Department for Transport

Sustainable Aviation Fuels Mandate

Consultation-stage Cost Benefit Analysis

Department for Transport
Great Minster House
33 Horseferry Road
London SW1P 4DR

This publication is also available on our website at
www.gov.uk/government/organisations/department-for-transport

Any enquiries regarding this publication should be sent to us at
www.gov.uk/government/organisations/department-for-transport

Contents

Glossary

ASTM American Society for Testing and Materials

AtJ Alcohol to Jet

BAU Business as usual

BECCS Bioenergy with Carbon Capture and Storage

BtL Biomass to Liquid

CBA Cost benefit analysis

CC(U)S Carbon capture, (utilisation) and storage

CORSIA Carbon Offsetting and Reduction Scheme for International Aviation

DACCS Direct air Carbon Capture and Storage

DESNZ Department for Energy Security and Net Zero (formerly part of the Department for Business Energy and Industrial Strategy, BEIS)

DfT Department for Transport

ETS Emissions Trading Scheme

FOAK First-of-a-kind

GHG Greenhouse gas

HEFA Hydroprocessed Esters and Fatty Acids

HVO Hydrotreated Vegetable Oil

IAS International Aviation and Shipping

ICAO International Civil Aviation Organization

IEA International Energy Agency

LCF Low Carbon Fuels

MSW Municipal solid waste

NPV Net Present Value

Power to Liquid Power to Liquid

RTFO Renewable Transport Fuel Obligation

SAF Sustainable Aviation Fuel

TAG Transport Appraisal Guidance

TRL Technology Readiness Level

UCO Used Cooking Oil

WtL Waste to Liquid

Executive summary

Background

1. In July 2021, the UK Government published a consultation on introducing a Sustainable Aviation Fuel (SAF) blending mandate, which will place an obligation on fuel suppliers to supply a certain percentage of sustainable low-carbon aviation fuels from 2025. The Jet Zero Strategy, published in July 2022, set out the government's wider strategy for decarbonising the UK aviation sector, and confirmed the expectation that SAF will play an important role in this transition.

2. This cost benefit analysis accompanies a second consultation on the proposed SAF mandate and sets out our initial analysis on the potential costs and benefits of the policy. The consultation is considering further options on trajectories, as well as policy sub-options including a buy-out mechanism, a cap on the amount of HEFA[1] permitted under the mandate, and a target on the level of Power to Liquid (PtL) fuels produced. Given significant uncertainty over input assumptions, most crucially relating to the availability of feedstocks for SAF production, the consultation does not suggest a preferred option for many of these policy elements. The analysis uses a wide range of assumptions throughout, in order to illustrate the potential range of outcomes associated with the policy options considered.

3. A final cost benefit analysis will be published alongside the government response to the consultation. It is hoped that, by that stage, further certainty will be available on input assumptions as a result of the responses received as part of this consultation and the Biomass and Low Carbon Fuels strategies, which are expected later this year. Further analysis will also be carried out to assess wider whole energy system implications of different levels of SAF for instance on the costs of decarbonisation in other sectors and security of supply. Throughout this cost benefit analysis, there are references to questions within the consultation document, which call for further evidence from respondents.

Policy options

[1] Hydroprocessed Esters and Fatty Acids

4. The table below sets out the options included within the analysis for each of the policy elements. For the Power to Liquid mandate and HEFA cap, central options are not included, due to the uncertainty surrounding the evidence needed to produce a central estimate. These options are considered separately in sections 2-5, and the overall costs and benefits of the combined options are presented in Section 6.

Table 1. Summary of options included in analysis.

	Main mandate trajectory (% of fuel supply)	**Power to Liquid mandate trajectory** (% of fuel supply)	**HEFA cap** (tonnes of HEFA permitted)	**Buy-out price** (£/litre)
0 – Business As Usual	No mandate - uptake assumed to reach 10% by 2050	N/A	N/A	N/A
1 – Low	0.5% in 2025, 10% in 2030, 17% in 2040	0% in 2025 0.05% in 2030, 1.5% in 2040	0 – no HEFA allowed within the mandate in all years	£1.60/litre (main mandate) £2/litre (Power to Liquid mandate)
2 – Medium	2% in 2025, 10% in 2030, 22% in 2040	N/A	N/A	£2/litre (main mandate) £2.75/litre (Power to Liquid mandate)
3 - High	4% in 2025, 10% in 2030, 32% in 2040	0.05% in 2025, 1% in 2030, 8% in 2040	140,000 tonnes in 2025, increasing to 240,000 tonnes by 2040	£3/litre (main mandate) £4.15/litre (Power to Liquid mandate)

Evidence and methodology

5. Our analysis draws on a significantly improved evidence base on the costs, greenhouse gas savings, and feedstock and energy demands associated with SAF production, informed by analytical tools commissioned from the Aviation Impact Accelerator team, led by Cambridge University's Whittle Laboratory and the Cambridge Institute for Sustainability Leadership. However, there is still significant uncertainty surrounding these assumptions, due to the early stage of development of the SAF industry. The expected fuel mix is calculated under each policy option based on the relative cost-effectiveness of each SAF type and constrained by feedstock availability. The additional costs and benefits of the mandate options are then calculated, relative to the Business As Usual scenario.

6. The largest uncertainty is around the availability of feedstock for SAF production. Given the lack of consensus in this area, and ahead of the publication of both the Biomass Strategy and the Low Carbon Fuels Strategy later this year, the analysis has used a wide range of feedstock availability assumptions, with no central value. As such, all results are presented as a range, with substantial variation in results. Under the lower bound assumption of feedstock availability, trajectories cannot be met by SAF in the majority of years, meaning additional costs to business in the form of buy-out, and minimal carbon savings. We are particularly interested in improving our evidence base on future feedstock availability ahead of the final cost benefit analysis.

7. Another area of uncertainty is around the benefits associated with the policy. Updated cross-government guidance for valuing greenhouse gas savings within the traded sector (i.e., within the scope of the UK ETS and CORSIA schemes) was published by the Department for Business Energy and Industrial Strategy in 2021. This is referred to as 'Department for Energy Security and Net Zero (DESNZ) guidance' in this document following changes in government department structures. DfT Transport Analysis Guidance (TAG) still adopts the previously recommended approach of assuming there are no additional carbon savings as a result of policy interventions within the traded sector, whilst the latest cross-government guidance now makes no distinction between valuing carbon savings in the traded and non-traded sectors. Ahead of a review of the DfT guidance expected later this year, both sets of guidance have been used, and the benefits of the policy are presented as a range. The current DfT guidance results in low NPVs as there are limited monetised benefits.

8. Similar issues exist relating to the additionality of carbon savings delivered by diverting limited feedstock resources from decarbonisation uses in other sectors. There will be interactions between greater SAF uptake and the options and costs of decarbonising other sectors, and also implications for maintaining security of supply. For instance, greater feedstock use may have implications for other sectors and may require additional electricity generation capacity or continued reliance on aviation fuel imports. The standard approach to appraisal used here does not account for these interactions. We will give further consideration to wider whole system implications ahead of the final cost benefit analysis.

Expected impacts

9. The estimated costs and benefits of the policy vary considerably across the options and under the different input assumptions. Without a HEFA cap or Power to Liquid mandate, and under the DESNZ carbon valuation guidance, the NPVs range from a relatively small negative value (£-178m) to a significant positive value (£4.9bn), depending on feedstock availability. Low feedstock availability assumptions lead to lower carbon benefits and high buy-out costs, as there is insufficient SAF available to meet the mandate in the majority of years under all trajectories. Under DfT TAG guidance, the NPVs are always negative due to the limited net carbon savings, ranging from £-5,797m to £-716m.

10. The NPV results highlight the importance of ensuring that SAF trajectories are aligned with a credible view of SAF uptake, and this is why we do not have a preferred trajectory but will be reviewing these in light of the upcoming DESNZ biomass and DfT Low Carbon Fuel Strategies. The NPV range also indicates the importance of assumptions on whether carbon is captured in traded or non-traded sectors and the appropriate carbon valuation approach. We will be exploring these further ahead of the final CBA.

11. When considering the HEFA cap and Power to Liquid mandate, a high level of HEFA permitted under the mandate and a low target on Power to Liquid production result in no change to overall NPVs of each of the trajectories, though there are some additional costs to businesses. Limiting the amount of HEFA and requiring a high

level of Power to Liquid makes all the trajectory options more expensive, and results in the maximum NPV falling to £2.9bn. Buyout costs are also assumed to be significantly higher. More details on the combined results of the policy options are included in section 6.

12. The potential energy demands of the mandate have also been estimated. Demand for low-carbon hydrogen for SAF production could be between 5 and 19TWh in 2040, and low-carbon electricity demand between 3 and 27TWh. This could pose significant challenges in terms of scaling up UK capacity to meet these demands both in 2040 and onwards if trajectories continue to increase past this point. However, as not all SAF used under the mandate is likely to be produced domestically, not all of this energy needs to come from UK sources, though there are substantial uncertainties relating to the global availability of SAF and the ability for the UK to access this.

13. Finally, there are further costs and benefits that have not been quantified at this stage. These include administration and transition costs as a result of complying with the mandate, and non-CO_2 and industrial benefits as a result of reduced kerosene use and increased domestic SAF production. Additionally, there will be wider energy system costs associated with providing the necessary resources and infrastructure required to comply with the SAF mandate. We will consider further evidence on these ahead of the final cost benefit analysis.

1. Policy rationale

Policy background

1.1 The UK is committed to delivering our legal obligations to achieve net zero by 2050 and deliver on upcoming carbon budgets as laid out in the Net Zero Strategy.[2] These will require the rapid decarbonisation of the UK economy, requiring a 68% reduction in GHG emissions by 2030 and a 78% reduction by 2035 (including international aviation and shipping emissions) from 1990 levels.

1.2 The Jet Zero Strategy, published in July 2022, committed the UK aviation sector to reaching net zero emissions by 2050, and to UK domestic flights reaching net zero by 2040. This strategy is aligned with the Transport Decarbonisation Plan (TDP)[3], Flightpath to the Future[4], and the Net Zero Strategy, though the Net Zero Strategy pathways suggest that the UK can reach net zero without fully decarbonising the international aviation and shipping sectors.

1.3 Sustainable aviation fuels (SAF) are one of the key levers available to accelerate the transition to net zero aviation. These are advanced fuels obtained from sustainable feedstocks, which can be blended into conventional jet fuel without requiring significant aircraft or engine modifications. When fully replacing fossil kerosene, they can achieve lifecycle emissions savings of around 70% typically, and when produced with low-carbon electricity and carbon captured from the air potential savings can reach 100% compared to conventional jet fuel.[5] Using SAF also reduces sulphur dioxide and particulate matter emissions, and potentially other non-CO_2 impacts, including contrails.

1.4 An initial SAF mandate consultation was published in 2021, setting out our ambition to introduce a UK SAF blending mandate, a requirement for a certain percentage of aviation fuel supplied to be sustainable, low carbon fuels. This was first announced in the Prime Minister's Ten Point Plan in November 2020. In July 2022, the government

---

[2] BEIS (October 2021) *Net Zero Strategy: Build Back Greener* net-zero-strategy-beis.pdf (publishing.service.gov.uk)
[3] DfT (July 2021) *Decarbonising Transport* Transport decarbonisation plan - GOV.UK (www.gov.uk)
[4] DfT (May 2022) *Flightpath to the future* Flightpath to the future: a strategic framework for the aviation sector - GOV.UK (www.gov.uk)
[5] Aviation Impact Accelerator, *Resource to Climate Comparison Evaluator* RECCE: Resource to Climate Comparison Evaluator (aiatools.org)

confirmed the introduction of a SAF mandate from 2025. A long-term obligation can generate demand for SAF, provide an incentive to SAF producers (in the form of a tradable credit) and signal to investors the vital role the government believes the technology will play in the UK.

Problem under consideration

1.5 The UK aviation sector produced 38.1 million tonnes of CO_2 equivalent ($MtCO_2e$) in 2019.[6] The continued growth in passenger demand has meant that UK aviation fuel use has more than doubled from 5.4 Mt in 1990 to 12.2 Mt in 2019, despite significant aircraft efficiency improvements. Although aviation emissions fell to 15.4 and 14.0 $MtCO_2e$ in 2020 and 2021 respectively, as a result of the COVID-19 pandemic, aviation is currently forecast to be one of the largest emitters by 2050.[7] Reaching net zero aviation emissions by 2050, as committed to in the Jet Zero Strategy, will therefore require significant emissions savings, whilst also balancing the need not to negatively impact efforts to decarbonise the wider system.

1.6 The Jet Zero Strategy identified SAF as one of the key technologies for delivering GHG emissions savings in the UK aviation sector, especially in the medium-term, however SAF production and use is currently limited in the UK. SAF production relies on technology that is yet to be proven at scale, leading to high initial capital and operating costs and uncertainty on return on investment. Without a long-term regulatory and policy framework in place to support industry and provide certainty, these factors act as barriers to an investable proposition for SAF technology developers and investors. Consequently, production capacity will continue to be limited in the UK. A SAF blending mandate will guarantee a level of SAF demand that provides more certainty to investors, and as a result will increase production levels and drive emissions reductions.

1.7 The UK Government is already addressing some of the supply-side barriers through a series of grant funding competitions, such as the recently announced Advanced Fuels Fund (AFF) grants[8], which aim to take UK SAF production plants through to commercialisation. In parallel, the government is working in partnership with industry and investors, including through the Jet Zero Council SAF Delivery Group (SAF DG), on how to create the long-term conditions for investable projects in the UK.

Rationale for intervention

1.8 There are a range of market failures and wider strategic factors which justify government intervention to promote the supply of SAF in the UK.

[6] *Final UK greenhouse gas emissions national statistics* Final UK greenhouse gas emissions national statistics: 1990 to 2021 - GOV.UK (www.gov.uk)

[7] BEIS (October 2021) *Net Zero Strategy: Build Back Greener* net-zero-strategy-beis.pdf (publishing.service.gov.uk)

[8] *Advanced Fuels Fund competition winners* Advanced Fuels Fund competition winners - GOV.UK (www.gov.uk)

Negative externalities

1.9 Externalities are costs and/or benefits associated with the production or consumption of a good, which are not directly experienced by the agents taking part in a transaction. These external costs and benefits lead to allocations of resources and consumption of goods which differ from the socially optimal level. Where this occurs, government intervention is justified to bring the consumption of goods into line with the optimal level.

1.10 The use of fossil-based kerosene in aviation imposes a negative externality on society. Greenhouse gases emitted from combustion of kerosene contribute to climate change and a range of associated impacts including rising sea levels and increased risk of extreme weather events. These impacts will lead to severe and long-lasting environmental and economic damage, which will be experienced, in large part, by those not involved in the original consumption of flights.

1.11 In recognition of the negative externalities associated with carbon emissions, the UK was the first major economy to legislate the requirement to reach net zero emissions by 2050. The UK has set legally binding carbon budgets which set the economy-wide course for decarbonisation and will include emissions from International Aviation and Shipping (IAS) from the 6th Carbon Budget.[9] The Jet Zero Strategy, published in 2022, also set out an ambitious emissions-reduction trajectory for the aviation sector.

1.12 There are existing mechanisms in place to attempt to internalise the negative externalities associated with aviation, namely the UK Emissions Trading Scheme (ETS)[10] and Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).[11] Trading schemes such as the UK ETS put a cap on total emissions in the sectors they cover and provide tradable credits which allow business to emit carbon, up to the capped amount. Over time, the total cap on emissions in these sectors is reduced. Businesses need to purchase allowances to cover the GHG emissions produced, in the case of aviation CO_2 emissions from fuel consumed during flights. CORSIA is a global carbon offsetting scheme. It does not cap the total

[9] Carbon budgets place a restriction on the total amount of greenhouse gases the UK can emit over a 5-year period. IAS emissions have not been formally included in carbon budgets up to and including the fifth carbon budget. Instead, these have been set using a ‘headroom approach’ (excluding IAS emissions, but with lower emissions allowed for other sectors). Following the recommendation of the Climate Change Committee, the Sixth Carbon budget (covering 2033-2037) legally includes IAS emissions within the target for the first time.

[10] The UK Emissions Trading Scheme (UK ETS) replaced the UK’s participation in the EU ETS on 1 January 2021. The UK ETS applies to energy intensive industries, the power generation sector and parts of the aviation sector. Within the aviation sector, the routes covered by the UK ETS include UK domestic flights, flights between the UK and Gibraltar, and flights departing the UK to European Economic Area states and Switzerland conducted by all included aircraft operators, regardless of nationality. For more information, see: https://www.gov.uk/government/publications/participating-in-the-uk-ets

[11] In 2016, the International Civil Aviation Organization (ICAO) adopted the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to address CO_2 emissions from international aviation. International aviation emissions are capped at 85% of 2019 levels, and any emissions above this level must be offset. CORSIA is implemented in three phases: a pilot phase (2021-2023), a first phase (2024-2026), and a second phase (2027-2035). For the first two phases (2021-2026), participation is voluntary. For more information, see: https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx

aviation emissions in its scope, instead it requires qualifying airlines to offset the growth in CO_2 emissions on routes in scope above a baseline level (currently equal to the level of international aviation CO_2 emissions in 2019, changing to 85% of 2019 levels from 2024) by purchasing credits generated by projects that reduce emissions from other sectors.

1.13 Market-based mechanisms, such as the UK ETS and CORSIA, encourage GHG emissions reduction at cheapest cost, as businesses that face the cheapest decarbonisation options are expected to be the first to act to abate, whilst businesses that face more expensive options to reduce emissions continue to purchase credits. They establish a market price for carbon, which encourages emissions innovation to reduce GHG emissions in future and avoid paying the carbon price. Investment in SAF allows airlines to reduce the number of allowances or credits they need to purchase. However, not all flights are currently within the scope of these schemes. Also, carbon prices under CORSIA are currently relatively low, meaning that ticket prices do not always reflect the wider social cost of flying, and are not sufficiently incentivising the uptake of decarbonisation solutions such as SAF, hence the need for further intervention to decarbonise the sector.

Imperfect information and investor uncertainty

1.14 In the early years of deployment, high SAF production costs will result in initially high market prices, and low demand. Cumulative deployment is expected to bring this cost down significantly, driven by economies of scale and technology learning effects, such as those seen in the offshore wind power sector.[12]

1.15 Without certainty surrounding the future demand for SAF and long-term information on cost reductions combined with uncertainty on future carbon pricing, investors will be wary of investing in SAF production. This is especially the case given the very high capital costs associated with first-of-a-kind (FOAK) plants and the high levels of technology risk associated with SAF, given the low technology readiness levels associated with most SAF pathways. Further uncertainty exists surrounding the alternative solutions to decarbonise aviation, which are all at nascent stages, and whether one technology will emerge as a winner, leading to stranded assets. This uncertainty and imperfect information is likely to discourage investment in SAF production and may lead to a scenario where production is unable to meet the growing demand.

1.16 Government support, by way of a long-term demand signal for SAF, can provide certainty to the market and encourage investment into production, bridging the potential gap between supply and demand, and driving cost reductions through economies of scale and learning. Further, early intervention and support in this market will drive the industry to move faster than it otherwise would. Research shows that a UK SAF industry will bring jobs, investment and GVA benefits to the UK, without support these benefits are put at risk.

---

[12] Carbon Brief (September 2019) Analysis: Record-low price for UK offshore wind cheaper than existing gas plants by 2023 (carbonbrief.org)

Industrial benefits

1.17 As laid out in the Net Zero Strategy[13] the global shift towards net zero offers an opportunity for the UK to create new green jobs and put the UK at the forefront of growing global markets. The aviation sector contributes significantly to the UK economy, directly employing 230,000 people and contributing £22 billion to GDP prior to the pandemic.[14] Failing to invest in decarbonising aviation may harm the competitiveness of the UK aviation sector, as other nations decarbonise their own aviation sectors, causing negative impacts to UK employment and growth.

1.18 Many SAF projects are also developing within existing industrial clusters, working in synergy with other industries such as low carbon hydrogen, to deliver wider net zero objectives and provide regeneration opportunities and clean growth. Research by Sustainable Aviation shows domestic SAF production could contribute up to £1,952 million per year to the UK economy in 2035, potentially supporting between 6,400 and 13,600 jobs.[15] The recently announced winners of the Advanced Fuels Fund competition funding for example are expected to support over 5,000 jobs in the construction and operation of the plants funded.

