# Clear Skies Ahead

## Ensuring Success for the UK SAF Mandate

By Philip New

PRYSM GLOBAL

September 2025

**Philip New** has spent the last two decades immersed in the energy transition, working as an executive business leader, non-executive company director and senior adviser. He worked for BP for over 30 years, including as CEO of BP Biofuels and CEO of BP Alternative Energy, where he created and launched BP Ultimate in markets around the world. He then ran the Energy Systems Catapult, a UK Government supported but independent innovation agency focused on accelerating the transition of the UK energy system. He has advised the UK Government on Sustainable Aviation Fuels policy and is a Senior Adviser to Prysm Global.

**Prysm Global** is a strategic regulatory affairs consultancy, helping companies navigate regulation, policy and politics

# Acknowledgements

The following organisations made this report possible by funding it: AirlinesUK, Fuels Industry UK, Sustainable Aviation, International Airlines Group, Virgin Atlantic, EasyJet, Heathrow Airport, Manchester Airports Group, Boeing, Airbus, Shell and LanzaJet. Many were generous with their time and insight. The report is independent, and funding it does not imply support for all the content.

Key contributions to this report were provided by:
Featherstone Fuels, Ceres Waste, Renewables & Environment, Glenauk Economics, Boeing, Cranfield University (Professor Ron Corstanje, Dr Toby Waine, Professor Neil Harris).

Further Insight, counsel and guidance was provided by:
NFU, RTFA, ICF, LanzaTech, Saligo Projects, Nova Pangea, Matt Casswell, ePure, Ensus, bp, Imperial College, GFI, Mission Possible Partnership.

Lily Meech, from Boeing, not only drove the Cascade modelling but has been of incalculable support in pulling everything together.

# Clear Skies Ahead

## Ensuring Success for the UK SAF Mandate

PRYSM
GLOBAL

# Foreword

Reducing emissions from air travel is a commitment shared by the UK Government and the many organisations across the UK that have a stake in aviation. Low carbon Sustainable Aviation Fuel will be the single most important driver of emissions reduction and the Government has implemented a thoughtfully designed mandate mechanism that sets targets and frames markets.

This report has been commissioned by stakeholders from a wide range of industries, often with different interests but with a common concern – the consequences for growth, for net zero, and of the freedom to travel, of missing the SAF targets. The author was asked to identify risks to meeting the mandate and suggest appropriate mitigations.

UK SAF policies provide a strong foundation for a flourishing SAF sector, but there are two key risks (and one important opportunity to raise the game). Left unattended, missing the mandate is a strong possibility.

The root of the concerns is that the cheapest way to make SAF is to process vegetable oils and other fats – agricultural commodities where supply already struggles to meet demand and where sustainability exposures are perceived as relatively high. The UK mandate responds to this in two ways: it limits the feedstocks that can be used to wastes only, and it caps the amount of SAF made using vegetable oil – so creating a market for innovative new technologies that use a wide range of other feedstocks.

The unintended consequence is a growing dependence on imported waste vegetable oils to meet the largest portion of the mandate. However, it has been impossible to establish whether these oils really are wastes at the end of their useful life. As demand has increased, prices have increased and supply has responded. Used cooking oil is now often more valuable than virgin cooking oil. This has already forced a response – certification criteria have been tightened – but one way or another there will be a shortfall of supply in this part of the mandate.

The second problem is getting the new technologies for the next generation of SAF to graduate from pilot plant to commercial facilities. The mandate is unique in defining a discrete market, and important supply side mechanisms have been deployed. But the risk remains that these technologies emerge too little, too late. The UK cannot depend on other countries for supply. There is both a need and an opportunity for a new UK industry.

Diversifying the feedstocks for the SAF that we can make now, allowing the use of globally abundant starch crops and leveraging the incentives and guardrails already built into the mandate to underpin sustainable practice, is a pragmatic response to the used cooking oil challenge.

A whole-systems approach to the interventions to create a supportive investment and operating environment for the next generation of SAF plants is required if targets are to be met and a resurgent UK chemical process sector is to emerge.

There is a strong case that improving regulatory alignment (particularly between ground and aviation fuels) and continued focus on improving cross departmental collaboration are very important enablers.

