (direct, construction and upstream)	£1.8bn	£10.1bn

Table 8: Estimated economic potential for developing UK SAF production

7.5 RECOMMENDATIONS

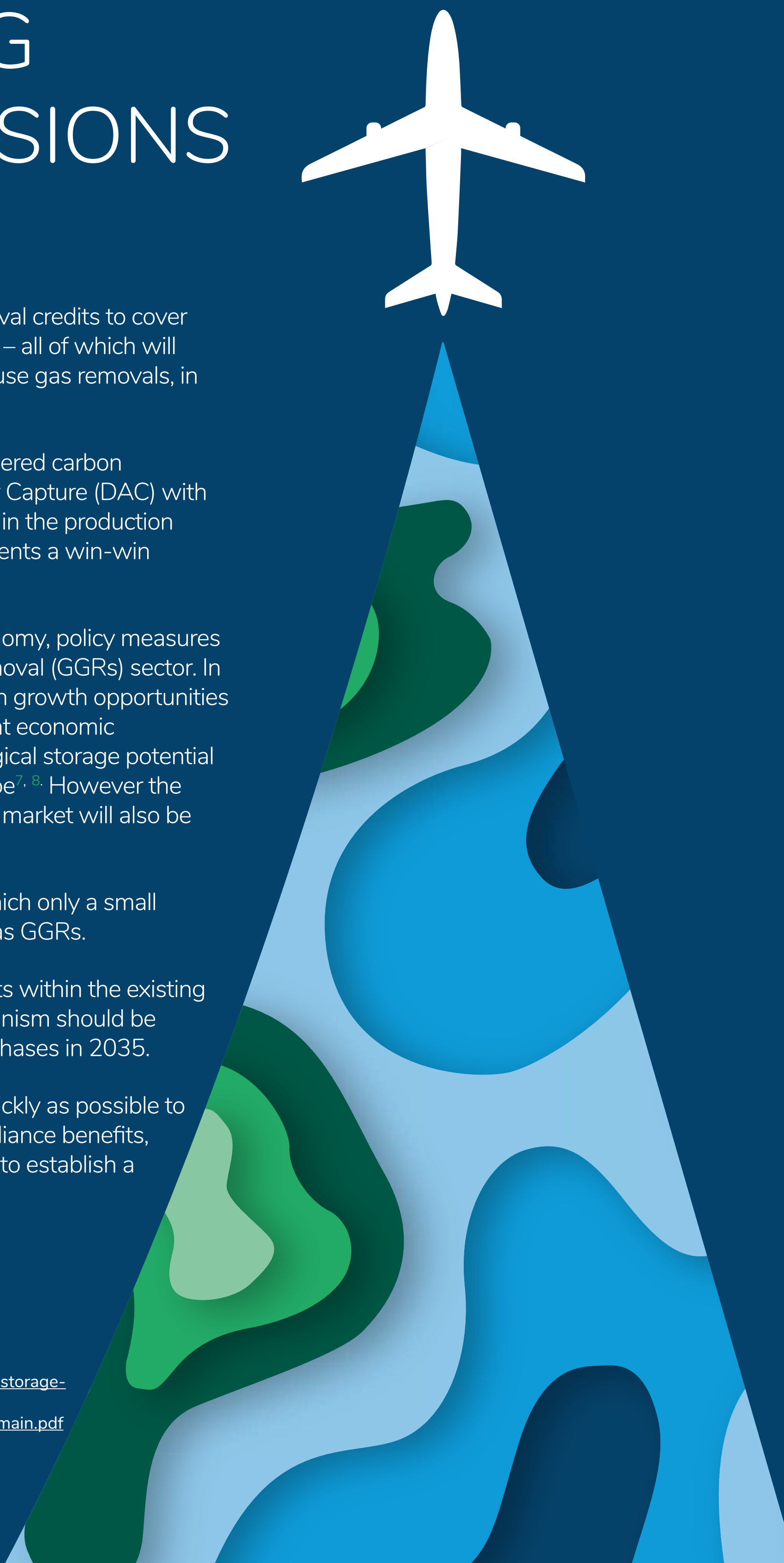
As a competitive industry, fuel suppliers will look to source SAF from global markets. If UK SAF support schemes are not established soon, there is a risk of missing out on creating a UK SAF industry. This would cause loss of the benefits of a domestic SAF industry and lead to the UK aviation industry being reliant on global energy markets. With rapid progress in the US and EU, time is now short for the UK to take a leading role in global SAF development. Sustainable Aviation welcomes the UK Government second stage SAF mandate consultation and believes this will help to incentivise a market in SAF production. To maximise this potential for the UK however, further actions are recommended:

- Delivering commercial UK Sustainable Aviation Fuel production at scale this decade by providing a price stability mechanism for SAF to deliver at least five UK SAF plants under construction by 2025, and also legislating for a SAF mandate.
- Integrate low carbon strategies to accelerate progress to net zero by aligning all of Government to ensure sufficient electrical and hydrogen generation is in place. This would accommodate the energy requirements of a UK wide net zero emission future. The needs of UK aviation to achieve net zero must be included in these plans, since electricity and hydrogen are critical for the roll out of all SAF pathways but are especially critical for PtL.
- Recycle funds generated by aviation through the UK ETS to fund a price support mechanism for the development of SAF and other low carbon solutions to boost UK production.
- Ensure access to sustainable waste feedstock by recognising the strategic decarbonisation role of SAF in the waste management hierarchy.

The UK still has a global leadership opportunity to produce advanced SAF, from wastes and engineered carbon removals. Realising this potential will create wider SAF export opportunities for the UK over the longer term.

Airlines operate in a competitive market and to provide air travel to the UK consumer at competitive prices they will source SAF from international fuel markets. For the UK to supply fuel to these international markets and help ensure low-cost SAF is available, the correct incentives need to be put in place now. The UK risks losing out on the emerging SAF industry and the economic benefits, through job creation and opportunities to export technical expertise.

8. GROWING GREENHOUSE GAS REMOVAL SOLUTIONS AND MANAGING RESIDUAL EMISSIONS



8.1 KEY MESSAGES

- By 2050, aviation will require out-of-sector carbon removal credits to cover 13% of aviation emissions (8.8Mt CO_2) to reach net zero – all of which will need to take the form of durable and additional greenhouse gas removals, in line with best practice on net zero.
- At 2050 most of these credits will be supplied by engineered carbon removal technology – with a significant role for Direct Air Capture (DAC) with permanent storage. DAC will also play an important role in the production of Power-to-Liquid (PtL) SAF, so its development represents a win-win solution for aviation.
- To scale sufficiently to meet the needs of the whole economy, policy measures are required urgently to support the greenhouse gas removal (GGRs) sector. In a further parallel with SAF, this presents significant green growth opportunities for the UK and internationally. The UK can be a significant economic beneficiary of an engineered GGRs sector – it has geological storage potential for over 70bn tonnes of CO_2 – one of the largest in Europe[7, 8]. However the availability of carbon removal credits on the international market will also be important to UK aviation.
- There is a central role for the UK ETS and CORSIA, in which only a small fraction of credits available today would be categorised as GGRs.
    - There should be an increasing eligibility of GGRs credits within the existing CORSIA scheme, and a future net-zero aligned mechanism should be introduced at the conclusion of the CORSIA planned phases in 2035.
    - The UK ETS should include eligible GGRs credits as quickly as possible to allow purchasers of GGRs to gain carbon pricing compliance benefits, with price support investigated to enable these credits to establish a strong demand signal more quickly.

7 https://www.bgs.ac.uk/geology-projects/carbon-capture-and-storage/co2-storage-capacity-estimation/
8 https://nora.nerc.ac.uk/id/eprint/509387/1/1-s2.0-S1876610214023558-main.pdf

8. GROWING GREENHOUSE GAS REMOVAL SOLUTIONS AND MANAGING RESIDUAL EMISSIONS

8.2 CONTEXT

Following the achievement of deep cuts in carbon emissions by 2050 as set out in the previous chapters, UK aviation is forecast to have 8.8Mt CO_2 of residual emissions by 2050. This would make aviation one of the three biggest sector-based sources of demand for greenhouse gas removal (GGRs).