1.19 Outside of the aviation sector, by replacing conventional jet fuel with SAF the UK can improve its fuel security while fostering industrial development across the whole country. Not only can SAF use result in new domestic plants being developed across our four nations, but it also gives a route for existing oil refineries to transition towards more sustainable products, strengthening existing supply chains, building new ones and retaining the UK industry's expertise and skills.

1.20 The jobs and growth benefits are not quantified further in this CBA. This is because we can estimate how much SAF is required under the SAF mandate, but not whether SAF would be produced in the UK or not. Furthermore, where SAF is produced this modelling would require an understanding of total investment in constructing SAF plants and producing SAF, which would require a significant increase in the scope of this CBA. Finally, there is uncertainty on the additionality of any jobs associated with SAF produced in the UK. Given the wide amount of additional data to quantify this impact, it is considered disproportionate to include this within the CBA.

Policy objectives

1.21 The following critical success factors of the policy have been defined:

- Reduce greenhouse gas emissions associated with aviation and contribute to lower emissions across the UK as a whole.

---

13 BEIS (October 2021) *Net Zero Strategy: Build Back Greener* net-zero-strategy-beis.pdf (publishing.service.gov.uk)

14 DfT analysis of ONS data

15 Sustainable Aviation (2020) *Sustainable Aviation Fuels road-map* https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_FuelReport_20200231.pdf

- Encourage investment in the nascent UK SAF industry by providing long-term certainty for investors.
- Incentivise innovation in less-commercially developed fuel pathways, which have the potential to provide the greatest GHG reductions, driving down costs and encouraging learning spillovers.
- Encourage sustainable use of feedstocks across transport and the wider economy, avoiding unintended consequences, such as diverting biomass from other more efficient decarbonisation uses across the energy system.

Policy options considered

1.22 The Jet Zero Strategy committed to reaching net zero aviation by 2050 by focussing on a combination of six key measures: system efficiencies, SAF, zero emission flight, markets and removals, influencing consumers, and addressing non-CO_2. The analysis underpinning the strategy highlighted that SAF will need to play an important role in ensuring that we meet our economy-wide carbon budgets, and the transport sector's agreed 'effort share', given that other technologies such as hydrogen aircraft or greenhouse gas removals are not expected to be deployed until 2035 at the earliest. Even with the most optimistic assumptions on the entry-into-service dates of zero emission aircraft, aircraft lifetimes and fleet renewal rates mean that conventional aircraft that enter into service within the next 10 years will still be in service by 2050. Drop-in solutions like SAF will therefore be crucial to the longer-term decarbonisation of aviation, and there will be no singular solution that can be relied upon, meaning that investment to scale up the SAF industry is needed now to ensure we have the required production capability in future.

1.23 Various policy options for supporting the use of SAF in the UK were considered at the long-list stage. One potential alternative option was to introduce an obligation to supply SAF under the RTFO. This would have some benefits including that it would maintain a single policy framework to reward sustainable transport fuels in the UK, with which industry is already familiar, and it could facilitate reporting and compliance processes and timescales. However, this would still require us to define an additional obligated party as this could otherwise translate to an obligation on suppliers of road transport fuel, who may not necessarily supply aviation fuels too. As SAF is more expensive than conventional fossil fuel jet, an obligation under the RTFO could mean that these costs were passed through to the road fuel supply chain and not the aviation fuel supply chain, which would not be in line with the polluter pays principle. Relying on the existing RTFO provisions could also create complexity when these rules need to change to reflect the specific needs of SAF.

1.24 Another alternative option considered was the continuation of grant funding support for plant development without the addition of demand-side policy such as a mandate or an obligation under the RTFO. This was not considered a viable option as without a strong demand signal from government, producers would be operating under significant uncertainty over whether their fuel would have a market in the UK. Producers also highlighted that they would have difficulty in securing financing from investors without some form of demand certainty.

1.25 A SAF mandate was therefore chosen as the preferred option, alongside the package of already announced support measures for the SAF sector, such as capital grants for SAF production through the Advanced Fuels Fund.

1.26 The following sections set out options and analysis relating to detailed policy design elements of the SAF mandate. Section 2 sets out analysis relating to the overall trajectory and ambition, sections 3-5 consider further policy design options (a buy-out price, a HEFA cap, and a Power to Liquid mandate), while section 6 considers the combined impact of the chosen policy elements.

2. Mandate trajectory

Options considered

2.1 This section sets out the overall trajectory options considered. Per HMT Green Book guidance, the first option presented (Option 0) represents the ‘Business As Usual’ (BAU) counterfactual.

2.2 The previous consultation[16] set out five high level potential SAF mandate trajectories, as a percentage of UK aviation fuel demand. The trajectories all started at 0.5% in 2025, reaching 3%-10% in 2030, and then 15%-75% in 2050. The preferred option suggested by the consultation responses was Scenario E (‘Early SAF breakthrough’), which reached 10% in 2030 and 75% in 2050.

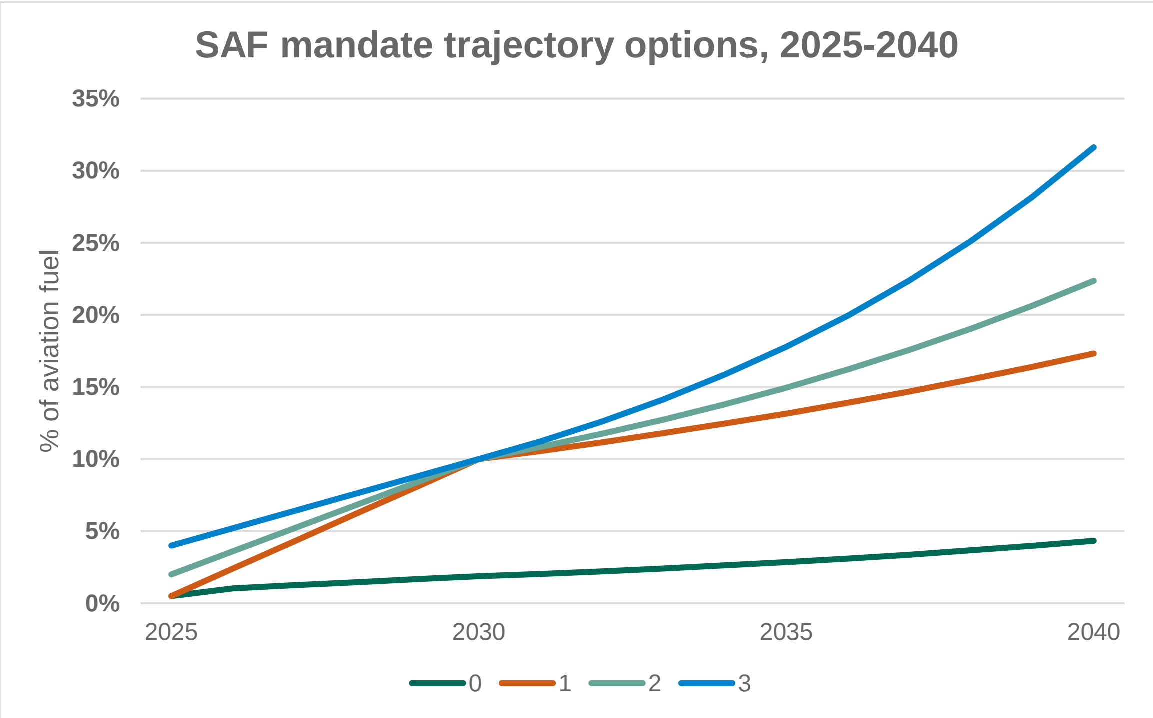
2.3 For this analysis, we are considering three options (low, medium, high), split into pre- and post-2030, which capture the range of potential trajectories. The options now start at different points, but all centre on a 10% uptake in 2030, as committed to in the Jet Zero Strategy. These options only go out to 2040, given the timescales of the legislation that will be introduced. The option to increase these targets further post-2040 will be reviewed in line with the future review points set out in the consultation document. An illustrative example of how these trajectories could continue out to 2050 is included in figure 2 (though these are not being committed to at this stage).

[16] Mandating the use of sustainable aviation fuels in the UK - GOV.UK (www.gov.uk)

Table 2. SAF mandate trajectory options - Mandated SAF level as a % of total aviation fuel

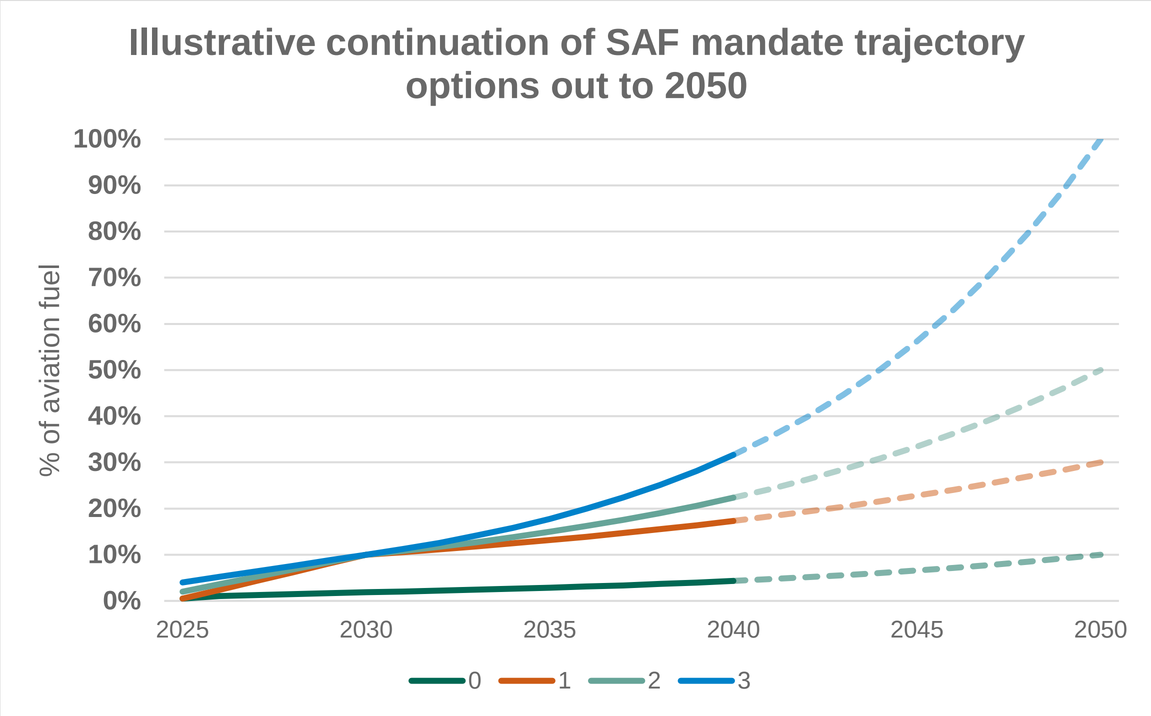
Option	***2025***	***2030***	***2040***
0 – BAU	0.5%	2%	4%
1 - Low	0.5%	10%	17%
2 – Medium	2%	10%	22%
3 - High	4%	10%	32%

Figure 1. SAF mandate trajectory options, 2025-2040[17]



[17] Note that legislation will flatline targets beyond 2040, they will not end at that point.

Figure 2. Illustrative continuation of SAF mandate trajectories out to 2050



Option 0 - Business As Usual

2.4 The 'Business As Usual' scenario assumes that no mandate is introduced, and there is no additional intervention in the UK SAF sector beyond what has already been announced. As is currently the case, there is no obligation on SAF supply under the RTFO. However, suppliers can choose to claim under the scheme and be awarded certificates for the volumes of SAF supplied into the UK, where they meet the eligibility criteria. The UK ETS and CORSIA provide some incentive for airlines to use SAF, though, especially in the case of CORSIA, this incentive is currently fairly limited given the current relatively low carbon prices under the scheme.

2.5 In the absence of an obligation on SAF, supply in the UK is assumed to be low, given the lack of demand certainty. Uptake is assumed to reach 2% of UK jet fuel demand by 2030, and 10% by 2050. This is in line with the assumed SAF uptake in the Jet Zero Strategy's Continuation of Current Trends scenario. It also aligns with emerging evidence from the RTFO, where limited SAF has been claimed. Industry stakeholders have suggested that the RTFO in its current form does not provide an effective contribution towards the cost of producing SAF, especially for less commercially developed pathways such as Power to Liquid.

Options 1 - 3

2.6 Option 1 represents the lowest of the proposed trajectories, though still highly ambitious. The level of the mandate, as a proportion of UK aviation fuel use, begins low at 0.5% in 2025, increasing sharply at a linear rate to 10% in 2030. From there, it increases to 17% in 2040, bringing the SAF mandate target in line with the total RTFO target level.

2.7 Option 2 represents the central trajectory. The level of the mandate, as a proportion of UK aviation fuel use, begins at 2% in 2025. This is in line with similar schemes in other regions. The mandated level then rises linearly to 10% in 2030. From there, it increases to 22% in 2040, and is on track for a 2050 ambition of 50%, in line with the High Ambition scenario from the Jet Zero Strategy.

2.8 Option 3 represents the highest ambition trajectory. The level of the mandate, as a proportion of UK aviation fuel use, begins at 4% in 2025, rising linearly to 10% in 2030. From there, it increases exponentially to 32% in 2040, and is on track for a 2050 ambition of 100%, in line with the High Ambition with a breakthrough on SAF scenario in the Jet Zero Strategy. This trajectory would have significant feedstock implications and is likely to be at the very upper end of what could be feasible, especially in the medium-term.

2.9 There are substantial risks around the feasibility of all of the options considered here if there are insufficient feedstocks available to produce the required SAF, either domestically or via imports. There are further feasibility risks around the additional pressures the trajectories could have on the electricity grid as well as on demands for hydrogen and captured CO_2. The potential feedstock and energy requirements of each of the options out to 2040 are set out in section 2.86 onwards. Given the scope of currently proposed trajectories, full estimates out to 2050 have not been included, though it is important to consider the scale of potential energy system impacts if these trajectories ramp up significantly post-2040. Initial analysis suggests that a maximum ambition of 100% SAF uptake by 2050 could result in over 300TWh of low-carbon electricity demanded, which is likely to be impossible to meet through UK production alone.

2.10 In all three trajectories, we do not expect all SAF claimed under the mandate to be produced domestically. The UK currently imports 61% of its jet fuel, though there is uncertainty surrounding the expected level of imports for SAF, as discussed in section 2.44 onwards.

2.11 A buy-out price is proposed as a core part of the mandate policy, to incentivise compliance with the mandate whilst also serving as a price cap on the cost to industry and consumers where the supply of SAF is not possible or too costly. For options 1 to 3, a buy-out price of £2/litre is assumed to apply to producers where the mandate is not met. A brief explanation of how the buy-out price is included in the analysis is set out in section 2.53, with further details on the rationale, methodology and the range of different buy-out prices tested included in section 3.

Assumptions and methodology

Scope

2.12 The scope of the analysis covers impacts delivered by a SAF mandate starting in 2025, through to 2040. The following impacts are included:

Direct, monetised costs:

- Additional cost of SAF as a result of a change in aviation fuel use.
- Buy-out cost to business, where the mandate is not met through supplying fuel.
- Resulting impact on ticket prices.[18]

Non-monetised costs:

- Other additional costs as a result of complying with the mandate (e.g., investment in refuelling infrastructure, admin costs, etc.).

Direct, monetised benefits:

- GHG savings from reduced kerosene use in aviation.
- Cost savings on kerosene as a result of a change in aviation fuel use, and savings on ETS allowances and CORSIA credits, where flights fall under the scope of these schemes.
- Buy-out revenue to government, where the mandate is not met through supplying fuel.

Non-monetised benefits:

- Growth impacts on GVA and employment.
- Change in other environmental impacts, including non-CO_2 emissions and contrails.

Other indirect impacts:

- Impact on availability of feedstocks, and energy demands.

Evidence and assumptions

2.13 Since the publication of the first consultation on the SAF mandate, we have worked to significantly improve our evidence base on the costs, GHG savings, and feedstock and energy implications of SAF, and the availability of these feedstocks.

2.14 Our updated analysis is informed heavily by the Aviation Impact Accelerator (AIA), led by Cambridge University's Whittle Laboratory and the Cambridge Institute for Sustainability Leadership.[19] DfT commissioned the AIA team to build a bespoke modelling tool, drawing on their publicly available RECCE tool[20], to determine the

[18] Ticket price impacts are not included as an additional cost within the appraisal, instead they have been modelled to illustrate how costs to businesses may be passed onto consumers. The secondary impact on demand as a result of increased ticket prices has not been modelled at this stage of the analysis, however we intend to incorporate it into the final Cost Benefit Analysis to be published later this year.

[19] The AIA is informed by a large group of stakeholders across the aviation and SAF supply industry. This is through direct working partnerships and industry surveys. For more information, see: The project - Aviation Impact Accelerator (aiazero.org)

[20] RECCE: Resource to Climate Comparison Evaluator (aiatools.org)

most cost-effective fuel mix under a SAF mandate, and to calculate the associated costs, greenhouse gas and feedstock and energy implications. Further details on each set of input assumptions are provided in the following sections.

Jet fuel demand

2.15 The mandated level of SAF under the policy is presented as a percentage of aviation fuel used on UK-departing flights (represented by bunker fuel sales). Our assumptions on expected fuel demand come from internal modelling using the DfT's Aviation Model and align with the scenarios produced as part of the Jet Zero Strategy[21], whilst also incorporating the latest forecasts of UK and foreign GDP growth, GDP deflator, oil prices, and exchange rates.

2.16 Given the significant uncertainty surrounding aviation demand, we have tested a range of assumptions on expected aviation fuel demand. For our central case, expected fuel demand is based on the Jet Zero Strategy's Continuation of Current Trends scenario. The fuel demand associated with the High Ambition scenario has also been modelled, reflecting a situation with lower kerosene demand due to the uptake of other decarbonisation technologies. All options assume around 11.5 million tonnes of jet fuel are used in 2025, reaching between 10.5 – 12.2 million tonnes in 2040.

Kerosene prices and carbon prices

2.17 Forecasts of kerosene prices used within the analysis come from internal DfT analysis of historic crude oil and jet fuel price data, and BEIS forecasts of oil prices.[22] Given the historic volatility of kerosene prices, a range of price series is tested in the analysis.

2.18 It is assumed that, in the counterfactual case, airlines face the cost of kerosene plus a carbon price, where that fuel is used within scope of either the UK ETS or CORSIA schemes. Just under 30% of emissions from UK departing flights are currently covered by the UK ETS, while around 70% are covered by CORSIA, although there is significant overlap between the two schemes.[23] Overall, it is estimated that around 15% of emissions from UK departing flights are not currently covered by either the UK ETS or CORSIA, but this is expected to fall to below 10% from 2027. The range of ETS allowance and CORSIA credit prices included in this analysis are in line with the illustrative price series published by DfT as part of the Jet Zero consultation.[24]

[21] For further information on DfT's Aviation Model, see the Jet Zero Strategy modelling framework: Jet zero: modelling framework (publishing.service.gov.uk)

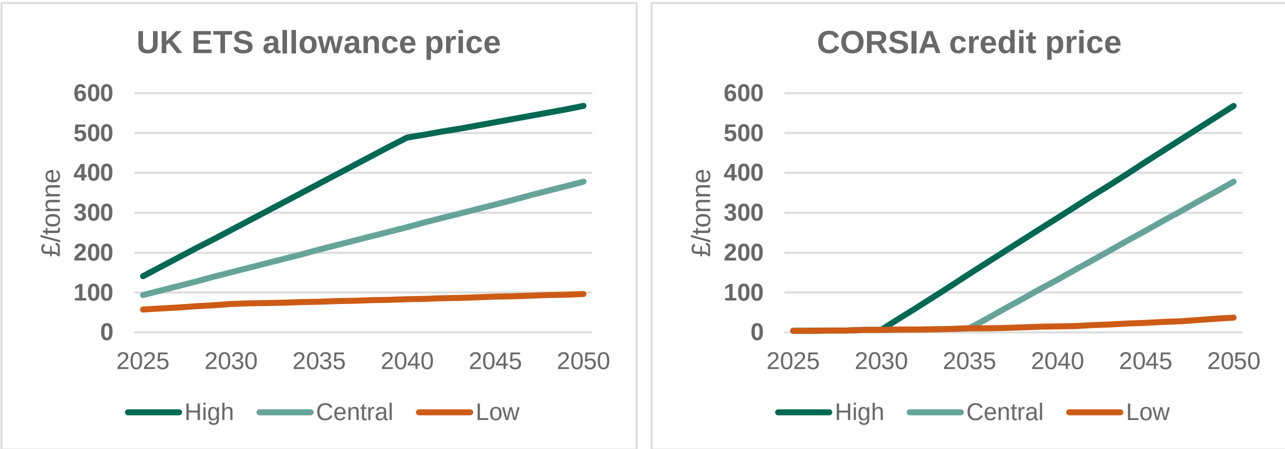
[22] Oil price forecasts were provided by the Department for Business Energy and Industrial Strategy for internal use within DfT aviation analysis.