This is about creating new markets, with new products – which is never easy.  If we succeed we will not only meet the mandate targets but also have a lower emitting, more sustainable aviation sector. In addition we stand to gain new industries, new jobs and better environmental performance across the broader economy. The SAF opportunity can be a powerful catalyst for the UK Green Industrial Revolution.

If this report helps at all in making this possible it will have been worthwhile.

**Philip New**
July 2025

# Table of Contents

# Executive Summary

## Introduction

Sustainable Aviation Fuel (SAF) is essential for the aviation industry to make its contribution to the UK's statutory objective of getting to Net Zero. It is the most material direct decarbonisation lever available to the sector for at least the next 15 years.

In the short term, there are no comparable alternatives. Aviation is among the very hardest to abate sectors of the economy; according to the Climate Change Commission's Seventh Carbon Budget, aviation will be the UK's largest emitting sector in 15 years' time.

However, there are various challenges that must be overcome for SAF to play its full role in decarbonisation. The SAF market is nascent. SAF costs more than fossil fuels – and most potential ways of making SAF have not yet been commercialised. There is some voluntary demand but any material use of SAF as a decarbonisation tool requires policy intervention. Governments around the world recognise this and are developing programmes to stimulate the adoption of SAF.

The UK Government has taken a leadership position regarding SAF. It has established a well-designed mandate framework to create market pull. It lays out progressive aviation fuel carbon reduction targets with a price-capped penalty for non-compliance (the buy out).

It has three defining characteristics:

1. It has distinct sub-markets – limiting exposure to current production routes and feedstocks while creating space for investment in emerging technologies accessing a diverse range of sustainable feedstocks.

2. It is based on emissions reductions rather than volume.

3. The buy-out price is fixed and set at a level high enough to provide an incentive for compliance and support investment in new technologies while capping the exposure of suppliers and passengers.

Compared with other jurisdictions it also has the most ambitious short-term targets (as a percentage of aviation fuel) and the most constrained range of products that can be used to deliver them.

If mandate targets are not met, the immediate consequences are serious:

- The buy out is triggered – UK passengers will pay a very high price for fuel, with no emissions benefits, and then

- The target is reduced – undermining investment confidence, or
- Demand is reduced, through the rationing of access to air travel.

The further implications of missing the mandate in its early years are very worrying:

- It will undermine the case for the continuation of SAF policy – potentially postponing decarbonisation progress by at least a decade.
- UK economic growth goals that are aviation-driven will suffer a serious setback.
- The case for infrastructure investment in aviation will be delegitimised.
- The international competitiveness of the UK economy will be further diminished.

This report has been commissioned in response to these concerns by a very broad range of companies and institutions spanning the many sectors that have a stake in aviation decarbonisation: airlines, airports, airframe manufacturers, fuel suppliers, renewable fuel producers and technology developers.

The purpose of the report is to assess the risk of non-fulfilment of the mandate targets, to identify the key challenges and propose potential mitigations. Because of the importance of meeting shorter-term targets the report focuses on the next ten years. The report is not intended as a critique of policy but rather as a constructive contribution to the successful delivery of policy goals.

Like all liquid fuels, SAF is a global commodity. It can be made anywhere and moved anywhere. Some SAF feedstocks can themselves be transported easily (vegetable oils, ethanol) so production does not need to be close to feedstock sources. Others (electricity, CO2, Municipal Solid Waste) are more point specific – but will still need to be bid away from alternative applications.

This requires an understanding of multiple complex market dynamics interacting as an often “messy” system with significant exposure to national/trade bloc policy choices. This will be a policy-driven sector for years to come.

The approach taken in the report is deliberately market driven and written from a commercial perspective. In understanding the risks to policy delivery, theoretical calculations of capacity are helpful but limited. Perspectives on how markets and market actors may respond are also important.

## Risk Assessment

The report starts with a risk assessment that:

- Reviews the economics and emissions performance of different SAF pathways currently allowed by the mandate.
- Summarises the policies introduced in different jurisdictions to drive SAF demand and interactions with adjacent markets such as renewable road fuels.
- Explores potential competitive dynamics within and between markets.
- Assesses the supply capacity of key feedstock types.