The term GGRs covers both nature-based projects (such as afforestation) and so-called "engineered" solutions – including Direct Air Capture and Storage (DACS) and Bioenergy with Carbon Capture and Storage (BECCS), amongst other technologies.

LEADING CARBON REMOVAL SOLUTIONS

NATURE-BASED
Storage in plants and soils

FORESTRY

Includes:

- Afforestation
- Reforestation
- Wetlands

AGRICULTURE

Includes:

- Agroforestry
- Biochar
- Farm management aimed at increasing soil carbon stocks

Less costly, closer to deployment, most vulnerable to reversal

ENGINEERED
Storage in rocks and materials

ENERGY & INDUSTRY

Includes:

- Bioenergy with CCS (BECCS)
- Direct air capture + storage
- CO_2 mineralisation

More costly, greater R&D needs, less vulnerable to reversal

Figure 18: Two broad types of carbon removal – "engineered" and nature-based

The Road-Map plans for a shift towards engineered GGRs by 2050 for several reasons, including their durability and scalability as well as their materiality to other aspects of aviation decarbonisation.

However, storing carbon in natural ecosystems is viewed as critical by the United Nations Intergovernmental Panel on Climate Change (IPCC) and other authorities for tackling climate change, supporting adaptation, and nature-based projects deliver other social and environmental co-benefits. They are eligible in CORSIA and therefore feature strongly in aviation's transition by default, at least over the next 10-15 years.

8. GROWING GREENHOUSE GAS REMOVAL SOLUTIONS AND MANAGING RESIDUAL EMISSIONS

8.2 CONTEXT (CONTINUED)

To help govern this transition from nature-based towards engineered carbon removals, an independent reference point is the "Oxford Principles[9]". These provide a clear guide for how organisations and sectors should transition from the current state of offsetting today, to a point at or before 2050 when "net-zero aligned" durable GGRs are used to cover residual emissions. These principles underpin the net-zero transition pathway described in the Road-Map.

8.3 DEVELOPMENT SINCE LAST ROAD-MAP

Scientific advice is clear and consistent that GGRs are essential to delivering net zero[10]. In its Sixth Assessment report[11], the IPCC said that "deployment of carbon dioxide removal to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO_2 or Green House Gas (GHG) emissions are to be achieved". Globally, a nascent GGRs sector exists in which business models are emerging and value chains are incomplete, particularly where geological storage is required. The 'Northern Lights' project in Norway, the world's first, is due to begin operating in 2024.

Nonetheless, since 2020, there have been significant developments in the GGRs sector and in both the compliance and voluntary carbon markets. The introduction of tax incentives in the US has led to the rapid emergence of engineered removal technology projects, most notably in Direct Air Carbon Capture and Storage (DACCS) and the formation of the first "Advanced Market Commitment" for GGRs[12] in the US in 2022 – a corporate demand signal designed to add momentum into the market.

In the lead up to COP26, there was a strong focus on standardisation in the voluntary carbon market[13] to further unlock private carbon finance, focussing on ensuring high integrity credits (durable, additional and with high quality monitoring, reporting & verification (MRV[14]) and thereby building confidence for buyers. In the offset compliance market, the baseline for CORSIA was changed to 85% of 2019 levels with airlines expecting to be contributing from 2024.

UK Supply Forecast (Mt)