[23] Flights from the UK to the EEA and Switzerland are in scope of both the UK ETS and CORSIA. We are carefully considering the approach to CORSIA implementation and interaction with the UK ETS, and we will consult further in due course.

[24] See Annex B for details of illustrative ETS and CORSIA prices Jet zero: further technical consultation (publishing.service.gov.uk). The continuation of current trends scenario uses the Central ETS price series and the Low CORSIA price series. These assumptions are designed to illustrate the potential range of carbon prices faced by airline operators in future for analysis purposes. The assumptions do not represent the UK Government's view on the most likely evolution of market prices under any carbon pricing mechanism.

These price series are illustrated in figure 3, with details of the methodology for these included in annex 7.1.

Figure 3. Range of UK ETS allowance and CORSIA credit prices used in analysis



SAF production costs

2.19 The SAF production costs used as inputs to the AIA analysis come from their own bottom-up techno-economic modelling, which considers the capital and operating expenditure of the different technologies, alongside the amount and price of feedstock required for each production route. Costs are expected to fall over time, based on learning curves and predictions of future technology costs. Overall, the central values suggest that SAF will be around 2-5 times the cost of kerosene (without a carbon price) in 2025, falling to 1.2-2.8 times the cost by 2040.

2.20 We have independently validated the assumptions on SAF costs within the AIA tool against a range of other available literature, including from the International Council on Clean Transportation[25] (ICCT), the World Economic Forum (WEF)[26], PWC[27], independent analysis for DfT by E4Tech, and against market SAF prices provided by Argus media. It is currently understood that spot market for SAF is currently trading at higher prices than those used in this analysis. For example, in the later stages of 2022, Argus Media reported spot SAF prices of around £3,000/tonne. Stakeholders have informed the Department that these prices are based on small numbers of trades (as most SAF is provided through direct contracts) which can be distorted by market forces, hence a preference to use the SAF price projections from the AIA tool.

2.21 There is significant uncertainty surrounding SAF costs, due to the early stage of technology development, and some of the reports quoted above suggest cost estimates that are outside the range used within our analysis, including some estimates that the potential for Power to Liquid costs to fall could be higher. In the

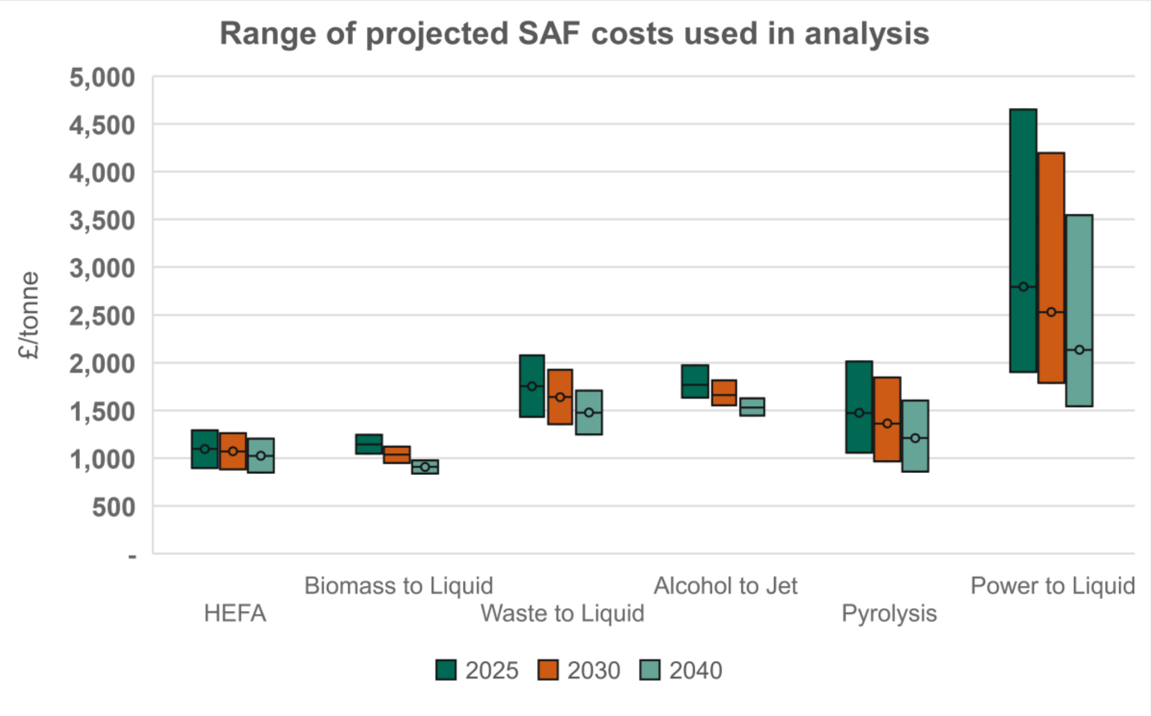
[25] ICCT (2019) *The cost of supporting alternative jet fuels in the European Union*. https://theicct.org/sites/default/files/publications/Alternative_jet_fuels_cost_EU_20190320_1.pdf

[26] WEF (2020) *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathways to Net-Zero Aviation*. https://www3.weforum.org/docs/WEF_Clean_Skies_Tomorrow_SAF_Analytics_2020.pdf#:~:text=The World Economic Forum’s Clean Skies for Tomorrow,the transition to net- zero flying by mid-century

[27] PWC (2022) *The real cost of green aviation* https://www.strategyand.pwc.com/de/en/industries/aerospace-defense/real-cost-of-green-aviation.html

long run, costs of advanced fuels such as Power to Liquid will be heavily dependent on the cost of low-carbon electricity. To reflect this and the significant volatility in aviation fuel prices in general, a range of optimistic and pessimistic estimates of SAF costs have been tested in the analysis, as illustrated in Figure 4, with further details in annex 7.2. The central values used in the analysis are indicated by the markers in the middle of the bars.

Figure 4. Range of SAF production costs used in analysis



SAF greenhouse gas savings

2.22 The greenhouse gas savings associated with SAF within the AIA modelling consider the emissions associated with electricity demand, land use change and the direct net GHG emissions in feedstock processing during the fuel production process. Again, these values have been compared against the range of external evidence discussed above, and other sources such as the ICAO lifecycle assessments, and information provided by industry under the Advanced Fuel Fund competition. To account for significant technological uncertainties here, a range of optimistic and pessimistic greenhouse gas savings have also been tested in the analysis (see annex 7.3 for details).

2.23 It should be noted that, while there are lifecycle savings associated with using SAF, interactions with carbon cap and trade schemes mean that emissions savings may be offset elsewhere in the traded sector. Assumptions on whether a mandate will result in net emissions savings across the economy are explained in further detail in sections 2.56-2.59. In addition, increased use of SAF in aviation may have implications for the amount of feedstock available for use in other sectors including use of feedstock with CCUS to produce electricity or hydrogen, both of which generate negative emissions. These issues will be further considered in the final cost benefit analysis.

Feedstock availability and demand

2.24 Understanding feedstock availability, both in terms of total global supply and the percentage of total supply available to the UK, is a crucial input for the SAF mandate modelling. Feedstock availability inputs inform possible mandate trajectories, as well as having large impacts for the HEFA cap analysis, possible Power to Liquid mandate options and total buy-out costs.

2.25 Forecasting the total global supply of feedstocks over the appraisal period is very challenging. Each identified feedstock requires data on current availability and usage, possible growth in supply and collection rates over time, potential risks to the supply chain and possible competing uses. This data may be limited or unreliable. Based on these inputs, forecasts must then be made up to 2040, which in turn will have their own sensitivities and uncertainties inherent to forecasting.

2.26 Furthermore, the level of total forecasted supply that the UK could secure, and the price at which this could be secured, will be dependent on another range of variables. These include, but are not limited to, trade risks based on feedstock concentration geographically, and increasing competition to access feedstocks due to a large international commitment to decarbonisation.

2.27 Given significant uncertainty surrounding feedstock availability, and the significant impact it has on the results of the analysis, we are using a range of input assumptions, with no central value. The upper bound, informed by the AIA, estimates that the SAF mandate can be met in all but the highest trajectories without any buy-out. The lower bound is taken from interim research conducted by Ricardo[28] underpinning the DESNZ Biomass Strategy. This results in significantly constrained SAF availability.

2.28 This wide range was generated by considering several factors including the share of global feedstocks available to the UK, the share of feedstocks in the UK that are available to aviation, and assumptions on growth rates on production and collection of feedstock globally, as well as the import of final product SAF from other countries.

2.29 Assumptions on availability of direct air capture carbon (DAC) as a feedstock for Power to Liquid are not provided by the Ricardo analysis for DESNZ, so DAC availability assumptions draw on the AIA analysis, which are informed by evidence from the IEA.[29] There is however, still significant uncertainty surrounding the availability of DAC, and this should be considered throughout the analysis.

Interaction with the LCF Strategy and Biomass Strategy

[28] Ricardo Energy & Environment are technical consultants who have been contracted by DESNZ to produce modelling and estimates regarding the future availability of UK and global biomass and feedstocks.
[29] International Energy Agency (2022) *Direct Air Capture: A key technology for net zero* https://iea.blob.core.windows.net/assets/78633715-15c0-44e1-81df-41123c556d57/DirectAirCapture_Akeytechnologyfornetzero.pdf

2.30 The Ricardo research regarding feedstock availability mentioned above, as well as similar research commissioned by DfT, will inform the publication of the DESNZ Biomass Strategy and DfT Low Carbon Fuels Strategy later this year.

2.31 These publications will set out the government view on feedstock availability and demand, which will have implications for this analysis. By using this wide range of availability assumptions, this analysis aims to represent, at a minimum, the best- and worst-case scenarios for feedstock availability that are currently available and the implications of this on the CBA. However, once these strategies are finalised, we expect to be able to define a narrower range of assumptions about how much feedstock might be available for UK aviation domestically and internationally in future.

2.32 One important point that these scenarios reveal is the inherent uncertainty regarding feedstock availability for Sustainable Aviation Fuel production. As noted, the UK currently imports a significant amount of global feedstock. Global feedstock supply is likely to be constrained going out to 2050 – given competing pressures for land for use in other sectors. Global demand for feedstock is likely to increase in future, and this may constrain our ability to maintain the current high import shares that we currently access. Given the complexity of global feedstock markets it will always be difficult to predict the level of feedstock we may be able to access at a commercially viable price.

Feedstock scenarios

2.33 The high feedstock scenario is generated using the optimistic end of evidence suggested by the Aviation Impact Accelerator. The AIA modelling draws on initial feedstock availability data for the UK from a 2017 Ricardo report[30], which was used in the BEIS Net Zero Strategy. It then applies IEA growth rates to both growth of feedstock availability and the collection rate of those feedstocks. For international feedstock availability, reporting from the IEA[31] and World Bioenergy Association[32] was taken with the same growth and collections rates as above applied.

2.34 Under this scenario there is sufficient feedstock supply to meet demand in the majority of years across the range of potential SAF trajectories. This scenario assumes that UK aviation will receive 3% of domestic feedstock and 1% of global feedstock in the upper bound estimates, it assumes that global levels of feedstock are constant, but the collection rates of feedstock improve, allowing a significant increase in the amount of feedstock available for aviation through higher utilisation of potential feedstock.

2.35 The low feedstock scenario is based on a lower bound feedstock availability scenario generated from interim research carried out by Ricardo, commissioned by The Department for Energy Security and Net Zero as part of the Biomass strategy. It takes a scenario which assumes that global traded feedstock falls significantly as

---

[30] Ricardo Energy & Environment (2017) *Biomass Feedstock Availability* Biomass Feedstock Availability (publishing.service.gov.uk)

[31] IEA *Bioenergy* Bioenergy – Analysis - IEA

[32] World Bioenergy Association (2021) *Global Bioenergy Statistics* Global Bioenergy Statistics 2021 - World Bioenergy Association

more is consumed domestically by countries trying to meet carbon targets through domestic feedstock production, and that competition for traded feedstock also increases between countries that want to import feedstock. This results in UK feedstock consumption of global feedstock production falling to 1% in 2035 and 0.2% in 2050.

2.36 Finally, the modelling assumes that aviation can access 3% of all feedstock available to the UK (including domestic production and imports). This figure represents the proportion of total UK emissions domestic and international UK aviation was responsible for in 2020.[33] It is recognised that historically UK aviation is responsible for a larger portion of total emissions than in 2020 due to Covid-19, however, to represent a more pessimistic view on feedstock availability as well as giving a wider range, this figure was chosen. The result of these assumptions is that in the upper bound we assume the aviation sector has 27,693 GWh of feedstock available in 2030, and 3,671 GWh in the lower bound.

2.37 In both feedstock availability scenarios, UK SAF production is assumed to have access to 3% of available domestic feedstocks. This assumption uses the proportion of 2020 UK emissions (including International Aviation and Shipping) which come from aviation, as a proxy for the amount of feedstock that the aviation sector may be able to access. These assumptions will be updated after the production of the DESNZ Biomass strategy and DfT Low Carbon Fuel strategy, which will allow a much richer consideration of feedstock allocation between different sectors of the economy.

2.38 It is recognised that these are broad assumptions and that, given the suitability of different feedstocks available to SAF, it is likely that UK SAF production may receive higher proportions of certain feedstocks and lower proportions of others. Once the biomass and Low Carbon Fuels strategies are published the assumptions used in this modelling, and ultimately in the appraisal underpinning the legislation, will be updated.

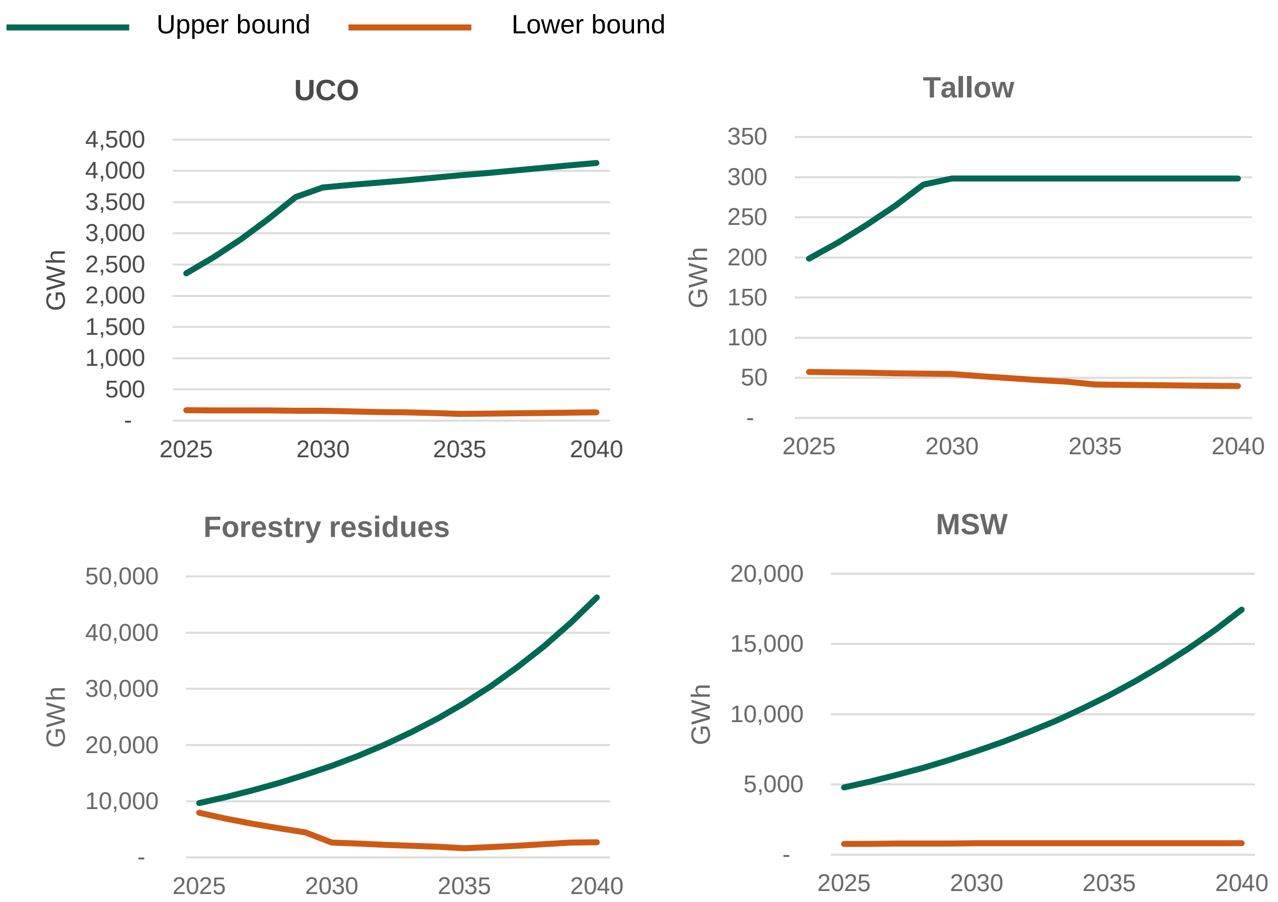
2.39 As noted throughout this analysis, there are limits to the amount of sustainable feedstock that is available. Increasing demand for feedstock where supply is below the sustainable limit can bring forward extra sustainable supply of feedstock and deliver further additional carbon savings. Increasing demand for feedstock beyond the sustainable limit is likely to divert sustainable feedstock away from other applications. There may therefore be opportunity costs associated with using feedstock for SAF production if demand goes beyond the sustainable availability. Modelling these complex interactions is beyond the scope of this analysis. The DESNZ biomass strategy and DfT Low Carbon Fuel Strategy will explore potential sustainable supply scenarios for the UK further. It should also be noted that investment in technology to produce energy from feedstock in the UK, will also help produce economies of scale and learning rates in these technologies supporting the cost-effective roll out of these technologies globally.

2.40 The Department welcomes further evidence on the availability of feedstocks for SAF production (see consultation call for evidence question 1).

---

[33] Final UK greenhouse gas emissions national statistics 1990 to 2020 (www.gov.uk)

Figure 5. Range of assumptions on feedstocks available to UK aviation used in analysis



2.41 Under the wide range of feedstock availability assumptions displayed in figure 5, the SAF mandate trajectories have very different outcomes. When using the upper bound feedstock scenario all the SAF mandate trajectory options can be met through the supply of SAF in the majority of years. In the lower bound scenario, there is not enough feedstock to meet any of the trajectory options and therefore suppliers are forced to buy-out of their obligations.

2.42 It should also be noted that some feedstocks have not been included in this analysis due to lack of data on availability and are therefore out of scope. This includes feedstocks such as waste gases waste oil products and other organic wastes, this is not an exhaustive list.

2.43 Assumptions on the volume of feedstocks and energy required to produce each unit of SAF were provided by the Aviation Impact Accelerator team, informed by their engagement with industry.[34]

Global SAF production and imports

2.44 For simplicity, given the significant uncertainty surrounding UK and global SAF production capacity, this cost benefit analysis makes no explicit assumptions on the

[34] The partners - Aviation Impact Accelerator (aiazero.org)

level of SAF that we expect to be imported to meet the mandate. This therefore has no impact on the overall estimates of costs and benefits of the policy, as we assume that production costs are the same, regardless of where SAF is produced. This is a simplifying assumption made for the purposes of analysis, and something we hope to explore further in future.

2.45 The UK currently imports at least 61% of its jet fuel, as set out in a BEIS publication suggesting the UK's self-sufficiency score for jet fuel is 0.39.[35] It should be noted that the self-sufficiency score does not represent current jet fuel imports perfectly, as it also includes UK exported jet fuel within the calculation for self-sufficiency. Therefore, actual current imports of jet fuel could be higher. Whether the UK continues to meet its jet fuel demand with this level of imports during the transition to SAF is incredibly uncertain.

2.46 It is expected that, in the short term, SAF production will be heavily focussed in developed nations. The UK aims to be at the forefront of early SAF production plants and is investing directly in UK SAF production through the Advanced Fuels Fund. However, in the medium and long term, with increasing technology readiness levels and increasing demand, it is expected that production will ramp up internationally. Several feasibility studies have been conducted by ICAO regarding the development of SAF industries in developing nations.[36] In the medium to long term, it is expected that nations with cheaper access to renewable energy and currently un-utilised feedstocks will be a key part of the international SAF mix.