## Products and Markets

Hydrotreating lipids (HEFA), using vegetable oils and other fats, is the most competitive pathway to make SAF. It is the only technology that is in commercial operation today. In the EU and UK this can be made using waste lipids only – most often used cooking oil (UCO) or tallow. Elsewhere virgin oils (palm oil, soy oil, rapeseed oil) can be used.

Biodiesel for ground fuels use can use the same feedstocks. Hydrogenated Vegetable Oil biodiesel (Renewable Diesel in the US) also uses a very similar process to HEFA. In assessing aggregate demand for feedstocks and processing capacity both markets need to be looked at.

Demand forecasts for SAF should be based on mandated targets with some allowance for voluntary purchases. Confirmed mandates amount to 6.55 million tonnes in 2030 (global AVTUR demand is forecast at 357 million tonnes). A prudent view of likely global SAF demand would therefore be between 5 and 10 million tonnes, rather lower than many other estimates.

This is largely because the US market lacks a mandate, and making SAF isn't as profitable as making Renewable Diesel using the same feedstocks and similar kit and while some other countries are starting to develop mandates in most cases the future trajectory and key design features are unclear.

The major driver of demand is the EU mandate –which has an ambitious sub-market for very expensive power to liquids SAF but otherwise will be met by using the lowest-cost types of qualifying SAF available – today this is exclusively HEFA made from UCO and other waste lipids. The EU accounts for almost half of global SAF demand in 2030. It is about 3 times the size of the UK mandate.

UCO supply is dominated by the major palm oil producing countries (Indonesia, Malaysia) and China. The US used to import large quantities of UCO from China, but earlier this year this trade largely ended in response to US regulatory interventions. Whether this volume flows to Europe or stays in China depends on the development of China's appetite for SAF, which still feels tentative.

HEFA production capacity is growing in Asia. The UK and EU have a large and growing dependence on the supply of UCO and UCO-HEFA from Asia to meet their mandates. As more processing capacity comes on stream the price of HEFA will depend on the supply of UCO and the demand from the EU and UK ground fuels markets and the EU SAF market. In 2024 89% of UK SAF and biodiesel consumption was UCO derived – overwhelmingly from Asian imports.

The UK mandate is fulfilled through the generation of certificates that are denominated by carbon intensity. The lower the carbon intensity, the higher the number of certificates. The cost of a certificate is a function of the cost of production of the physical litre and the carbon intensity of the fuel. The price is capped by the buy-out price – itself adjusted for the carbon intensity of the product.

The UK is unique in offering a sub-mandate market for 2g SAF. On current regulations 2g SAF will be a UK-dominated market in the short to medium term – we expect the market price to be set by the cost of the marginal compliance certificate (plus the cost of a litre of AVTUR).

There is a plethora of potential SAF technologies, using a very wide range of waste feedstocks from black bin waste (MSW) to flue gases and sewage sludge. The modelled cost of producing a physical litre of advanced SAF is higher than for HEFA, but good emissions performance can mean that some 2g products could compete, once technologies are matured and scaled up.

## Supply

Supply was assessed through deep dives into two of the leading contenders for scale in a future SAF market: UCO (for 1g HEFA SAF - already the dominant technology/feedstock combination) - and MSW (for 2g MSW FT SAF, with gasified municipal solid waste fractions passed across a Fischer-Tropsch catalyst to produce SAF).

Local authorities need to dispose of their black bag waste, and rather than pay to landfill it they look for other offtakes that will deal with the waste at lower cost. Today most of it is incinerated, creating steam to generate electricity. The electricity from waste sector typically operates on term contracts of up to 15 years. To secure access to MSW a SAF plant needs to bid waste away from EfW applications.

In aggregate there is more than enough usable waste – even with tighter recycling standards – to meet 2g demand. However, in the early years of the mandate availability of uncontracted MSW is constrained, the collection and bulking of MSW is largely controlled by a small number of vertically integrated "tier 1" suppliers who will want to maintain supply for their in-house EfW assets, and local authorities, who need to dispose of the waste collected in their area, will prefer to agree offtakes with trusted offtakers (they want to be assured that the waste will be disposed of without going to landfill) rather than depend on a relatively untested technology (like 2g SAF).