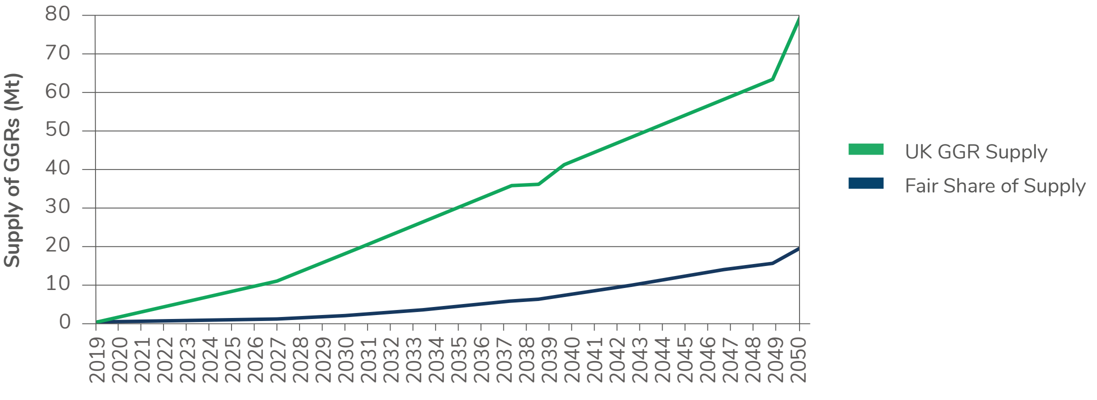


Figure 19: A mid-range forecast supply of GGRs in the UK (nature-based and engineered) given the right market and policy decisions (orange). Aviation's access to supply based on a "fair share" principle (derived from aviation sector share of emissions at 2050 in the UK 6th carbon budget).

9 The Oxford Principles for Net Zero Aligned Carbon Offsetting provide a holistic approach to achieving the goal of net-zero emissions and are intended to be used as a guide for policymakers, businesses, and individuals to ensure that their actions are aligned with this goal.
10 All IPCC modelled pathways aligned with limiting warming to 1.5 include some level of GGR to tackle residual emissions.
11 IPCC 6AR, C.11, https://www.ipcc.ch/report/ar6/wg3/resources/spm-headline-statements/
12 https://frontierclimate.com Advanced Market Commitment.
13 See, for example, the Taskforce on Scaling Voluntary Carbon Markets, https://www.iif.com/tsvcm.
14 MRV: Monitoring, Reporting and Verification.

8. GROWING GREENHOUSE GAS REMOVAL SOLUTIONS AND MANAGING RESIDUAL EMISSIONS

8.4 SUMMARY OF ANALYSIS

For this Road-Map update, new work assesses the availability and cost of GGRs, establishing three scenarios:

- An upside “foresight” scenario in which proactive policy and market conditions enable a planned and cost optimal use of GGRs in the transition to net zero carbon.
- A downside “scramble” in which tight market conditions in the 2030s and early 2040s results in high transition costs later and a ‘dash for carbon capture’.
- A mid-point “central” scenario is employed by the Road-Map. It indicates UK aviation requires a volume of GGRs to reach net zero which is well within a realistic equal share, with respect to other sectors from UK supplied credits. In reality, credits are a global commodity and so this represents a conservative position.

Further details of these scenarios will be published in the technical report.

8.5 KEY FINDINGS

GGRs represent a tiny fraction of carbon credits in the compliance or voluntary markets today. Engineered GGRs are the only realistic option to cover forecast residual emissions and need to be prioritised in the near-term to ensure scale up in the right timeframe. In the central scenario, the SA analysis shows there is the potential for 19.3Mt CO_2 supply of GGRs by 2050 (1Mt CO_2 in 2030), which could be available to the aviation sector. A “fair share”[15] apportionment of total GGRs available in the UK, has been applied based on the aviation sector’s share of emissions forecast in 2050 from the 6th carbon budget. This supply is sufficient to meet the aviation demand as estimated by this Road-Map (8.8Mt CO_2) with a high degree of tolerance.