2.47 It is expected that global SAF production will ramp up rapidly in the coming years. This ramp up is already occurring; 8 million litres of SAF were produced and used globally in 2016, compared to 300 million litres in 2022, and an expected 5 billion litres (4 million tonnes) by 2025.[37] There are also currently 41.6 billion litres (33 million tonnes) under offtake agreements, giving planned plants higher levels of certainty in the future demand for their product.

2.48 Assuming that there is sufficient global SAF production capacity, there are still further risks relating to the UK's ability to access this SAF, given other competing SAF mandate policies in other countries, especially if other countries have higher buy-out prices.

Methodology

2.49 The methodology used to calculate the costs and benefits associated with each of the policy options is described below.

Fuel mix

2.50 The fuel pathways included in the modelling are HEFA, Gasification with Fischer-Tropsch (Biomass to Liquid and Waste to Liquid), Alcohol to Jet, Power to Liquid and

[35] Energy Trends: September 2022, special feature article - Diversity of supply for oil and oil products in OECD countries in 2021 - GOV.UK (www.gov.uk)
[36] ICAO Environment Sustainable Aviation Fuel
[37] IATA Developing Sustainable Aviation Fuel (SAF)

Pyrolysis, as set out in table 3. The feedstocks modelled are used cooking oil (UCO), tallow, municipal solid waste (MSW), forestry residues and direct air capture carbon (DAC). These are the pathways and feedstocks used for analysis purposes but should not be interpreted as an exhaustive list of potential pathways and feedstocks eligible under the mandate. For more details on eligibility see Section 3 'Eligible fuels and sustainability criteria' of the consultation document. Hydrogen and electricity as fuels are not included in the modelling, though the hydrogen and electricity demands as a result of SAF production are captured by the analysis.

Table 3. SAF fuel pathways included in the analysis and their feedstocks

Fuel pathway	Feedstocks
Hydroprocessed Esters and Fatty Acids (HEFA)	Used Cooking Oil (UCO), tallow
Gasification with Fischer-Tropsch (Gas-FT) – Biomass to Liquid (BtL) and Waste to Liquid (WtL)	Forestry residues, Municipal Solid Waste (MSW)
Alcohol to Jet (AtJ)	Forestry residues
Pyrolysis	Forestry residues, MSW
Power to Liquid (PtL)	Direct Air Capture Carbon

2.51 The AIA model calculates the most economic fuel mix in each year to meet the proposed mandate level, given the relative cost-effectiveness of the aviation emissions reductions associated with the use of SAF, and constrained by the assumed availability of feedstocks. We have also incorporated planned production of SAF within the UK, informed by the successful bids received under the Advanced Fuel Fund to date.

Costs

2.52 Using the resulting fuel mix and assumptions on the relative price of SAF and kerosene, the additional cost of SAF due to the assumed change in aviation fuel is calculated, compared to the cost of kerosene plus any carbon price obligation that applies. Competing demands for feedstock have been considered in the SAF feedstock availability assumptions. However, the opportunity cost associated with lower feedstock availability for decarbonisation in other sectors is not quantified.

2.53 When the mandate cannot be met due to a shortfall of feedstocks, we assume that suppliers must pay the buy-out price. The level of the buy-out price must balance setting the price high enough to incentivise suppliers to produce SAF, but not so high that it places undue burden on industry. The central proposed buy-out price option is £2/litre. This value has been reached by taking the pessimistic production cost of the most expensive SAF, minus the cost of kerosene.

2.54 Further detail on the methodology for calculating the buy-out price and the wider range of options being consulted on is included in Section 3, however the £2/litre value is used within this first stage of the analysis, to demonstrate the potential costs faced by suppliers when the mandate is not met. The buy-out is treated as an economic transfer, as it does not involve the consumption of resources. It therefore appears on both sides of the appraisal, as both a cost to business and a benefit to government and does not affect the overall social net present value of the policy.

2.55 Later sections on the HEFA cap and Power to Liquid mandate set out the methodology for calculating the costs associated with each these, and section 6 sets out the combined costs the different policy components. Using the estimates of the additional costs of the mandate to airlines, the expected impacts on ticket prices are calculated, based on the assumption that fuel costs make up around 30% of ticket prices, and that around 75% of the additional costs of SAF will be passed onto the consumer. These are not an additional cost, rather they reflect how the costs of the mandate may be passed through from fuel suppliers onto airlines, and then onto consumers in the form of higher fares.

Benefits

2.56 The main monetised benefits of the SAF mandate are the greenhouse gas savings associated with switching from kerosene to SAF. However, a key assumption underpinning this calculation relates to the extent to which reductions in aviation sector emissions resulting from the use of SAF represent a net reduction in emissions. It can be argued that reductions in emissions from flights in scope of the UK ETS will not lead to a change in total emissions, unless the ETS cap is tightened in parallel, due to what is called the ‘waterbed effect’. This describes how, in the context of a cap-and-trade scheme for emissions (like the UK ETS), any reductions in emissions by one participant leads to offsetting increases in emissions by other participants, with the overall impact that net emissions remain at the level of the cap. This approach is reflected in current DfT Transport Appraisal Guidance (TAG), in line with the former cross government guidance on this issue.

2.57 However, updated cross-government guidance for valuing greenhouse gas savings within the traded sector was published by BEIS in 2021. The updated guidance recommends that any changes in traded sector emissions be treated as net emission changes and valued in the same way as emission reductions elsewhere in the economy, with an appropriate adjustment made for the impact of any trading scheme. There are several arguments for this change:

- The cross-government carbon appraisal values seek to represent the cost of abating the marginal tonne of carbon required to meet our decarbonisation targets, as such it is appropriate to use the same values for all sectors.
- The previous approach failed to sufficiently recognise that additional government action to support decarbonisation may be required alongside any emissions trading scheme.
- The level of future caps in the traded system is not independent of emissions in the sector, therefore any reduction in emissions from the sector may lead to lower cap levels in the future.

2.58 DfT is currently reviewing the treatment of traded emissions within TAG in light of the updated cross-government guidance and plan to publish an update shortly. As a result, both analytical approaches have been tested within the analysis, resulting in a wide range for the monetised benefits of the policy. In results tables, the first approach is referred to as 'DfT TAG' and the second as 'DESNZ', reflecting the respective guidance.

2.59 This range also depends on assumptions as to what extent SAF claimed under the mandate is also claimed by airlines against their obligations under the UK ETS or CORSIA. For the central case of this analysis, it is assumed that the proportions of the SAF claimed under the mandate that are also claimed against UK ETS and CORSIA obligations are equal to the proportions of the total fuel used on UK departing flights on routes in scope of these schemes. A sensitivity test has been performed under which it is assumed that all SAF claimed under the mandate is also claimed by airlines against their obligations under either the UK ETS or CORSIA, given the financial incentive for airlines to use SAF on routes subject to a carbon pricing scheme.

2.60 It can be argued that a similar 'waterbed effect' may also hold for use of feedstocks in a feedstock constrained world. By diverting feedstock from other sectors where it may otherwise have been used, the SAF mandate may simply move emissions reductions around the economy and have no overall impact on net emissions. In the worst case, where feedstock can be used more effectively in other sectors, the SAF mandate could actually have an adverse net impact on the UK's decarbonisation efforts. Our analysis does not currently model alternative uses of feedstocks in the wider economy. We aim to further explore this issue ahead of the final CBA, informed by the forthcoming Biomass Strategy. However, we believe that the range of benefits currently modelled already reflects a potential outcome whereby the SAF mandate does not deliver additional carbon savings.

2.61 Other positive impacts of the mandate have not been monetised in this analysis but are discussed qualitatively in the results section below.

Costs and benefits of the policy

2.62 This section presents the calculated costs and benefits for each of the options. Throughout the document, all costs and disbenefits are presented as negative values, and all benefits and savings as positive values.

Option 0 - Business As Usual

2.63 Options 1-3 are all assessed relative to the counterfactual 'Business As Usual' option, in which costs associated with UK aviation fuel use are estimated to be around £170bn over the period from 2025-2040, or just over £11bn per year on average. Over three quarters of the total costs are fuel costs, with the remaining coming from carbon pricing within the traded sector.

Table 4. Costs under option 0 (BAU)

Costs (£ millions, 2025-2040)	
Fuel costs	-132,402
ETS/CORSIA costs	-36,202
Total costs	**-168,605**

2.64 The baseline costs under the Business As Usual scenario vary significantly when different assumptions are applied, including on jet fuel demand, kerosene prices and carbon prices. The combined impact of these, reflecting the best and worst-case potential costs are presented in table 5. The upper bound reflects a world with high jet fuel demand, high kerosene prices and high ETS/CORSIA prices. The lower bound reflects a world with low jet fuel demand, low kerosene prices and low ETS/CORSIA prices.

Table 5. Sensitivities surrounding costs under option 0 (BAU)

Costs (£ millions, 2025-2040)	*Lower bound*	*Upper bound*
Fuel costs	-81,196	-213,895
ETS/CORSIA costs	-16,437	-107,053
Total costs	**-97,633**	**-320,948**

Options 1-3

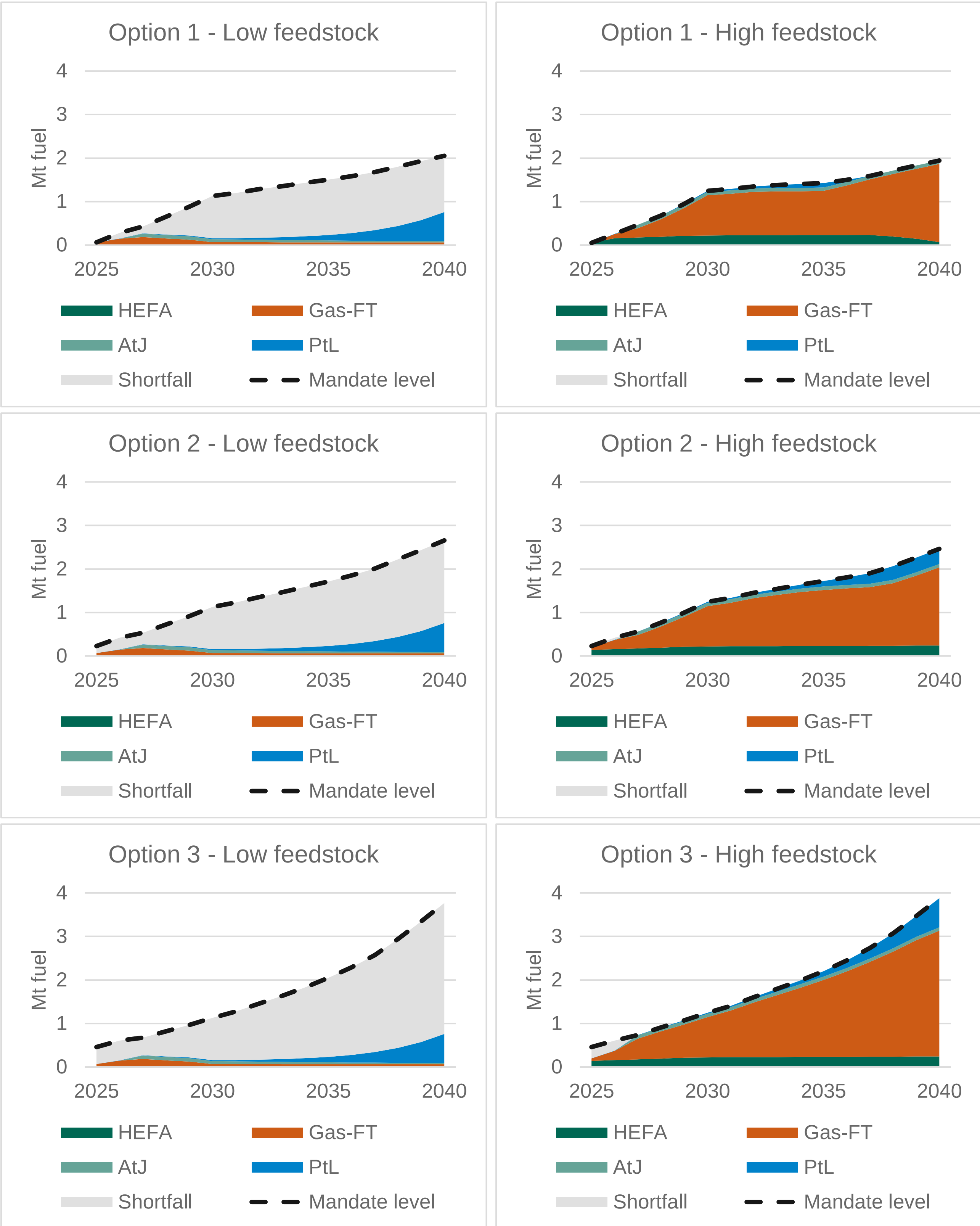
Fuel mix

2.65 Figure 6 sets out the assumed fuel mix for each of the mandate trajectory options, under the low and high feedstock assumptions.[38] The most cost-effective fuel types are prioritised, using the central assumptions on costs and GHG savings. The chosen assumptions on feedstock availability have a significant impact on the assumed fuel mix. Under the low feedstock availability assumptions there is insufficient SAF to meet the mandate in the majority of years, under any of the trajectory options, due to a lack of feedstocks. Power to Liquid use starts to increase from 2035 to meet some of this shortfall, as assumed production capability increases, though it is still limited before 2040. Total shortfall is represented by the light grey wedge of the chart.

2.66 Under the high feedstock availability assumptions there are sufficient feedstocks for the mandate to be met in all years under trajectory options 1 and 2, and there are sufficient forestry residues such that Gas-FT makes up the majority of the fuel mix, with a smaller amount of Power to Liquid needed. Trajectory option 3, which starts at 4% in 2025, is not expected to be achievable in 2025 and 2026 due to a lack of production capacity globally.

[38] The charts in Figure 6 should be interpreted as the assumed fuel mix under a certain set of assumptions, for the purposes of modelling the potential costs and benefits of the policy only. They should not be interpreted as a prescribed fuel mix under the mandate.

Figure 6. Modelled fuel mix for mandate trajectory options 1-3, under low and high feedstock availability assumptions



Costs

2.67 The costs over the baseline for each option are presented in the tables below, for the upper and lower estimates of feedstock availability. All other input assumptions are held at their central value for now, with sensitivities tested on these in the next section.

2.68 As shown in the fuel mix charts above, when the lower bound for feedstock availability is assumed, and even in the high feedstock availability case for the more ambitious trajectories, the trajectory options have points at which the mandate cannot be met. This shortfall is bought out at the buy-out price of £2/litre, the total cost of which is included in the tables below as a cost to business, but also in the benefits tables as a source of revenue for government. Buy-out costs could be significant under the low feedstock availability assumptions. Under Option 3, the most ambitious trajectory, in the low feedstock scenario, on average 75% of the obligated level is assumed to be bought out due to a lack of feedstocks.

2.69 As in the Business As Usual tables, costs are presented as negative values. The change in ETS allowances and CORSIA credits are included as a positive value, illustrating the savings on carbon pricing under the ETS and CORSIA that airlines will make by switching to SAF, despite the increased costs of the SAF itself. These savings are lower in the low feedstock case, as more kerosene is still being used, meaning carbon prices still apply.

Tables 6-8. Additional costs for options 1-3

Option 1

Cost over baseline (£ millions, 2025-2040)	*Low feedstock*	*High feedstock*
Fuel costs	-1,312	-5,982
ETS/CORSIA costs	276	3,246
Buy-out costs to business	-38,001	-
Total costs (undiscounted)	-39,037	-2,736
Total discounted costs	**-28,249**	**-2,308**

Option 2

Cost over baseline (£ millions, 2025-2040)	*Low feedstock*	*High feedstock*
Fuel costs	-1,320	-9,361
ETS/CORSIA costs	277	4,005
Buy-out costs to business	-46,275	-194
Total costs (undiscounted)	-47,318	-5,549
Total discounted costs	**-34,068**	**-4,338**

Option 3

Cost over baseline (£ millions, 2025-2040)	*Low feedstock*	*High feedstock*
Fuel costs	-1,320	-14,899
ETS/CORSIA costs	277	5,701
Buy-out costs to business	-59,915	-1,257
Total costs (undiscounted)	**-60,958**	**-10,456**
Total discounted costs	**-43,495**	**-7,992**

Cost sensitivities

2.70 As discussed, there are significant uncertainties surrounding many of the input assumptions. To illustrate the potential range of outcomes, sensitivities have been tested on option 2. The best- and worst-case costs are presented in Table 9. The upper bound for each reflects a world with low kerosene costs and carbon prices, and pessimistic assumptions on SAF costs, greenhouse gas savings and feedstock use. The lower bound reflects a world with high kerosene costs and carbon prices, and optimistic assumptions on SAF costs, greenhouse gas savings and feedstock use. In the lower bound case, the costs to business are negative overall.

2.71 As mentioned in the section on the costs of Option 0, the Business As Usual costs also change when input assumptions are varied, meaning the costs presented here are additional to a changed baseline, which should be considered when interpreting the results of sensitivity testing.

Table 9. Sensitivity testing on option 2 costs

Cost over baseline (£ millions, 2025-2040)	*Low feedstock*		*High feedstock*	
	Lower bound	Upper bound	Lower bound	Upper bound
Fuel costs	-690	-1,444	2,104	-13,329
ETS/CORSIA costs	1,223	86	8,213	596
Buy-out costs to business	-45,246	-47,899	-	-16,964
Total costs (undiscounted)	-44,713	-49,256	10,317	-29,697
Total discounted costs	**-32,180**	**-35,567**	**7,001**	**-20,766**

Non-monetised costs

2.72 Fuel suppliers, airports and airlines may face additional costs above those quantified here, as a result of complying with the mandate. These could include administration costs, blending costs and transition costs as a result of new infrastructure requirements. Government will also face some administration costs due to implementing the mandate.

2.73 Some initial evidence is available from the RTFO Post Implementation Review published in 2014[39], which used cost data provided by the UK Petroleum Industry Association (UKPIA) and government accounts. This analysis found that the largest proportion of costs resulting from complying with the RTFO were those associated with supplying biofuels, which made up over 80% of total costs. Further costs for suppliers included:

- Investment in infrastructure/facilities for supplying biofuels – estimated to be around £240m for the sector, over the lifetime of the RTFO.
- Blending costs of £3-4/tonne of biofuel.
- Administration costs (including reporting, trading, verification, audit, marketing and general management) – estimated to be in the region of £0.5m/year for each large, obligated company.

2.74 Road fuel retailers also incurred one-off costs associated with the infrastructure for sites to receive biofuel blends, and ongoing costs of maintaining these facilities, including tank cleaning, replacing filters, inspection and testing. Finally, government administration costs were estimated to be in the region of £0.5 - 1.5m/year.