Therefore the early MSW projects will need to offer significant discounts to EfW to secure feedstock. However, once the technology has been proven SAF should be well placed to secure increasing volumes of MSW as contracts expire and confidence builds (we modelled a 100% discount on the gate fee payable to EfW plants for the early mover projects, moving to a 25% discount once market confidence was established). Economics could be further improved if access to green hydrogen to carbon sequestration was available.

There are further pools of waste feedstocks that, while smaller, could offer very attractive economics, such as waste wood. Other 2g technologies also face competition in securing access to feedstock: AtJ technologies are currently constrained to ethanol made from agricultural wastes and flue gases. UK-originated supply will be limited. In all cases they will need to be bid away from ground fuels use. Even sewage sludge would need to be bid away from biogas markets.

MSW-FT can therefore be viewed as the default non-HEFA cap sub-mandate technology – it is a pathway that has the capacity to scale and supply the SAF required. To that extent, it caps the market price for 2g SAF – if this is the marginal technology in a well-supplied market other 2g technologies that can deliver certificates at a lower cost will stay in the market.

The UCO-HEFA challenge is quite different. The processing technology is well established and scaling rapidly. Intuitively the supply of used cooking oil should be a function of how much virgin oil is used, predominantly in food preparation, and how efficient the collection process is. In much of the world (including the UK) that reflects reality. People don't cook more to produce more waste oil. The incentive is the other way round – the onus is on using virgin product as efficiently as possible before eventual disposal.

The east Asian waste oil markets don't seem to work like that. Waste oils, thanks to the demand from European markets, price at near parity and sometimes at a premium to palm oil. The supply of waste oil has expanded massively over the past few years as demand has grown. Based on a conservative estimate of SAF demand, the call for waste oils will grow from around 6 million tonnes to 15 million tonnes by 2035.

In these markets used cooking oil is often not an end-of-life product, and sophisticated collection, trading, blending and bulking capabilities have developed. Vegetable oils are interchangeable, and their prices are highly connected. This also applies to the Asian waste oil market. While a premium exists, the market will find a way of meeting demand for waste oil – even if this pulls volumes away from other, non-fuel, applications. The likelihood is that waste oil prices will continue to rise – in part because underlying vegetable oil prices will respond to a tightening market and in part because waste oil premia will continue to increase. It is not likely that alternative sources of waste oils will emerge beyond east Asia over the coming decade.

So while it is unlikely that the supply of these “waste” oils will run out, if nothing else changes they will become increasingly expensive and there is a risk of backlash as producing nations respond to higher consumer costs and tax or even ban exports (as has already been seen in Indonesia) and consumer groups in the consuming nations raise concerns about the perceived unintended consequences of waste oil demand undermining sustainability claims.

## Risk Assessment: Summary

In assessing risk-to-mandate fulfillment there are three key, interconnected constraints. They are analogous to the “iron triangle” familiar to project developers:

- **Emissions** – will there be enough qualifying physical product available when needed to meet mandate requirements?
- **Cost** – can these products be supplied at a price that balances investability, affordability and international competitiveness?
- **Sustainability** – can these be supplied within acceptable sustainability criteria?

The fundamental risk is that emphasising any individual constraint, rather than seeking to balance all three, a successful outcome becomes much less likely.

The UK and EU appear to have chosen to prioritise the sustainability criterion – most clearly through the rejection of any feedstock other than waste. This has created a significant and growing dependence on imported UCO. The longer this continues, the greater the dependence will be and the more likely it is that a tipping point will be reached, where supply will be constrained either because (in the best case) tougher certification processes have restored a genuine end-of-life market (so eliminating supplies of “manufactured” wastes) or a backlash – whether from producers or consumers - forces a change. The irony is that the choices that were intended to uphold sustainability may have the opposite effect.