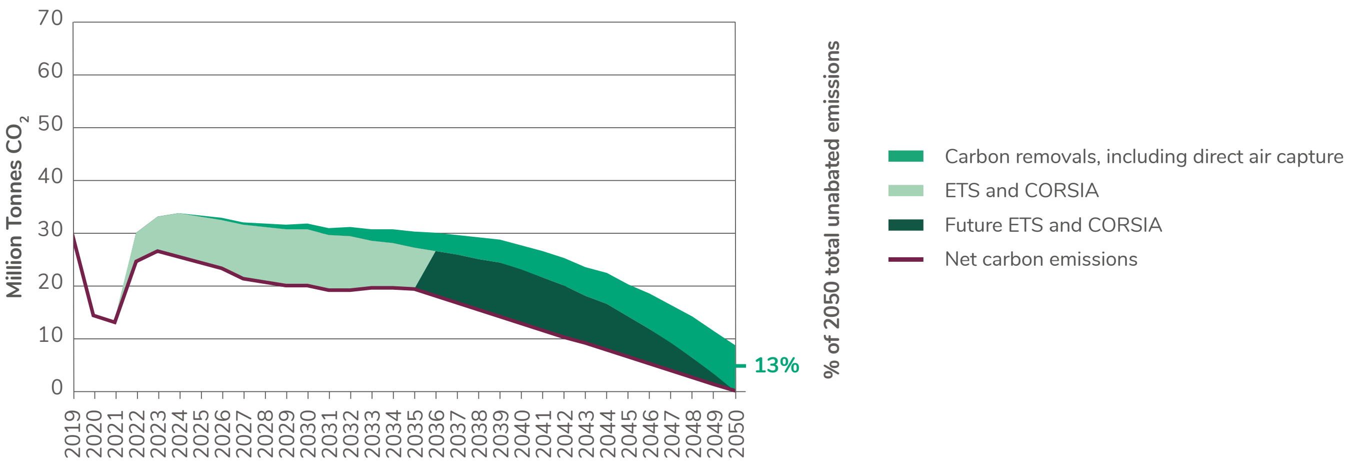


Figure 20: The approach to residual emissions in the SA roadmap

15 Forecast residual emissions in 6th Carbon Budget imply a 9.7% share in 2030 and 24.4% share in 2050 represents a fair figure for aviation to access GGRs alongside other hard-to-abate sectors, most notably the agriculture and land-use sectors.

8. GROWING GREENHOUSE GAS REMOVAL SOLUTIONS AND MANAGING RESIDUAL EMISSIONS

Currently total UK planned capacity is only 2.5-10.5Mt CO_2 depending on which projects are progressed to delivery, which is substantially below the analysed supply potential. A lack of policy intervention would see demand for GGRs from aviation exceed UK supply and establish reliance on the international market. Yet, engineered GGRs in the UK represents an extraordinary economic and net zero opportunity, given the UK's storage potential - it could be a net exporter of credits.

SA members recognise that aviation has a role to play in supporting the scale up of GGRs by sending a demand signal for engineered GGRs. This could take the form of an 'advanced market commitment', which would only be effective if aligned to new policy. Therefore, the sector should move forward in "lock-step" with Government policy, ensuring sufficient supply and demand signals to provide investor confidence. For aviation, there are co-benefits to accelerating the GGR market, most notably a strong alignment between DAC with PtL SAF, but also biogenic sources. Consequently, aviation should work with Government to prioritise DAC and CCS in the near-term, to avoid a disorderly and more costly transition associated with a "dash for carbon" feedstock later.

8.6 RECOMMENDATIONS

- To ensure UK sectors can depend on engineered GGRs there is an important role for compliance markets, new policy, and capacity building. UK ETS should incorporate GGRs credits to help establish initial investor confidence and consider the introduction of a price support mechanism to close the gap between ETS prices and the cost of supplying GGRs. A parallel focus on establishing UK knowledge and expertise will help to ensure sufficient supply.
- The mean cost of engineered carbon removal, if a timely scale up is achieved, is forecast to be competitive with estimates for carbon prices in obligation schemes. Government and industry should capitalise on this to influence CORSIA, working with ICAO to provide incentives to expand the volume of removals in CORSIA pre-2035 and for a new mechanism driving the transition to durable GGRs post-2035.
- Continued effort to accelerate standardisation in the voluntary carbon market is needed, providing confidence to buyers. This will have the most immediate, tangible impact, as the aviation sector can direct more voluntary carbon funding into UK nature-based solutions.

Engagement between Government and the aviation sector is essential to explore how an 'advanced market commitment' could be developed to accelerate the scaling up of GGRs in the UK alongside the necessary policy framework.

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