2.75 Overall, these costs have not been quantified for this initial analysis, given the uncertainty in adapting estimates from the RTFO to the aviation sector, and the

[39] Impact assessment: Renewable transport fuel obligation: Post implementation review (publishing.service.gov.uk)

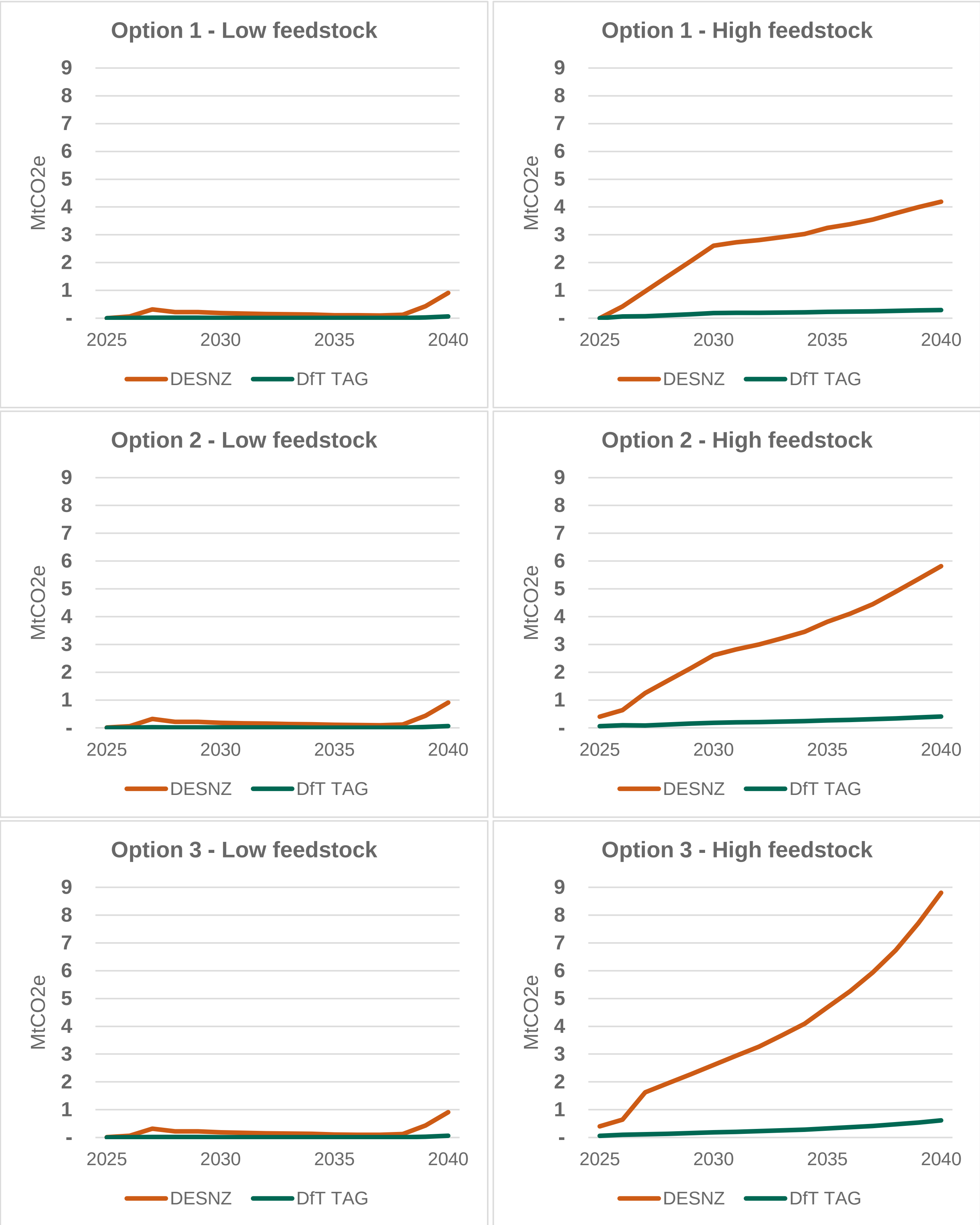
expectation that these costs would be small relative to overall fuel costs. The Department would welcome further evidence from industry on the expected further costs of complying with a mandate.

Benefits

2.76 Under the high feedstock availability assumptions, where there is sufficient feedstock to meet the mandate and assuming that aviation emissions are not offset by emission increases elsewhere in the traded sector (as per the DESNZ guidance), the proposed options all result in an additional 2.6 $MtCO_2e$ of emissions savings in 2030, relative to the ‘Business As Usual’ scenario. By 2040, the proposed options save between 4.2 and 8.6 $MtCO_2e$.

2.77 When applying the lower bound feedstock assumptions, these GHG savings are lower. This is because there is insufficient feedstock to meet the mandate, meaning the associated GHG savings are not achieved. Further, if we assume that emissions savings are offset by increases elsewhere in the traded sector (as per DfT TAG guidance), all options result in substantially lower emissions savings across the economy (less than 1Mt by 2040), as shown in figure 7.

Figure 7. Range of estimated emissions savings associated with mandate trajectory options 1-3, under high and low feedstock availability assumptions and two carbon valuation approaches



2.78 Tables 10-12 show the range of monetised benefits over the baseline for each of the three trajectory options. The ranges are driven by the carbon valuation method assumed. In the DfT TAG approach, only SAF used within the 7% of UK aviation activity that is outside the scope of the traded sector is assumed to result in net additional carbon savings, meaning monetised benefits are low. The DESNZ guidance assumes SAF used within both the traded and non-traded sectors result in net emissions savings. Both approaches use the central DESNZ carbon appraisal values, though for the DESNZ approach, where emissions savings arise from SAF use within the traded sector, the cost of ETS allowances/CORSIA credits is removed from the appraisal value, to avoid double counting. Buy-out costs are included here as a benefit to government, reflecting the economic transfer that takes place.

Tables 10-12 Additional benefits for options 1-3

Option 1

Benefits over baseline (£ millions, 2025-2040)	*Low feedstock*		*High feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Monetised carbon savings	72	818	877	10,022
Buy-out benefit to government	38,001	38,001	-	-
Total benefits (undiscounted)	38,073	38,819	877	10,022
Total discounted benefits	**27,533**	**28,075**	**633**	**7,250**

Option 2

Benefits over baseline (£ millions, 2025-2040)	*Low feedstock*		*High feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Monetised carbon savings	73	821	1,072	12,102
Buy-out benefit to government	46,275	46,275	194	194
Total benefits (undiscounted)	46,348	47,096	1,266	12,296
Total discounted benefits	**33,345**	**33,890**	**962**	**8,883**

Option 3

Benefits over baseline (£ millions, 2025-2040)	*Low feedstock*		*High feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Monetised carbon savings	73	821	1,354	15,288
Buy-out benefit to government	59,915	59,915	1,257	1,257
Total benefits (undiscounted)	59,988	60,736	2,611	16,545
Total discounted benefits	**42,772**	**43,317**	**2,196**	**12,050**

Benefit sensitivities

2.79 Sensitivities have been tested around the carbon saving benefits associated with Option 2. If we assume that all SAF is claimed on routes in scope of the UK ETS or CORSIA, in combination with the DfT TAG approach to valuing greenhouse gas savings, there are no additional monetised carbon benefits under any of the options as a result of the policy, as any changes in emissions occur within the traded sector and are assumed to be offset by increases in emissions elsewhere in the traded sector. Therefore, the lower bound estimate of monetised benefits of the policy is 0 in all cases. This could equally be used to represent a similar outcome whereby the diversion of constrained feedstock resources from other decarbonisation uses across the economy could lead to zero overall net emissions savings, as savings in the aviation sector would be offset by increases elsewhere.

2.80 The upper bound of benefits reflects the DESNZ carbon valuation method in combination with optimistic greenhouse gas saving assumptions and high carbon appraisal values. As buy-out is unchanged, it is excluded from this table.

Table 13. Sensitivity testing on option 2 monetised carbon savings

Benefits over baseline (£ millions, 2025-2040)	*Low feedstock*		*High feedstock*	
	Lower bound	Upper bound	Lower bound	Upper bound
Monetised carbon savings	0	1,614	0	13,026

Non-monetised benefits

2.81 The mandated use of SAF may have wider environmental impacts, other than on CO_2. Though the evidence is less developed and highly uncertain, early research suggests that the non-CO_2 and air quality impacts of flying could also be reduced from switching to SAF (though this is subject to significant scientific uncertainty and impacts will vary across different SAF types). For example, some early studies have suggested that using SAF reduced the size of contrails and the volume of contrail particle formation[40] [41], and the production of soot aerosols[42] [43], compared to jet fuel. Much more evidence is needed in this area to be able to make any claims about the non-CO_2 benefits of a mandate. As part of the Jet Zero Strategy, DfT has committed to improving its understanding of the non-CO_2 impacts of aviation, and the potential for SAF and other decarbonisation measures to mitigate these impacts.

2.82 A further benefit of the mandate is to provide long-term certainty for SAF producers and investors. We expect that this, in combination with further support provided for the domestic SAF industry such as through the Advanced Fuel Fund, will help to support the SAF production in the UK, and in turn provide jobs and GVA benefits to the UK economy. We have not quantified any such impacts in this analysis, due to the fact that the mandate does not specify that any amount of fuel must be produced domestically. However, there are additional jobs being generated and supported through wider support for SAF from the Department, for example through the Advanced Fuels Fund which is estimated to support up to 5,200 jobs.

Other impacts

Feedstock demands

[40] Civil Aviation Alternate Fuels Contrails and Emissions Research (2018) CAAFCER-Contrail-Results-Report_LTR-FRL-2018-0014-CAAFCER.pdf (cbsci.ca)

[41] Cleaner burning aviation fuels can reduce contrail cloudiness (2021) Cleaner burning aviation fuels can reduce contrail cloudiness | Communications Earth & Environment (nature.com)

[42] Speth et al (2015) *Black carbon emissions reductions from combustion of alternative jet fuels* Black carbon emissions reductions from combustion of alternative jet fuels | Request PDF (researchgate.net)

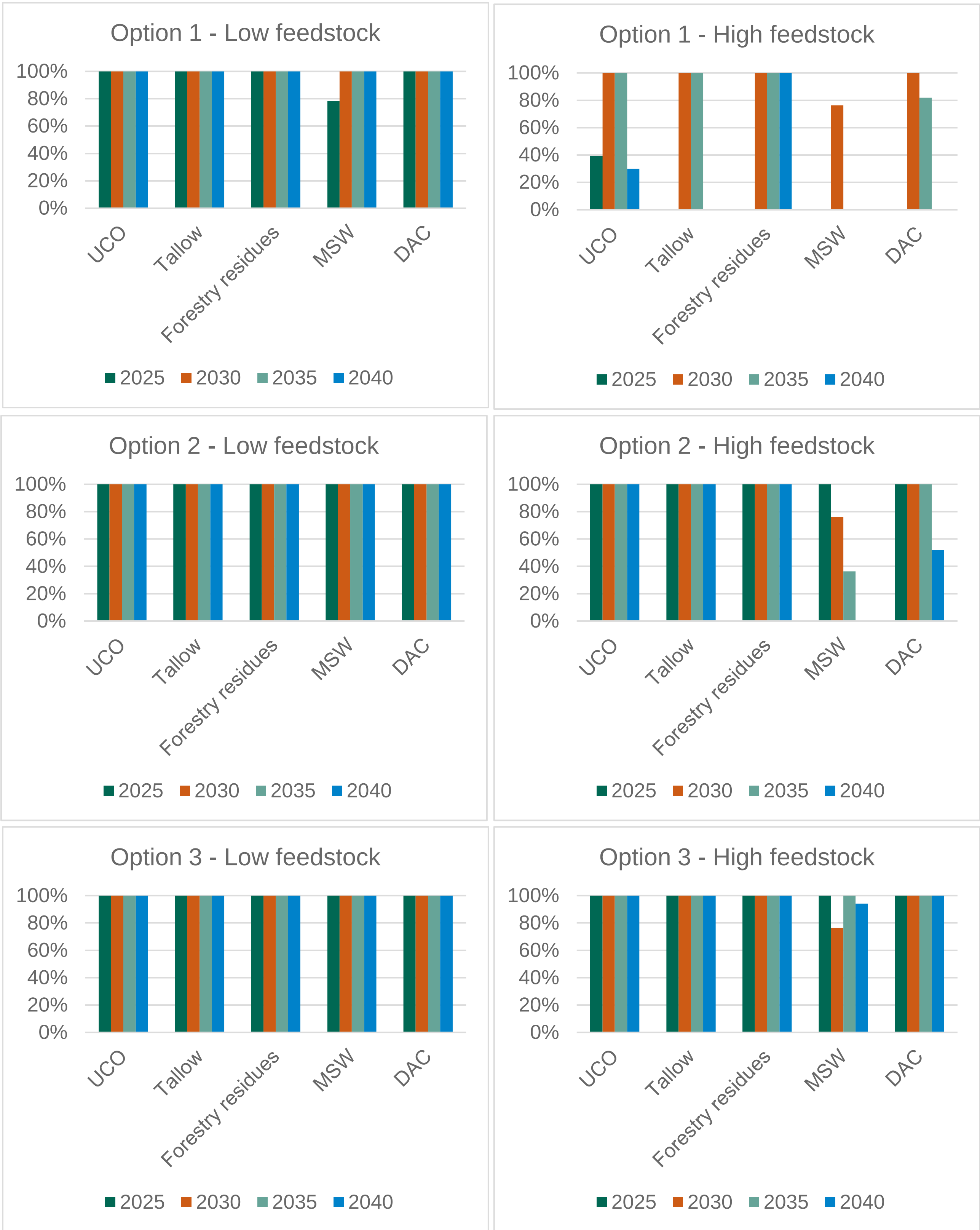
[43] Moore et al (2017) *Biofuel blending reduces particle emissions from aircraft engines at cruise conditions* Moore_et_al_Nature_2017.pdf (dlr.de)

2.83 Figure 8 sets out the share of available feedstocks that are used for options 1-3. Under the lower bound of feedstock availability, all of the feedstock available to UK aviation is assumed to be exhausted in all years for all trajectory options, other than MSW in 2025 under the lowest trajectory. Under the upper bound of feedstock availability, options 1 and 2 do not fully exhaust all of the feedstock available to UK aviation. Option 3, with the highest trajectory, uses 100% of available UCO, tallow, forestry residues and direct air capture carbon in all years.

2.84 The exhaustion of available feedstocks has clear implications for competing uses of feedstock resources across the economy. For example, within the transport sector, the RTFO currently utilises large amount of UCO and tallow refined as biodiesel to meet supplier obligations. Incentivising the use of these feedstocks within aviation rather than the RTFO could lead to an inefficient allocation of resources, given that HEFA is expected to have a higher abatement cost and lower conversion efficiencies than biodiesel, alongside the fact that road transport is not within the traded sector, removing the uncertainties surrounding whether emissions savings are additional. This issue in particular is discussed further in section 4 on a potential HEFA cap.

2.85 Similarly, feedstocks may also be used more cost-effectively in other sectors across the economy, resulting in an opportunity cost associated with the fact that these feedstocks could have been used to deliver emissions savings more efficiently elsewhere. The overall result of this could be a negative net impact on the UK's decarbonisation efforts, due to the diversion of limited resources away from more efficient uses. Although a full energy systems analysis is outside the scope of this appraisal, we will continue to work with DESNZ to further explore the issue of efficient allocation of feedstock resources to SAF production following the publication of the Biomass Strategy, and ahead of the final CBA.

Figure 8. Proportions of available feedstocks used under each trajectory



Electricity and hydrogen demands

2.86 The electricity and hydrogen demands associated with each of the options are shown in figure 9. The uptake varies across the options and feedstock assumptions. Using the upper bound of feedstock availability for option 1 sees electricity demand peak in 2035, and then fall again, reflecting that the amount of Power to Liquid modelled falls, as the mandate can be met by other cheaper fuel pathways.

2.87 In the other scenarios, especially when the lower bound of feedstock assumptions is used, a larger volume of Power to Liquid is needed, and the total electricity demand from SAF is projected to be between 3TWh and 27TWh by 2040. The majority of this additional electricity is used in the running of electrolysers to produce hydrogen. For context, this additional electricity demand is equivalent to between 0.6% and 5.5% of the UK's expected National Grid capacity in 2040 (assumed to be between 490TWh and 580TWh). In addition, electricity used to produce SAF should come from low-carbon sources, therefore, the proportion of SAF utilising low-carbon grid capacity will be greater than the figures presented above.

2.88 However, it is not expected that all of the SAF to meet the mandate will be produced domestically. The UK is estimated to currently import around 61% of its jet fuel[44], though it is unclear how this could change with the transition to SAF. The Advanced Fuel Fund aims to kick-start the domestic SAF industry. However, as the mandate ambition increases over time and greater volumes of SAF are needed, including a larger share of Power to Liquid, it’s likely that an increasing share of SAF will be imported, assuming that there is sufficient SAF production capacity globally to do so.

2.89 It is expected that some international producers of Power to Liquid fuels will have a comparative advantage in producing e-fuels, most specifically large parts of Africa, the Middle East and South America which may alleviate some of these feasibility risks in the long run.[45] However, investment and deployment of these technologies will be required domestically in the short run to meet demand and lower technology risks.

2.90 Despite the uncertainty around imports, domestic SAF production will put significant demands on the UK energy system, especially if the level of ambition of the mandate trajectory continues to ramp up significantly after 2040. For example, the most ambitious possible trajectory, reaching 100% SAF blend by 2050, could require over 300TWh of electricity. Even assuming, for simplicity, that 61% of fuel continues to be imported, this would still mean an additional electricity demand of over 20% of expected 2050 UK grid capacity. If there are higher rates of domestic production of jet fuel than current levels, the additional load on the grid will be even larger.

2.91 There are substantial risks associated with the feasibility of scaling up low-carbon electricity generation capacity to meet these needs, alongside wider demands for electricity as the economy decarbonises which will mean that the system is already delivering near its maximum capacity. Each additional unit of electricity will require additional infrastructure which will ultimately be an additional cost to UK consumers.

---

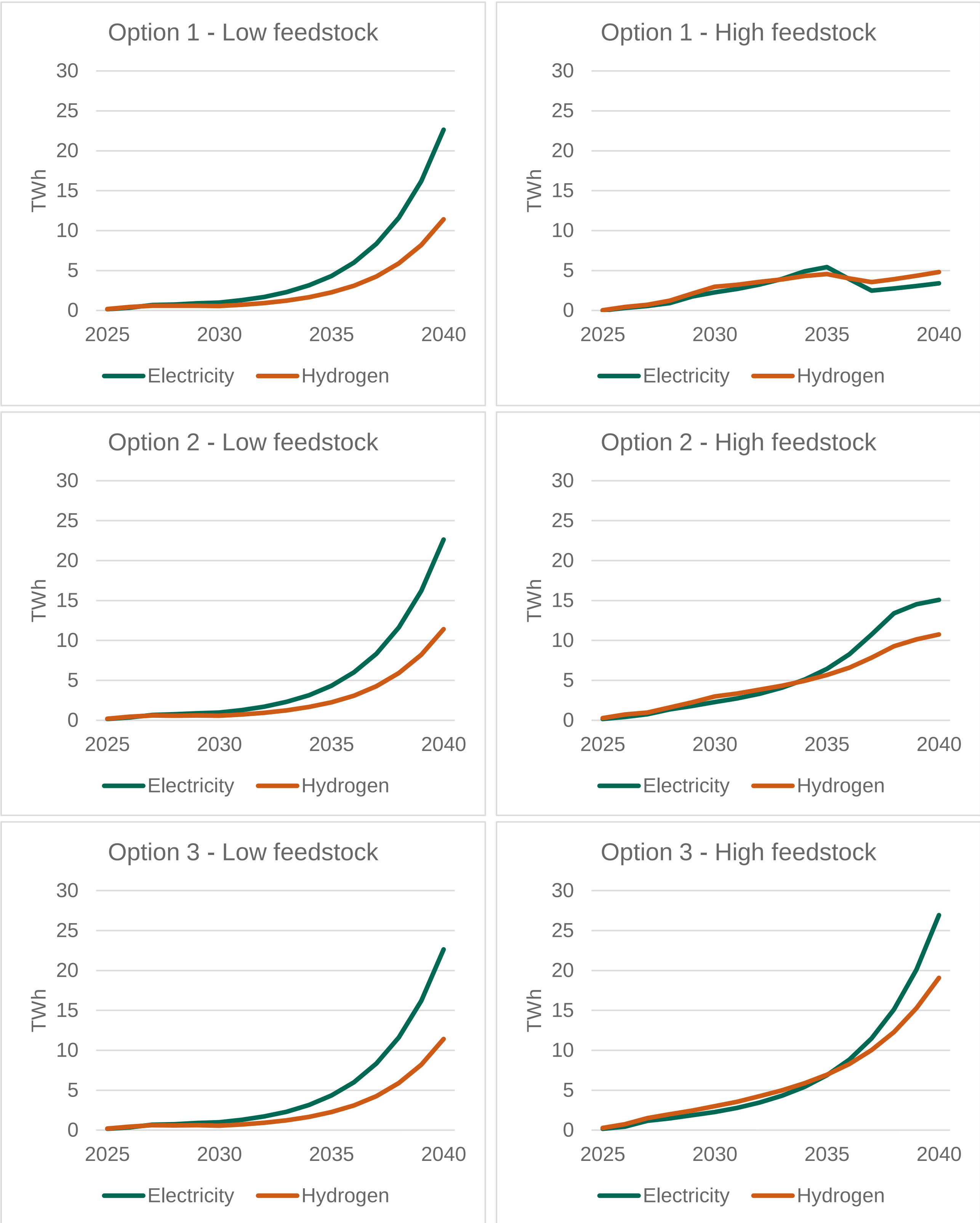
[44] Energy Trends: September 2022, special feature article - Diversity of supply for oil and oil products in OECD countries in 2021 - GOV.UK (www.gov.uk)

[45] Frontier Economics (2018) *Synthetic energy sources - perspectives for the German economy and international trade* efuel alliance: synthetic energy sources 2018

We aim to further explore the potential infrastructure and cost implications on the energy system with colleagues at DESNZ ahead of the final CBA.