In the medium term the best remedy will be the emergence of a vibrant, deep 2g market that takes the pressure off HEFA supplies and enables a very diverse set of low environmental impact feedstocks to be used, decarbonising one of the hardest parts of the economy to abate. This is clearly envisaged in the design of the UK mandate (the EU seems to be betting exclusively on PtL to do a similar job). The risk is that the 2g projects fail to break through the early challenges – securing backing to reach

FID, successful construction and commissioning and then sustained, profitable operation. Once there is confidence in this market, economics will improve, technologies will scale, and effective markets will form. Without it, dependence on HEFA will only increase.

The probability of these challenges being resolved will be improved if, at least in the UK, there was stronger alignment between the ground fuels and SAF markets – they use the same feedstocks, made into the same (or very similar) products. And yet they each have very different market rules. This distorts choices and risks higher costs and inefficient resource allocation.

Based on this analysis the report lays out a range of recommendations against three key challenges:

- The HEFA tipping point
- Advanced SAF – too little, too late?
- Regulatory misalignment

## Recommendations

### 1.0 The HEFA tipping point

Until advanced and synthetic forms of SAF achieve scale in both the UK and EU the mandates depend on HEFA to meet targets, and HEFA is today reliant on supplies of waste lipids. Demand for HEFA – and waste lipids - will increase as mandate targets grow. Supply of waste lipids from main palm oil producing countries (and China) has responded to higher prices. There are increasing concerns that the supply of waste lipids will hit a tipping point – whether because of shortage of supply (if tougher certification is effective) and potentially very high prices or because of societal or supply-side backlash.

We need to get ahead of the tipping point.

**1.1 If tougher certification doesn't deliver high credibility end-of-life wastes, demand should be reduced. This could be delivered through a cap or ban on the use of imported or low credibility UCO or through a reduction in the HEFA cap.**

In either case, there will be a supply shortfall for waste-based HEFA. If the issue is resolved through better control systems, supply to meet the continued increase in mandate volumes will fall short and prices will rise. If demand is constrained there will also be a supply shortfall.

Diversification of feedstocks for 1g SAF is an essential short-medium term mitigant.

**1.2 Diversification of feedstocks**

The three key recommendations are:

**1.21** Allow, within clear safeguards, the inclusion of intermediate crops and crops grown on degraded land. This is not anticipated to play a significant role mitigating volume risk, but there is an opportunity to benefit from EU experience. HEFA supply is largely EU sourced (and so supply chain complexity could be reduced) and there is an opportunity to develop, adapt and adopt verification standards.

**1.22** Allow, within clear safeguards, the use of low ILUC risk feedstocks drawn from crops that are globally abundant. Using starch-derived ethanol (made from milling wheat, corn etc) and upgrading this to SAF using ethanol-to-jet technology) can deliver SAF volumes that exceed the minimum emissions reduction hurdle and provide an incentive to reduce emissions through the value chain.

**1.22.1** Default ILUC factors should be applied to minimise the risk that high-risk crops are introduced.

**1.22.2** Concerns around unintended consequences can be addressed through the monitoring and verification of key sustainability requirements.

**1.22.3** A trial period with a high-confidence, easily monitored supply base makes sense – for example a waiver of the crop ban for UK grown starch crops for a defined period.

**1.23** Against a boundary condition of preserving the investment attractiveness of the 2g sub mandate there are three possible approaches to enabling a more diverse market:

- If certification works and/or supply of low credibility UCO is restricted: maintain the current sub-market volumes but redefine the HEFA cap as a cap on 1g pathways (and naming the non-HEFA SAF sub mandate "the advanced SAF mandate"), otherwise either
- Reduce the HEFA cap and allow crop-based AtJ SAF to compete with other 2g pathways in a much larger addressable market, or
- Develop a fourth, crop AtJ, sub-mandate market, carved out of the current HEFA mandate.

Timing is important. It is important that mitigations are in place ahead of any supply shortfall happening. On that basis the early development of a crop carve-out looks attractive.

The use of domestic wheat ethanol to produce SAF could have the quadruple benefit of:

- helping mitigate the dependence on vegetable oils,
- offsetting the impact on domestic agriculture and manufacturing of the loss of ground fuels market,
- providing an incentive for continuous improvement in agricultural and process emissions, and
- enabling the early deployment of AtJ technology - which also has a role in 2g SAF.