2.92 The energy demands modelled here are just those associated with SAF production, and do not take into account any by-products which may also be produced as part of the product slate and used within other sectors. It is also proposed that hydrogen as a direct fuel would be eligible under the mandate, however this has not been included in the analysis. If this option scales up sufficiently and offers a cost-effective alternative for decarbonising aviation, hydrogen demands for use within aviation could be higher than the estimates presented in figure 9.

Figure 9. Hydrogen and electricity demands associated with each trajectory option



Overall results

2.93 The central results of the first part of the appraisal for each of the trajectory options are presented in tables 14-16. Under the DESNZ carbon valuation approach, the NPV ranges from £-178m in the low feedstock availability case, to almost £5 bn in the high feedstock availability case. Using the DfT TAG carbon valuation guidance results in negative NPVs, with a range from £-700m in the low feedstock case to £-6 bn in the high feedstock case.

2.94 The results show that with high feedstock availability the NPVs for all three trajectory options are highly positive using the recently updated DESNZ approach to carbon valuation (ranging from £4.1bn to £4.9bn). The results also show that with high feedstock availability the NPVs are highly negative using the current DfT TAG approach to carbon valuation (ranging from –£1.7bn to –£5.8bn). In the case of low feedstock the NPV is always negative, with values from £-700m to £-200m.

2.95 It should be noted that the NPV using the TAG approach would be significantly higher if the carbon savings from SAF were not claimed by airlines against their ETS or CORSIA obligations. Given the importance of this for the NPV using TAG values, DfT are working with DESNZ to further consider interactions between the SAF mandate and UK ETS and CORSIA. DfT are also currently reviewing the treatment of traded emissions within TAG in light of the updated DESNZ guidance and plan to publish an update shortly. Similarly, we are working to improve our projections of feedstock availability through the DESNZ Biomass strategy and DfT Low Carbon Fuel strategy, and we will update our projections of feedstock availability following these reports. We will reflect the conclusions of both pieces of work in the final CBA.

2.96 Sections 3, 4 and 5 look in further detail at the change in these expected costs and benefits from assuming different buy-out prices and incorporating a HEFA cap and Power to Liquid mandate. Section 6 sets out the overall results of each of these policy elements combined.

Tables 14-16 Overall results for trajectory options 1-3

Trajectory option 1

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Discounted social costs	-28,249	-28,249	-2,308	-2,308
Discounted social benefits	27,533	28,075	633	7,250
Net Present Value	**-716**	**-174**	**-1,675**	**4,942**

Trajectory option 2

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Discounted social costs	-34,068	-34,068	-4,338	-4,338
Discounted social benefits	33,345	33,890	962	8,883
Net Present Value	**-723**	**-178**	**-3,377**	**4,545**

Trajectory option 3

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Discounted social costs	-43,495	-43,495	-7,992	-7,992
Discounted social benefits	42,772	43,317	2,196	12,050
Net Present Value	**-723**	**-178**	**-5,797**	**4,057**

Sensitivity analysis

2.97 The sensitivities tested in the costs and benefits sections above have been combined to provide overall sensitivities surrounding the Net Present Values of option 2.

Table 17. Sensitivities surrounding Option 2

£ millions over baseline	Low *feedstock*		High *feedstock*	
	High costs, low benefits	Low costs, high benefits	High costs, low benefits	Low costs, high benefits
Net Present Value	**-868**	**1,588**	**-8,546**	**16,711**

3. Buy-out

Background

3.1 The SAF mandate will place an obligation on suppliers of aviation fuel to demonstrate that a given proportion of fuel supplied is SAF, in line with trajectories presented in section 2. Suppliers will receive credits for each tonne of SAF supplied. The credits received per tonne will vary based on the GHG abatement each fuel provides relative to a baseline abatement of 70% compared to standard jet kerosene. Suppliers can meet their obligation in three ways:

- Obligation can be met entirely through the supply of SAF.
- Fuel suppliers who exceed their obligation can sell excess credits to those suppliers who do not meet their obligation.
- Suppliers can buy out of their obligation by paying a fixed sum per credit of fuel not supplied.

3.2 The purpose of the buy-out is to provide a mechanism to allow suppliers to fulfil their mandate obligation in a scenario where they are unable to do so through the supply of SAF or purchase of certificates. Setting the buy-out price at the correct level is critical to ensure compliance with the mandate. If the buy-out is set too low, then suppliers may choose to buy-out instead of supplying SAF, reducing emissions savings and compromising the policy aims. If the buy-out is set too high, any supplier unable to meet their obligation through the supply of SAF will face a large cost burden, which would in turn place an undue financial strain on industry and by extension consumers.

Principles

3.3 With the theory explained above in mind, there are three key principles identified which should drive the setting of a SAF buy-out price:

- Setting a buy-out price which ensures cost-effective carbon abatement, incentivising compliance with the mandate and ensuring UK SAF supply from domestic and global SAF markets.
- Ensuring no undue burden on industry, and by extension consumers, because of a buy-out price being set too high and avoiding a suboptimal allocation of feedstock.

- Encouraging research and development in fuel pathways not yet benefitting from economies of scale or learning rates, helping bring through new technologies which may provide greater GHG savings in the long run.

Methodology for setting a buy-out price

3.4 SAF is an emerging market; the technology is still being developed and most planned plants are still in the construction planning stage. In the short run, SAF will not be produced at a level to benefit from economies of scale. By comparison, the incumbent technology, standard jet kerosene, has benefitted from learning rates and is able to exploit economies of scale. SAF will, therefore, carry a cost premium to supply throughout the appraisal period, especially in the short-term. As SAF production increases and benefits from economies of scale this cost difference will decrease.

3.5 To incentivise compliance with the mandate, the minimum buy-out price will need to ensure that it is more expensive for a fuel supplier to simply purchase credits and meet remaining demand with kerosene than it is for a supplier to instead supply their obligated amount of SAF. If a fuel supplier decides not to supply SAF, they will incur the cost of the buy-out plus the cost of jet kerosene needed to meet fuel demand. The buy-out price can therefore be calculated as the cost per credit of the most expensive SAF fuel pathway less the cost to supply kerosene. Using the most expensive fuel pathway will ensure that all SAF fuel suppliers will be fully incentivised to meet the obligation.

3.6 Using the optimistic, mid, and pessimistic input assumptions on production costs and greenhouse gas savings for each SAF fuel pathway taken from the Aviation Impact Accelerator modelling, it is possible to calculate the minimum required buy-out price with the methodology described above.

3.7 A margin can then be applied to this buy-out price to account for price volatility, uncertainty surrounding our input assumptions, and to ensure the scheme incentive is competitive with other similar international schemes. Analysis of price volatility data from Argus Media for jet kerosene and SAF fuels over the past 12 months indicates a margin of 40%-50% would help to account for standard market price fluctuations and ensure that the buy-out price remained an effective incentive.

Key comparators

RTFO

3.8 The Road Transport Fuel Obligation (RTFO) is a useful policy against which to compare the SAF mandate, as an established fuel mix mandate with buy-out prices that industry is already very familiar with. In particular, the RTFO development fuel obligation (dRTFO) which covers more novel sustainable fuels with more comparable production costs to SAF than the more established biofuels available to road transport.

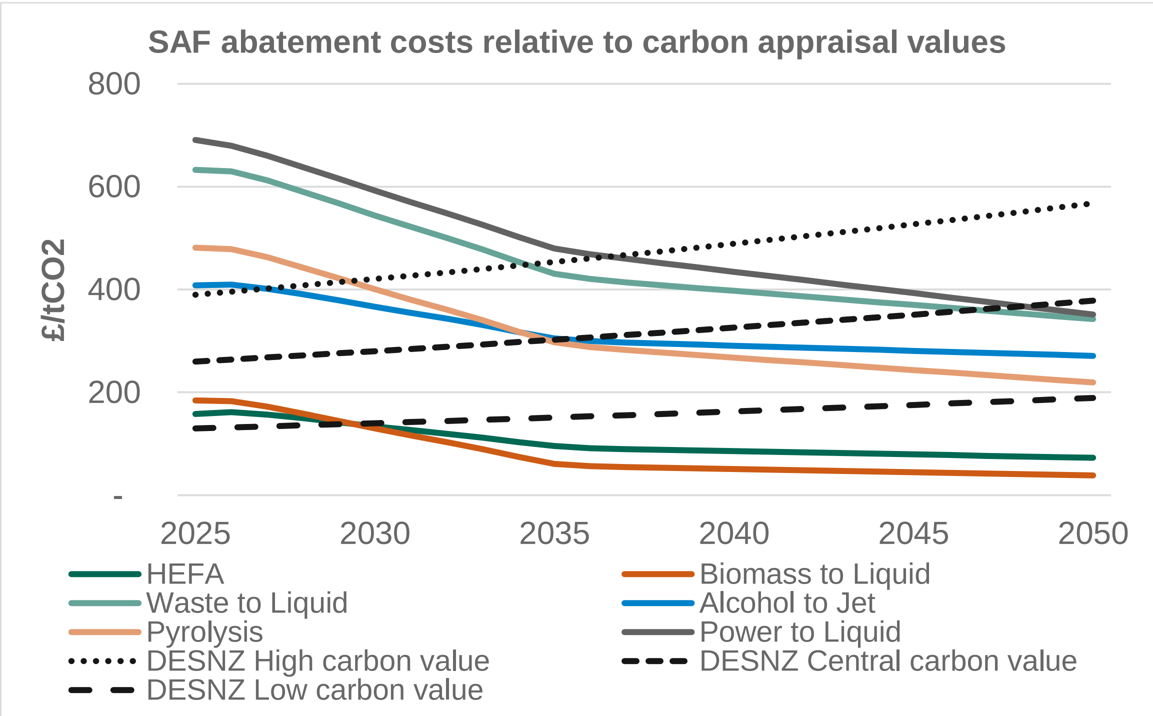
3.9 The dRTFO buy-out cost is £0.80 per litre, but since waste fuels are double rewarded the real incentive is double this buy-out price, £1.60 per litre. The dRTFO buy-out price serves as a sensible minimum buy-out price option for the SAF mandate. It is designed to act as an incentive to produce more expensive road fuels. As aviation fuel is more expensive to produce than road fuel, the SAF mandate will therefore likely require a higher buy-out price.

Social value of carbon

3.10 The carbon appraisal values included within government's Green Book guidance attempt to quantify the social value of carbon abatement. This cost represents the abatement cost of the most expensive measure/technology required to meet the government's climate change targets in any given year. In theory, if the cost of GHG abatement (£/tCO_2e abated) is in line with/less than these social values of carbon then the technology should be adopted. If it is higher, it means the technology does not provide efficient abatement.

3.11 SAF fuels, as noted previously, do not currently benefit from economies of scale and as such they have high production costs. This means that the cost of abatement currently associated with many of the SAF fuel pathways is greater than the DESNZ central carbon appraisal value. Over time, as production costs fall, all SAF fuel pathways are expected to become cost-effective in terms of the abatement they provide, as demonstrated in figure 10. Although the SAF industry does not currently offer cost-effective carbon abatement, buy-out prices must be calculated using current production costs in order to operate as a proper incentive for compliance.

Figure 10. SAF abatement costs relative to DESNZ carbon appraisal values



Options considered

3.12 Given the factors explained above, a range of possible buy-out prices are presented in this consultation, as set out in table 18.

Table 18. Buy-out price options considered

Option	Explanation	£/tonne	£/litre
Low	RTFO development fuel buy-out price	£2,051	£1.60
Medium	Pessimistic production costs	£2,567	£2.00
High	Pessimistic production costs plus margin	£3,846	£3.00

3.13 For simplicity, only one buy-out price option is used to calculate the costs of the buy-out in the appraisal. This is the medium buy-out price preferred option of £2.00 per litre, or £2,657 per tonne. This figure is reached using the methodology explained above of taking our most expensive SAF fuel pathway in terms of cost per abatement less the price of kerosene. The highest possible assumptions of production cost were used as an input to ensure that all fuel pathways will be incentivised for compliance with the mandate.

3.14 The low buy-out price option is the dRTFO buy-out price of £1.60 per litre or £2,051 per tonne. This buy-out price represents the current incentive for suppliers to supply SAF under the RTFO, however, that obligation can be met through the supply of other, often cheaper, development fuels. Therefore, a separate SAF mandate obligating specifically the supply of SAF should have at least the same buy-out price as the dRTFO in order to maintain that minimum incentive to supply.

3.15 The high buy-out price option is calculated by taking the most expensive fuel pathways cost of abatement less the price of kerosene (the recommended buy-out price of £2.00 per litre) and adding a margin of 50% to account for possible price volatility that may occur in the market. This gives a high buy-out price of £3.00 per litre or £3,846.

Impact on costs and benefits of the policy

3.16 The costs and benefits of the mandate trajectory options presented in section 2 included the central proposed buy-out price of £2/litre, to reflect the cost that businesses will face when the mandate is not met. The change in these costs and benefits as a result of assuming the higher and lower buy-out price options set out above are presented in tables 19-20. As before, the buy-out is treated as an economic transfer, meaning it counts towards the cost to business and benefit to government, but there is no impact on social net present value. Negative values represent further costs above those set out in section 2, while positive values represent benefits/savings.

Tables 19-20. Impact on costs and benefits of each trajectory option due to the upper and lower buy-out price options, relative to section 2 (2025-2040)

Low buy-out price (£1.60/litre)

Impact on (£ millions)	*Trajectory Option 1*		*Trajectory Option 2*		*Trajectory Option 3*	
	Low feedstock	High feedstock	Low feedstock	High feedstock	Low feedstock	High feedstock
Fuel costs	0	0	0	0	0	0
ETS/CORSIA costs	0	0	0	0	0	0
Buy-out costs to business	7,600	0	9,255	39	11,983	251
Total cost (undiscounted)	7,600	0	9,255	39	11,983	251
Discounted social costs	**5,496**	**0**	**6,658**	**38**	**8,544**	**247**
Monetised carbon savings	0	0	0	0	0	0
Buy-out benefit to government	-7,600	0	-9,255	-39	-11,983	-251
Total benefits (undiscounted)	-7,600	0	-9,255	-39	-11,983	-251
Discounted social benefits	**-5,496**	**0**	**-6,658**	**-38**	**-8,544**	**-247**
NPV	**0**	**0**	**0**	**0**	**0**	**0**

High buy-out price (£3/litre)

Impact on (£ millions)	*Trajectory Option 1*		*Trajectory Option 2*		*Trajectory Option 3*	
	Low feedstock	High feedstock	Low feedstock	High feedstock	Low feedstock	High feedstock
Fuel costs	0	0	0	0	0	0
ETS/CORSIA costs	0	0	0	0	0	0
Buy-out costs to business	-19,080	0	-23,235	-97	-30,083	-631
Total cost (undiscounted)	-19,080	0	-23,235	-97	-30,083	-631
Discounted social costs	**-13,798**	**0**	**-16,716**	**-95**	**-21,449**	**-621**
Monetised carbon savings	0	0	0	0	0	0
Buy-out benefit to government	19,080	0	23,235	97	30,083	631
Total benefits (undiscounted)	19,080	0	23,235	97	30,083	631
Discounted social benefits	**13,798**	**0**	**16,716**	**95**	**21,449**	**621**
NPV	**0**	**0**	**0**	**0**	**0**	**0**

3.17 For this analysis we are only assuming there is buy-out when there is a lack of feedstocks, otherwise we assume that the mandate is met. If additional suppliers buy out of their obligation, even in the case where there is sufficient feedstock to meet the mandate, then the benefits of the policy will fall. In the worst-case scenario, where 100% of the mandated supply is bought out, the monetised benefits of the policy will fall to 0. Again, while the social costs of the policy would not change, the additional cost to business under a £2/litre buy-out price would be £47bn for Option 1, £55bn for Option 2, and £68bn for Option 3. This represents the maximum possible costs of a mandate to business, under a £2/litre buy-out price. As the BAU costs were expected to be around £170bn, this would represent between a 28-40% increase in costs to industry.

Risks and uncertainties

3.18 As already highlighted, SAF remains a nascent industry with many FOAK production processes and technologies being developed. As such, key data inputs such as production costs associated with SAF production and the GHG abatement associated with each of the SAF pathways remain uncertain and highly variable. Furthermore, it is very difficult to accurately forecast how these inputs may evolve in the future. Feedstock prices and the evolution of other production costs depend on many factors, including uncertainty linked to global conflict and the increased demand for biofuels from other countries as they also decarbonise. There is a risk, therefore, that buy-out prices calculated now may be using data that is subject to significant change, which could mean the chosen buy-out price does not act as the desired incentive.

3.19 The significant uncertainty surrounding feedstock availability also poses difficulties in setting a buy-out cost. If availability of feedstock is closer to our lower bound, then any level mandate will be difficult to meet and a high buy-out price immediately places a significant cost burden on industry, without delivering the desired greenhouse gas savings of the policy. There is therefore a trade-off between setting a low buy-out price, likely resulting in higher levels of buy-out, but keeping the maximum costs to business lower, and setting a high buy-out price, which reduces the incentive to buy-out and delivers the carbon savings but increases the maximum costs of the mandate.

3.20 The Department would welcome any data from industry to improve the evidence base used to calculate the appropriate buy-out price (see consultation call for evidence question 3).

4. HEFA cap

Background

4.1 The SAF mandate will place an obligation on suppliers of aviation fuel to demonstrate that a given proportion of the fuel that they supply is SAF.

4.2 HEFA is currently the cheapest and most developed SAF fuel pathway. As such, it is expected that a large percentage of SAF supplied to meet the mandate in the early years will be HEFA. However, the feedstocks used to create HEFA (primarily UCO and tallow) can be used more efficiently to produce biodiesel and HVO, a key fuel type for difficult-to-decarbonise road transport modes under the RTFO. In 2020 UCO made up 50.5% of all fuel supplied under the RTFO[46] in the form of biodiesel.

4.3 A cap on the amount of HEFA that can be supplied under the mandate is therefore proposed as a key policy design element of the mandate, for the following reasons:

- To ensure sufficient feedstocks remain available for supply of road fuels and are not all diverted away from the RTFO to aviation fuel production.
- To encourage investment and innovation in production of later generation SAF types, such as Power to Liquid, which will be crucial to meeting the mandate in the longer term and have higher associated GHG reductions.
- To avoid the potential issues of using a higher cost fuel for lower or similar levels of carbon savings.

Options considered

4.4 A range of options for a HEFA cap are being considered, the upper and lower bounds of these options are set out in table 21 and described in further detail below.

[46] *Renewable Transport Fuel Obligation Annual Report 2020* Renewable Transport Fuel Obligation Annual Report 2020 - GOV.UK (www.gov.uk)

Table 21. Range of HEFA cap options considered

Option	**Details**
0 – BAU	No HEFA cap, where HEFA is unconstrained.
1 – Lower bound	HEFA cap set at zero therefore allowing no HEFA within the SAF mandate.
2 – Upper bound	HEFA cap set at highest level suggested by expected fuel mix modelling, starting at 140,000 tonnes in 2025

Option 0 - No HEFA cap

4.5 In a scenario with no HEFA cap (i.e., HEFA is unconstrained), it is likely that the SAF mandate will be met largely with HEFA fuel in the first 5-10 years of the scheme, as far as there is sufficient feedstock to do so. HEFA is the most developed of the available SAF fuel pathways and the cheapest to produce.

4.6 This could lead to competition for supply of feedstocks needed to produce HEFA, biodiesel and HVO, resulting in reduced supply of biodiesel and HVO needed to meet the RTFO and reduced GHG savings from the overall transport sector as a result.

Option 1 - Lower bound: HEFA cap set at zero

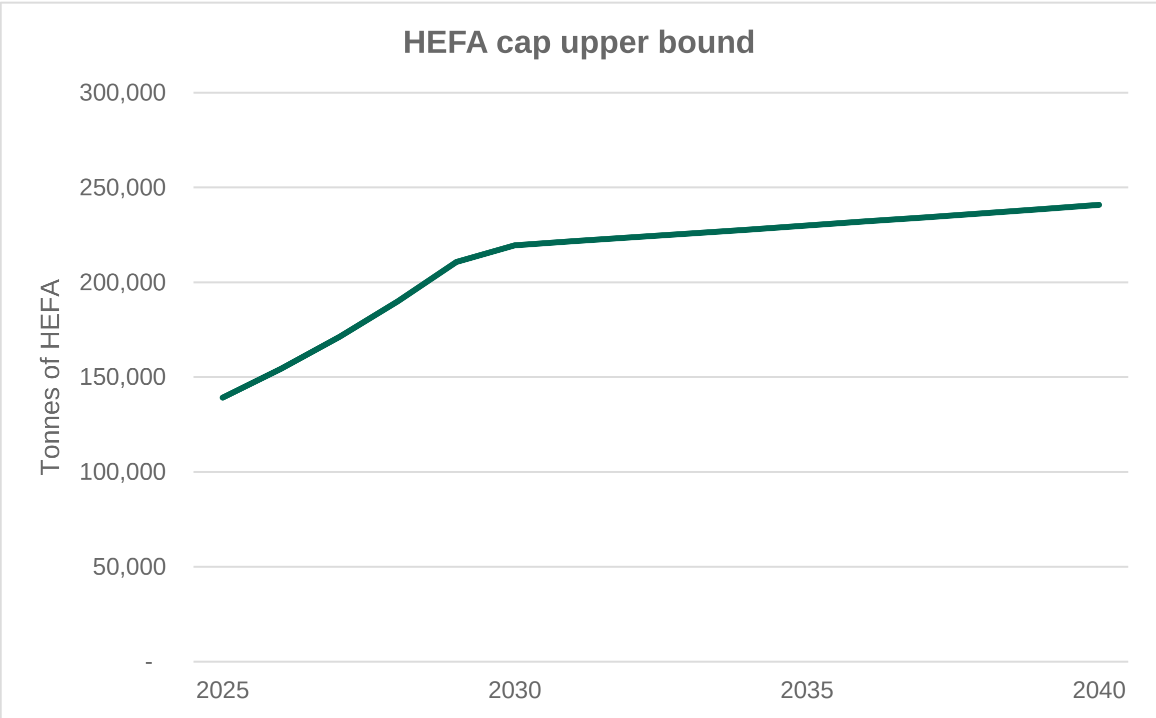
4.7 One potential method for modelling the level of the HEFA cap is to allow demand for UCO and tallow under the RTFO to be met first, and then to allow any remaining to be used within SAF production. Given limited supplies of UCO and tallow in the lower bound feedstock scenario, the modelling suggests that this would lead to a cap set at zero in all years, preventing the use of any HEFA in meeting the SAF mandate obligation.

4.8 This would protect the supply of UCO and tallow as a feedstock for fuels in the RTFO and avoid additional cost burdens placed on road transport, which would arise if feedstocks were diverted from meeting the RTFO to meeting the SAF mandate. However, it would likely place a large cost burden on fuel suppliers attempting to meet the SAF mandate in the early years of the scheme. High levels of buy-out with limited supply of SAF would likely mean a high impact on ticket prices, a large cost burden on industry and consumers with limited GHG savings. As such, this is not considered a desirable policy option. However, given the ambitious SAF mandate trajectories, this represents the lower bound of a potential HEFA cap and is included in this analysis to illustrate what impact this could have on the costs and benefits to the aviation industry of the SAF mandate policy.

Option 2 - Upper bound: HEFA cap set at highest level suggested by expected fuel mix modelling

4.9 The AIA model calculates the most economic fuel mix each year to meet the proposed mandate level, given the relative cost-effectiveness of the emissions reductions associated with the use of SAF, and constrained by the assumed availability of feedstocks. Under the higher feedstock availability assumptions, the modelled use of HEFA is 140,000 tonnes in 2025, increasing to just under 250,000 tonnes by 2040, as shown in Figure 11.

Figure 11. Proposed HEFA cap upper bound (Option 2)



4.10 Setting a HEFA cap at this level would result in a much lower burden to the aviation industry, as substantial volumes of HEFA would be eligible under the mandate. However, by 2030 only around 20% of the SAF supplied to meet the mandate would be able to be HEFA, incentivising investment in other fuel types. This option would still mean significant competition between the RTFO and SAF mandate for the supply of key feedstocks. This level of HEFA cap could allow up to 2,558 GWh of UCO and tallow to be used in aviation in 2025, increasing to around 4,000 GWh in 2030 and 4,400 in 2040.

4.11 Under a scenario with constrained feedstock, these feedstocks would likely be diverted away from potential use in the RTFO. This may cause difficulties for suppliers to also meet their RTFO obligations at the same time as supplying this level of HEFA to the SAF mandate. This could have knock-on implications in the form of increased costs for road users to cover RTFO buy-out and/or lower levels of overall transport carbon savings, which could partially or wholly offset additional carbon savings in the aviation sector. RTFO suppliers may be able to find other routes to meeting their RTFO obligations however, for example by supplying higher levels of bioethanol where there is space below the E10 blend wall or supplying biodiesel from a different feedstock. In this world the potential reduction in carbon savings in the RTFO may not arise.

Preferred option

4.12 A preferred option for a HEFA cap is not presented at this stage, given the uncertainties surrounding the availability of feedstocks and their demand across transport and the wider economy. It is the intention that the preferred option will be between the lower and upper bounds presented here. The analysis therefore aims to capture the range of potential costs and benefits of a HEFA cap.

4.13 Following the publication of the DfT Low Carbon Fuels Strategy and DESNZ Biomass Strategy later this year, we hope to have a clearer evidence base about the availability and most efficient allocation of feedstocks across the economy, which will inform the level of the HEFA cap. The Department would welcome any data from industry to improve the evidence base used to calculate the appropriate HEFA cap level (see consultation call for evidence question 2).

Impact on costs and benefits of the policy

4.14 Tables 22-23 set out the change in the costs and benefits of the trajectory options set out in section 2, due to the inclusion of each of the HEFA cap options. Negative values represent further costs above those set out in section 2, while positive values represent benefits/savings. The change in benefits uses only the DESNZ approach to valuing carbon benefits here, for simplicity. When using the DfT TAG carbon valuation approach, the change in benefits was lower in all cases, so the numbers here reflect the larger impact on the benefits and NPV of the policy.

Tables 22-23. Impact on costs and benefits of each trajectory option due to the upper and lower HEFA cap options, relative to section 2 (2025-2040)

HEFA cap Option 1 - Lower bound cap

Impact on (£ millions)	*Trajectory Option 1*		*Trajectory Option 2*		*Trajectory Option 3*	
	Low feedstock	High feedstock	Low feedstock	High feedstock	Low feedstock	High feedstock
Fuel costs	77	-2,515	85	-2,329	85	320
ETS/CORSIA costs	-13	117	-14	155	-14	-550
Buy-out costs to business	-377	-149	-408	-753	-408	-1,600
Total cost (undiscounted)	-313	-2,547	-337	-2,927	-337	-1,829
Discounted social costs	**-244**	**-1,924**	**-268**	**-2,291**	**-268**	**-1,511**
Monetised carbon savings	-35	-312	-38	-616	-38	-2,098
Buy-out benefit to government	377	149	408	753	408	1,600
Total benefits (undiscounted)	342	-163	370	137	370	-499
Discounted social benefits	**270**	**-123**	**298**	**205**	**298**	**-247**
NPV	**26**	**-2,047**	**30**	**-2,086**	**30**	**-1,758**

HEFA cap Option 2 - Upper bound cap

Impact on (£ millions)	*Trajectory Option 1*		*Trajectory Option 2*		*Trajectory Option 3*	
	Low feedstock	High feedstock	Low feedstock	High feedstock	Low feedstock	High feedstock
Fuel costs	0	0	0	0	0	0
ETS/CORSIA costs	0	0	0	0	0	0
Buy-out costs to business	0	0	0	0	0	0
Total cost (undiscounted)	0	0	0	0	0	0
Discounted social costs	**0**	**0**	**0**	**0**	**0**	**0**
Monetised carbon savings	0	0	0	0	0	0
Buy-out benefit to government	0	0	0	0	0	0
Total benefits (undiscounted)	0	0	0	0	0	0
Discounted social benefits	**0**	**0**	**0**	**0**	**0**	**0**
NPV	**0**	**0**	**0**	**0**	**0**	**0**

4.15 Setting a HEFA cap at 0 (option 1) makes the policy more costly in the high feedstock availability case as HEFA is a cheaper fuel type, therefore limiting its production means it must be replaced by more expensive pathways. In the low feedstock case, there is no available feedstock to replace the HEFA with other fuel types, therefore, rather than leading to additional fuel costs, suppliers must supply kerosene at the lower price. Suppliers must however also pay the buy-out price (here assumed to be the central buy-out price of £2/litre), though this does not count towards the social costs. The benefits are also reduced due to the lower SAF use.

4.16 The upper bound cap option (option 2) imposes no additional costs or benefits on the aviation sector over those outlined in section 2, as the expected HEFA uptake is already either at or below this level across all trajectory options, meaning no change in production is required. A high HEFA cap however poses significant risks of imposing costs on road transport users under low feedstock availability options. Although, these costs are beyond the scope of this analysis at this stage – these costs could be significant.

Risks and uncertainties

4.17 Modelling of the expected fuel mix used to calculate the proposed HEFA cap relies heavily on assumptions of the production costs and greenhouse gas savings associated with each SAF type, along with assumptions on feedstock availability, both to aviation and road transport. The novel nature of these technologies and difficulties in forecasting production costs means that these inputs have a large range and uncertainty associated. Many factors contribute to estimates of total feedstock supply and as such these estimates are inherently uncertain.

5. Power to Liquid mandate

Background

5.1 This consultation is seeking views from stakeholders regarding the inclusion of a mandate to incentivise development of advanced synthetically produced hydrocarbon fuels, such as Power to Liquid. These fuels have the potential for very low lifecycle emissions as they only require low-carbon electricity for hydrogen production and climate neutral CO_2 for production of the fuel. However, these fuels require large amounts of energy to produce and are at a lower technology readiness level than other types of SAF and are therefore more expensive to produce, with further development required to meet a commercial level of production.

5.2 Given the decarbonisation potential of these fuel pathways, the Department wants to ensure suppliers are incentivised towards their further development. A Power to Liquid mandate will therefore require jet fuel suppliers to ensure a fraction of the SAF supplied under the main mandate meets the definition of the fuels that can be supplied under this mandate. This mandate will make up a proportion of the main mandate and have a higher buy-out price; the process behind calculating the potential buy-out price is discussed in sections 5.6-5.7.

5.3 Currently, only the Power to Liquid pathway is currently eligible for this mandate, therefore this analysis focuses on that pathway. However, in time there may be other eligible pathways that meet the requirements of the Power to Liquid mandate.

Options considered

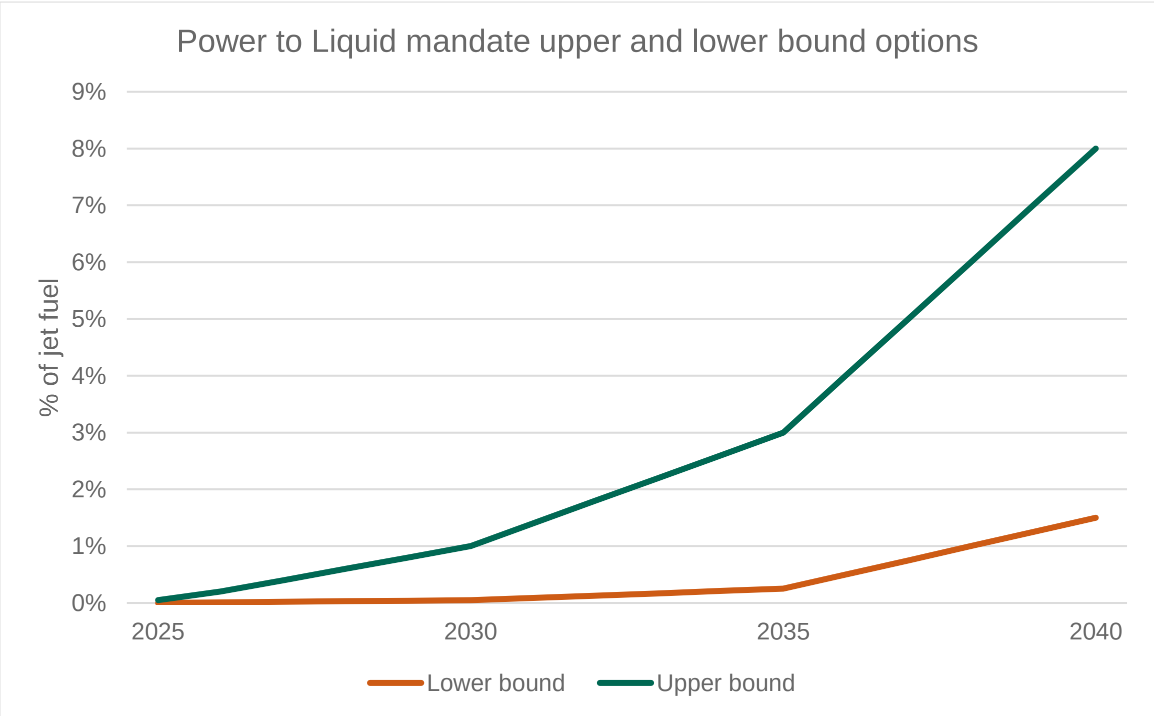
5.4 The upper and lower bound of the range of options considered for a Power to Liquid mandate are set out in table 24, and in figure 12. All options start at 0% in 2025 and mandate an uptake of Power to Liquid that is less than 10% of total jet fuel demand in 2040. A wide range is considered, without a preferred option, to account for the significant uncertainty surrounding what level of Power to Liquid production might be possible, and whether Power to Liquid fuels are the most effective use of hydrogen and electricity across the economy.

5.5 The lower bound is set at a quarter of the maximum uptake of Power to Liquid calculated under the AIA modelling, to reflect a case whereby this level of production rates is not realised, or costs do not fall as expected. The upper bound is higher than the maximum Power to Liquid uptake suggested by our modelling, but loosely aligns with higher ambition as proposed under similar mandates in other countries. There is potential for the level of the Power to Liquid mandate to be increased at one of the future review points, once further evidence is available. The risks around setting a Power to Liquid mandate level now that is too high are set out in section 5.12-5.15.

Table 24. Range of Power to Liquid mandate options

Option	**Details**
0 – BAU	No Power to Liquid mandate.
1 – Lower bound	A Power to Liquid mandate set at a low level, reaching 1.5% of total jet fuel in 2040
2 – Upper bound	A Power to Liquid mandate set at a very high level, reaching 1% of total jet fuel in 2030, increasing to 8% by 2040.

Figure 12. Upper and lower bound Power to Liquid mandate options, as % of UK jet fuel



Power to Liquid mandate buy-out price

5.6 A separate mandate for Power to Liquid fuels requires a separate buy-out price. This is because, as Power to Liquid is a more costly fuel type, a higher buy-out price is needed to incentivise obligation with the Power to Liquid mandate than with the main mandate. The Power to Liquid buy-out price options are set out in table 25 and have been calculated in the same way as the main buy-out price options (see section 3). Only the central buy-out price (£2.75/litre) is used for analysis within this section, for simplicity.

5.7 The Do-Nothing approach would mean that the Power to Liquid mandate was subject to the same buy-out price as the main mandate, with the current recommendation being £2.00 per litre. If the same methodology used to calculate the "Medium" buy-out option of £2.00 per litre were applied to the pessimistic production cost estimates for Power to Liquid fuel pathways, the recommended buy-out price would be £2.75 per litre or £3,525 per tonne. If the margin of 50% is then applied to this buy-out price, the pessimistic production cost plus margin gives a buy-out price of £4.15 per litre or £5,320 per tonne.

Table 25. Range of Power to Liquid buy-out price options considered

Option	Explanation	£/tonne	£/litre
Low	Recommended option for main mandate	£2,567	£2.00
Medium	Pessimistic production costs	£3,525	£2.75
High	Pessimistic production costs plus margin	£5,320	£4.15

Impact on costs and benefits of the policy

5.8 The change in the costs and benefits of the mandate, as outlined in section 2, due to the inclusion of each of the Power to Liquid mandate options is set out in tables 26-27. In our modelling, the Power to Liquid mandate will result in additional costs if the level of the Power to Liquid mandate is set higher than the uptake of Power to Liquid that is expected in the same SAF trajectory without the Power to Liquid mandate. For each SAF trajectory fuel mix in section 2, the uptake of Power to Liquid varies across the options, driven by the variation in feedstock availability assumptions. In the lower feedstock case, where the mandate cannot be met in the majority of years, as much Power to Liquid as possible is produced. Under the high feedstock availability assumptions, for the lower trajectory options, the uptake of Power to Liquid is lower, as there is sufficient feedstock to produce other more cost-effective fuels first.

5.9 When the modelled uptake of Power to Liquid is lower than the mandated level, the shortfall is assumed to be bought out at the central proposed buy-out price of £2.75/litre (£3,525/tonne). This results in additional buy-out costs to business, but also additional benefits to government, meaning there is no overall impact on the social costs and benefits of the policy. In reality, we would expect that the higher buy-out price applied to Power to Liquid fuels would incentivise additional Power to Liquid production to meet the mandate, rather than all being bought out, which would result in additional social costs.

5.10 Tables 26-27 show that, under the low Power to Liquid mandate trajectory, there are no changes in costs in the majority of cases, as the Power to Liquid mandate level is below the expected Power to Liquid uptake without the mandate anyway. The upper bound Power to Liquid mandate trajectory results in additional buy-out costs to business for all main mandate trajectory options, as the Power to Liquid mandate level is higher than the modelled Power to Liquid uptake. For both the upper and lower bound Power to Liquid mandate options, the additional cost to business is highest for main mandate trajectory Option 1. This is because this is the scenario in which the modelled Power to Liquid uptake is lowest, given the mandate trajectory is lowest and there is sufficient feedstock availability for it to be met by more cost-effective SAF types.

Tables 26-27. Impact on costs and benefits of each trajectory option due to the upper and lower Power to Liquid mandate options, relative to section 2 (2025-2040)

Power to Liquid mandate Option 1 – Lower bound

Impact on (£ millions)	*Trajectory Option 1*		*Trajectory Option 2*		*Trajectory Option 3*	
	Low feedstock	High feedstock	Low feedstock	High feedstock	Low feedstock	High feedstock
Fuel costs	0	0	0	0	0	0
ETS/CORSIA costs	0	0	0	0	0	0
Buy-out costs to business	0	-1,937	0	-8	0	0
Total cost (undiscounted)	0	-1,937	0	-8	0	0
Discounted social costs	**0**	**-1,214**	**0**	**-8**	**0**	**0**
Monetised carbon savings	0	0	0	0	0	0
Buy-out benefit to government	0	1,937	0	8	0	0
Total benefits (undiscounted)	0	1,937	0	8	0	0
Discounted social benefits	**0**	**1,214**	**0**	**8**	**0**	**0**
NPV	**0**	**0**	**0**	**0**	**0**	**0**

Power to Liquid mandate Option 2 – Upper bound

Impact on (£ millions)	*Trajectory Option 1*		*Trajectory Option 2*		*Trajectory Option 3*	
	Low feedstock	High feedstock	Low feedstock	High feedstock	Low feedstock	High feedstock
Fuel costs	0	0	0	0	0	0
ETS/CORSIA costs	0	0	0	0	0	0
Buy-out costs to business	-10,204	-16,912	-10,204	-11,943	-10,204	-10,204
Total cost (undiscounted)	-10,204	-16,912	-10,204	-11,943	-10,204	-10,204
Discounted social costs	**-7,166**	**-11,384**	**-7,166**	**-8,226**	**-7,166**	**-7,166**
Monetised carbon savings	0	0	0	0	0	0
Buy-out benefit to government	-10,204	-16,912	-10,204	-11,943	-10,204	-10,204
Total benefits (undiscounted)	-10,204	-16,912	-10,204	-11,943	-10,204	-10,204
Discounted social benefits	**-7,166**	**-11,384**	**-7,166**	**-8,226**	**-7,166**	**-7,166**
NPV	**0**	**0**	**0**	**0**	**0**	**0**

Non-monetised costs and benefits

5.11 The inclusion of a Power to Liquid mandate could potentially bring significant further benefits to the UK which are currently non-monetised. By including a mandate which will effectively incentivise further investment in these more novel fuel pathways, it is hoped that the UK will benefit in the long run from increased research and development funding, which generates jobs and spill-over investments. Further, increased funding today should result in cost reductions and production efficiencies being implemented more quickly, ultimately leading to lower costs in the long run. The scale-up of Power to Liquid could also accelerate the early scale-up of other technologies such as carbon capture and hydrogen production, both of which are inputs to Power to Liquid production and will be needed for future decarbonisation of aviation and other sectors.

Risks and uncertainties

5.12 There are several considerations to be made regarding the level of the Power to Liquid mandate including technological and commercial readiness, availability of renewable electricity and hydrogen, and the additional costs of the mandate if targets are not met.

5.13 Power to Liquid is currently the only fuel pathway eligible for this mandate and is itself at the very early stages of technology development. Other potential future novel fuels are even less developed. There is therefore large uncertainty around the market's readiness to meet a high Power to Liquid mandate level in the short-term. Setting an overly ambitious Power to Liquid mandate now could ultimately lead to high levels of buy-out, if the market is not sufficiently developed in time, increasing costs to business and passengers.

5.14 In addition, there will be limited amounts of low-carbon hydrogen and electricity available in the UK, which will impact the availability of domestically produced Power to Liquid. Power to Liquid is a very energy-intensive fuel and the electricity grid in the UK would need significant expansion to meet SAF demand entirely through domestic production, alongside meeting the energy demands associated with the decarbonisation of other sectors in the UK. Further, there will be limited access to low-carbon hydrogen and direct air capture carbon required for the production of Power to Liquid in the short run, which also has competing uses across the economy. The estimated electricity and hydrogen demands of the mandate options are set out in section 2, though, as explained in this section, not all of this electricity and hydrogen must be produced domestically as we expect part of the mandate to be met by imports.

5.15 As such, the Department has proposed Power to Liquid mandate options which are currently set at a relatively low share of total fuel, with the expectation of increasing the level in the future. This has been done to minimise the potential risks discussed above and to limit the additional costs to industry. Further, this approach gives the Department and industry time to fully consider all potential advanced fuel options, whilst still providing an incentive to develop these fuel pathways in the meantime. The Department will continue to build its evidence base for these pathways and will review the level of the Power to Liquid mandate periodically.

6. Combined impact of policy options

Costs and benefits of the policy

6.1 In this section the costs and benefits of the various policy elements from the sections above are combined, to show the overall impact of the proposed SAF mandate.

6.2 The costs and benefits presented in tables 28-36 are all assessed relative to the BAU (Option 0), as set out in section 2. The costs and benefits of a mandate with the central buy-out price, no HEFA cap and no Power to Liquid mandate are the same as those set out in section 2 but are included here again for completeness.

Tables 28-36. Overall results

Mandate trajectory 1 with central buy-out price, no HEFA cap or Power to Liquid mandate

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Fuel costs	-1,312	-1,312	-5,982	-5,982
ETS/CORSIA costs	276	276	3,246	3,246
Buy-out costs to business	-38,001	-38,001	0	0
Total costs (undiscounted)	-39,037	-39,037	-2,736	-2,736
Monetised carbon savings	72	818	877	10,022
Buy-out benefit to government	38,001	38,001	0	0
Total benefits (undiscounted)	38,073	38,819	877	10,022
Discounted social costs	**-28,249**	**-28,249**	**-2,308**	**-2,308**
Discounted social benefits	**27,533**	**28,075**	**633**	**7,250**
Net Present Value	**-716**	**-174**	**-1,675**	**4,942**

Mandate trajectory 2 with central buy-out price, no HEFA cap or Power to Liquid mandate

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Fuel costs	-1,320	-1,320	-9,361	-9,361
ETS/CORSIA costs	277	277	4,005	4,005
Buy-out costs to business	-46,275	-46,275	-194	-194
Total costs (undiscounted)	-47,318	-47,318	-5,549	-5,549
Monetised carbon savings	73	821	1,072	12,102
Buy-out benefit to government	46,275	46,275	194	194
Total benefits (undiscounted)	46,348	47,096	1,266	12,296
Discounted social costs	**-34,068**	**-34,068**	**-4,338**	**-4,338**
Discounted social benefits	**33,345**	**33,890**	**962**	**8,883**
Net Present Value	**-723**	**-178**	**-3,377**	**4,545**

Mandate trajectory 3 with central buy-out price, no HEFA cap or Power to Liquid mandate

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Fuel costs	-1,320	-1,320	-14,899	-14,899
ETS/CORSIA costs	277	277	5,701	5,701
Buy-out costs to business	-59,915	-59,915	-1,257	-1,257
Total costs (undiscounted)	-60,958	-60,958	-10,456	-10,456
Monetised carbon savings	73	821	1,354	15,288
Buy-out benefit to government	59,915	59,915	1,257	1,257
Total benefits (undiscounted)	59,988	60,736	2,611	16,545
Discounted social costs	**-43,495**	**-43,495**	**-7,992**	**-7,992**
Discounted social benefits	**42,772**	**43,317**	**2,196**	**12,050**
Net Present Value	**-723**	**-178**	**-5,797**	**4,057**

Mandate trajectory 1 with central buy-out price, upper bound HEFA cap (option 2), and lower bound Power to Liquid mandate (option 1)

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Fuel costs	-1,312	-1,312	-5,982	-5,982
ETS/CORSIA costs	276	276	3,246	3,246
Buy-out costs to business	-38,001	-38,001	-1,937	-1,937
Total costs (undiscounted)	-39,037	-39,037	-4,673	-4,673
Monetised carbon savings	72	818	877	10,022
Buy-out benefit to government	38,001	38,001	1,937	1,937
Total benefits (undiscounted)	38,073	38,819	2,814	11,959
Discounted social costs	**-28,249**	**-28,249**	**-3,523**	**-3,523**
Discounted social benefits	**27,533**	**28,075**	**1,848**	**8,464**
Net Present Value	**-716**	**-174**	**-1,675**	**4,942**

Mandate trajectory 2 with central buy-out price, upper bound HEFA cap (option 2), and lower bound Power to Liquid mandate (option 1)

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Fuel costs	-1,320	-1,320	-9,361	-9,361
ETS/CORSIA costs	277	277	4,005	4,005
Buy-out costs to business	-46,275	-46,275	-202	-202
Total costs (undiscounted)	-47,318	-47,318	-5,558	-5,558
Monetised carbon savings	73	821	1,072	12,102
Buy-out benefit to government	46,275	46,275	202	202
Total benefits (undiscounted)	46,348	47,096	1,274	12,304
Discounted social costs	**-34,068**	**-34,068**	**-4,346**	**-4,346**
Discounted social benefits	**33,345**	**33,890**	**969**	**8,891**
Net Present Value	**-723**	**-178**	**-3,377**	**4,545**

Mandate trajectory 3 with central buy-out price, upper bound HEFA cap (option 2), and lower bound Power to Liquid mandate (option 1)

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Fuel costs	-1,320	-1,320	-14,899	-14,899
ETS/CORSIA costs	277	277	5,701	5,701
Buy-out costs to business	-59,915	-59,915	-1,257	-1,257
Total costs (undiscounted)	-60,958	-60,958	-10,456	-10,456
Monetised carbon savings	73	821	1,354	15,288
Buy-out benefit to government	59,915	59,915	1,257	1,257
Total benefits (undiscounted)	59,988	60,736	2,611	16,545
Discounted social costs	**-43,495**	**-43,495**	**-7,992**	**-7,992**
Discounted social benefits	**42,772**	**43,317**	**2,196**	**12,050**
Net Present Value	**-723**	**-178**	**-5,797**	**4,057**

Mandate trajectory 1 with central buy-out price, lower bound HEFA cap (option 1), and upper bound Power to Liquid mandate (option 2)

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Fuel costs	-1,235	-1,235	-8,497	-8,497
ETS/CORSIA costs	264	264	3,363	3,363
Buy-out costs to business	-48,582	-48,582	-14,278	-14,278
Total costs (undiscounted)	-49,553	-49,553	-19,411	-19,411
Monetised carbon savings	68	783	846	9,709
Buy-out benefit to government	48,582	48,582	14,278	14,278
Total benefits (undiscounted)	48,650	49,365	15,123	23,987
Discounted social costs	**-35,659**	**-35,659**	**-13,793**	**-13,793**
Discounted social benefits	**34,993**	**35,511**	**10,311**	**16,688**
Net Present Value	**-666**	**-148**	**-3,482**	**2,895**

Mandate trajectory 2 with central buy-out price, lower bound HEFA cap (option 1), and upper bound Power to Liquid mandate (option 2)

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Fuel costs	-1,235	-1,235	-11,690	-11,690
ETS/CORSIA costs	264	264	4,160	4,160
Buy-out costs to business	-56,887	-56,887	-11,466	-11,466
Total costs (undiscounted)	-57,859	-57,859	-18,995	-18,995
Monetised carbon savings	68	783	1,003	11,486
Buy-out benefit to government	56,887	56,887	11,466	11,466
Total benefits (undiscounted)	56,955	57,670	12,469	22,951
Discounted social costs	**-41,502**	**-41,502**	**-13,983**	**-13,983**
Discounted social benefits	**40,835**	**41,353**	**8,994**	**16,442**
Net Present Value	**-666**	**-148**	**-4,989**	**2,459**

Mandate trajectory 3 with central buy-out price, lower bound HEFA cap (option 1), and upper bound Power to Liquid mandate (option 2)

£ millions over baseline	Low *feedstock*		High *feedstock*	
	DfT TAG	DESNZ	DfT TAG	DESNZ
Fuel costs	-1,235	-1,235	-14,579	-14,579
ETS/CORSIA costs	264	264	5,151	5,151
Buy-out costs to business	-70,527	-70,527	-13,060	-13,060
Total costs (undiscounted)	-71,499	-71,499	-22,489	-22,489
Monetised carbon savings	68	783	1,156	13,190
Buy-out benefit to government	70,527	70,527	13,060	13,060
Total benefits (undiscounted)	70,595	71,310	14,216	26,250
Discounted social costs	**-50,928**	**-50,928**	**-16,669**	**-16,669**
Discounted social benefits	**50,262**	**50,780**	**10,525**	**18,969**
Net Present Value	**-666**	**-148**	**-6,144**	**2,300**

Ticket price impacts

6.3 We expect that airlines will pass at least some of the changes to their operating costs as a result of purchasing SAF to consumers, in the form of increased ticket prices. These are not an additional cost to those outlined in the section above, rather they reflect how these costs may be passed on. The methodology for calculating ticket price impacts is included in annex 7.4.

6.4 The average one-way ticket price under the Business As Usual scenario is expected to be £173 in 2030 and £183 in 2040, based on data from DfT's aviation model. Using the costs to business presented in tables 28-36, our indicative analysis suggests that under high feedstock availability assumptions, the three trajectory options could increase the average one-way ticket price by £1.90 - £3.30 (1.1-1.9%) in 2030 and by £0-£9.50 (0-5.2%) in 2040. Under low feedstock availability assumptions, our analysis suggests this increase could be £9.30-£10.70 (5.4-6.2%) in 2030 and £10.60-£26.50 (5.8-14.5%) in 2040.

6.5 The actual ticket price impacts of the SAF mandate policy will depend in part on the options chosen relating to the trajectory, buy-out price, HEFA cap and Power to Liquid target. As this consultation does not set out a preferred option on these elements, we are not able to set out central estimates of the ticket price impacts at this stage but hope to do so alongside the government response to the consultation. Impact on ticket prices will be an important factor when making final decisions about the SAF mandate. The government intends to ensure that the introduction of the mandate does not result in significant impacts on air fares and is therefore unlikely to retain a very high mandate trajectory in the case of low feedstock availability. As such, the impact on ticket prices is not expected to be at the upper end of the range presented above.

7. Annexes

Annex 7.1. Methodology behind illustrative ETS and CORSIA price series

7.1 These assumptions, taken from Annex B of the Jet Zero further technical consultation[47], are designed to illustrate the potential range of carbon prices faced by airline operators in future for use in scenario analysis. The assumptions do not represent the UK Government's view on the most likely evolution of market prices under any carbon pricing mechanism.

ETS Price Assumptions	Rationale
Low – The 2021 value is based on the average UK ETS auction clearing price for May 2021 to October 2021. We assume a rough anchor point of £71/t in 2030 based on ICIS projections[48] which implies ~4.5% annual growth to 2030. From 2030 onwards we assume an annual growth rate of 1.5% (this is the same as the annual growth rate assumed in the revised approach to valuing greenhouse gas emissions in policy appraisal published by DESNZ in September 2021[49]).	This methodology aims to reflect a scenario in which carbon prices under a UK ETS scheme remain relatively low. This series implies there is no global market-based mechanism with a net zero consistent target by 2050.
Mid - The 2021 value is based on the average UK ETS auction clearing price for May 2021 to October 2021. We then interpolate linearly to the DESNZ central appraisal carbon value by 2050.	This methodology is based on that underpinning the previous DESNZ traded sector appraisal series historically used in our aviation model. This methodology reflects both the current prices faced by operators and the introduction of a global market-based mechanism with a Paris Agreement-consistent goal by 2050.
High - The 2021 value is based on an average UK ETS auction clearing price for May 2021 to October 2021. We then interpolate linearly to the DESNZ high appraisal carbon value in 2040. The	This methodology is also based on that underpinning the previous DESNZ traded sector appraisal series historically used in our aviation model. This methodology reflects both the current prices faced by operators and the introduction of a global market-

[47] DfT (March 2022) *Jet Zero: Further Technical Consultation* Jet zero: further technical consultation (publishing.service.gov.uk)

[48] ICIS (May 2021) *Insight: UK carbon trading system launch* https://www.icis.com/explore/resources/news/2021/05/14/10640017/insight-uk-carbon-trading-system-launch.

[49] BEIS (2021) *Valuation of greenhouse gas emissions: for policy appraisal and evaluation* https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation

series follows the DESNZ high appraisal carbon value series thereafter.	based mechanism with a Paris Agreement-consistent goal being in place by 2040.

CORSIA Price Assumptions	Rationale
Low - based on CAEP ICAO post-COVID modelling for 2021 – 2026.[50] The same growth rate of 9.5% per year is then applied consistently thereafter.	This methodology aims to reflect a scenario in which carbon prices under CORSIA (or a similar international scheme post 2035) remain relatively low. This series implies the scheme continues beyond its current 2035 endpoint but is not adjusted or replaced to converge with a Paris Agreement consistent emission reduction goal by 2050.
Mid - based on CAEP ICAO post-COVID modelling for 2021 – 2026. The same growth rate of 9.5% per year is then applied consistently until 2035. After 2035 we linearly interpolate up to the DESNZ central appraisal value in 2050.	This methodology aims to reflect a scenario in which CORSIA continues as designed until its current end point in 2035 and thereafter it is adjusted or replaced such that carbon prices converge with the DESNZ central appraisal value by 2050.
High - based on CAEP ICAO post-COVID modelling for 2021 – 2026. The same growth rate of 9.5% per year is then applied consistently until 2035. After 2030 we linearly interpolate up to the DESNZ central appraisal value in 2050.	This methodology aims to reflect an ambitious scenario in which CORSIA continues in its current design until 2030 and is then adjusted or replaced such that carbon prices grow to meet the DESNZ high appraisal values by 2050.

Annex 7.2. SAF production cost assumptions used in analysis

Production cost (£/tonne)

		2022			2035			2050		
Fuel Route	**Feedstock**	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**
HEFA	Used Cooking Oil	906	1112	1309	866	1044	1231	817	985	1152
	Tallow	906	1112	1309	866	1044	1231	817	985	1152
Biomass to Liquid	Forestry Residues	1103	1211	1319	855	925	995	809	873	936
Waste to Liquid	Municipal Solid Waste	1477	1821	2166	1280	1526	1772	1181	1378	1575
Alcohol to Jet	Forestry Residues	1682	1831	2069	1472	1556	1655	1395	1477	1567
Pyrolysis	Forestry Residues	1112	1211	1368	876	925	985	828	876	930
	Municipal Solid Waste	1718	1871	2113	1491	1575	1676	1302	1378	1463
Power to Liquid	DAC (wind)	1396	3002	4607	1215	2242	3269	912	1957	3003
	DAC (nuclear)	1969	2954	4923	1674	2264	3741	1280	1871	3150

[50] International Civil Aviation Organisation (2021) *Update to Scenario Based Analyses of Potential Impacts of Covid19 on CORSIA Organization* https://www.icao.int/environmental-protection/CORSIA/Documents/CAEP_Update%20COVID-19%20impact%20analyses.pdf

Annex 7.3. SAF GHG saving assumptions used in analysis

Change in lifecycle GHG intensity, relative to kerosene

		2022			2035			2050		
Fuel Route	**Feedstock**	**High**	**Mid**	**Low**	**High**	**Mid**	**Low**	**High**	**Mid**	**Low**
HEFA	Used Cooking Oil	-84%	-80%	-75%	-84%	-80%	-75%	-84%	-80%	-84%
	Tallow	-84%	-80%	-75%	-84%	-80%	-75%	-84%	-80%	-84%
Biomass to Liquid	Forestry Residues	-122%	-75%	-28%	-122%	-75%	-28%	-122%	-75%	-122%
Waste to Liquid	Municipal Solid Waste	-91%	-47%	-3%	-91%	-47%	-3%	-91%	-47%	-91%
Alcohol to Jet	Forestry Residues	-84%	-75%	-53%	-84%	-69%	-53%	-84%	-69%	-84%
Pyrolysis	Forestry Residues	-116%	-69%	-22%	-116%	-69%	-22%	-116%	-69%	-116%
	Municipal Solid Waste	-84%	-41%	3%	-84%	-41%	3%	-84%	-41%	-84%
Power to Liquid	DAC (wind)	-94%	-82%	-69%	-94%	-82%	-69%	-94%	-82%	-94%
	DAC (nuclear)	-94%	-91%	-88%	-94%	-91%	-88%	-94%	-91%	-94%

Annex 7.4. Ticket price impact methodology

7.2 Evidence from DfT's aviation model suggests that fuel costs make up 22% of ticket prices on average, and carbon costs a further 6%. These figures vary with market and route length, among other factors. Routes within the UK and Europe are currently subject to higher carbon costs than routes to outside Europe, so carbon costs make up a greater share of ticket prices, whereas the share of fuel costs are higher for long-haul routes, given the larger volume of fuel needed.

7.3 In perfectly competitive markets, we would expect airlines to pass through 100% of additional costs to customers. With markets not characterised by perfect competition, the rate of passthrough depends on several factors, including the level of competition, the profitability of the route, the length of the route, and consumers responsiveness to price increases. One factor found to be very important in determining passthrough is airport capacity constraints.[51] If an airport is operating at full capacity, airlines could be making supernormal profits. If operating costs then increase, the airline may still be able to profitably supply the same capacity as before, until the point that marginal costs rise enough to reduce route-level supernormal profits to zero. Capacity constraints therefore reduce the extent to which airlines are likely to pass through carbon costs to air fares.

[51] Dray, L., Doyme, K., & Schäfer A.W., 2020. *Airline profit maximisation, cost passthrough, and scarcity rents in capacity-constrained aviation systems*, Journal of Transport Economics and Policy, 54(4), 244-266

7.4 There is therefore significant variation in the potential for airlines to pass costs on to customers. The literature suggests a wide range of passthrough rates, ranging from 0% at congested airports to 100% at non-congested airports. Research by the ICF et al. estimates average passthrough rates of around 74% for intra-EEA flights, and 77% for other routes.[52] Research into the impact of carbon pricing on aviation by Frontier Economics claims that 65-80% of airline operating costs tend to be passed onto passengers.[53]

7.5 For the ticket price estimates included in section 6.4, we use an average assumption that fuel and carbon costs comprise around 30% of fares, and a medium cost passthrough assumption of 75%. Estimated Business As Usual ticket prices are taken from DfT's aviation model. The lower bound of the range of impacts reflects the option with the lowest cost to business (trajectory option 1, with HEFA cap option 2 and PtL mandate option 1), the upper bound of the range reflects the option with the highest cost to business (trajectory option 3, with HEFA cap option 1 and PtL mandate option 2). We assume for simplicity that all costs faced by fuel suppliers are passed on to airlines. We have not considered any secondary impacts of these ticket price changes on aviation demand for this analysis but hope to do so as part of the final cost benefit analysis.

---

[52] ICF, ATA, Cambridge Econometrics, HFW, NewClimate, & Starcx, S., 2020. *Assessment of ICAO's global market-based measure (CORSIA) pursuant to Article 28b and for studying cost passthrough pursuant to Article 3d of the EU ETS Directive*.

[53] Frontier Economics, AIR Transportation Analytics (2022) *Economic research on the impacts of carbon pricing on the UK aviation sector*, page 129.
https://www.frontier-economics.com/media/5109/economic-research-on-the-impacts-of-carbon-pricing-on-the-uk-aviation-sector.pdf