## 2.0 Advanced SAF – too little, too late?

The report concludes that Advanced SAF has the potential to meet – and exceed – the current mandate targets and, especially when CCS is included, at competitive emissions-adjusted costs, so reducing overall compliance cost.

UK leadership in market design creates the potential for UK job creation, technology leadership and product and knowledge exports.

The mandate creates clear demand, with emissions denominated certificates and a clear buy-out cost providing important market-pricing signals. This is complemented by a strong set of supply-side support mechanisms – the Advanced Fuels Fund, SAF clearing house and the revenue certainty mechanism.

Despite this, challenges remain in getting the first mover projects and technologies to scale. The report makes three main recommendations:

- Get the RCM right.
- Reduce operating cost.
- Reduce the cost of capital through mitigating execution risk.

### 2.1 Getting the RCM right

The initial elements of the RCM design have been announced and provide a good platform. There are some critical, and challenging, design details that need to be completed: the term, the scope, the governance and the price discovery mechanics are central. Recommended design principles include:

- Focusing on enabling investment to flow while supporting the emergence of a robust merchant market.
- Maintaining a level of competitive tension in the design will be important.
- A high-trust, high-transparency governance environment will be required.
- Allowing levy collections and disbursements to be balanced across years rather than in-year will reduce risk and cost.

### 2.2 Reducing operating cost

Lower-cost SAF production should lead to lower overall compliance cost, better returns and more efficient use of resources, including feedstocks. It has several elements.

Accessing advanced SAF feedstocks can be problematic. Almost all of them have alternative uses and need to be bid away from existing technologies. In many cases these feedstocks are used in applications where there are alternative low or zero carbon options. While SAF technologies are unproven this can mean that high premiums are demanded. It is recommended that:

- Hard-to-abate sectors should be preferentially treated rather than penalised.
- A time-limited performance guarantee be provided to ensure that the risk to feedstock sources is limited.
- Hard-to-abate sectors are defined as "recovery plus" in a revised waste hierarchy.

Although there is a plethora of potential advanced SAF technologies with a broad range of potential feedstocks it is recommended that:

- Consideration be given to further diversifying feedstocks for advanced SAF (if necessary, adopting some of the safeguards proposed for interim and starch crops). An example might be sustainably sourced wood pellets.

Enabling SAF plants access to green hydrogen brings a range of potential benefits (lower emissions, feedstock efficiency and potentially hybrid advanced/synthetic SAF production). The green hydrogen qualifications for SAF are more demanding than for other sectors. It is recommended that:

- The National Hydrogen Production Business Model rules apply economy wide.

It is also recommended that:

- The development of a merchant market for access to CCS capacity is explored.
- On the assumption that where a CCS option is available it should be the most economic sequestration option, where timely CCS access is uncertain, allow a SAF project to purchase 3rd party carbon removal credits, to de-risk access to CCS, improve investment economics, reduce pressure on feedstock supply and lower SAF costs.
- Mechanisms are developed that provide investor assurance on the longevity of current regulatory conditions. Examples include the current counterfactual on hard to recycle plastics and the treatment of negative emissions in the mandate.

### 2.3 Reducing the cost of capital

Mitigating execution risks on first mover plants will reduce cost of capital on the earliest plants, improving their competitiveness and investibility. The original “Icebreaker” proposal put forward three options:

- Funding support for technology-risk insurance premiums.
- A light-touch variant of the debt-comfort package offered to investors in the Thames Tideway Project.
- Bespoke, project-specific and granular KPI performance guarantees.

It is recommended that they be revisited with a view to adoption.

## 3.0 Regulatory Misalignment

Regulatory disconnects increase risk, cost and uncertainty. The emissions savings construct applied in the SAF mandate has great appeal as a mechanism to incentivise the outcomes we seek while retaining protection (using thresholds and possibly caps) against the use of feedstocks associated with higher sustainability concerns. It is recommended that:

**3.1** A consistent, feedstock-neutral, GHG denominated, and energy-based mandate system be adopted for both SAF and ground fuels.

**3.2** Current default ILUC factors be applied in determining feedstock qualification.

**3.3** Consideration be given to waiving ILUC factors in determining emissions reduction for certificate generation purposes, so reducing the volumes of 1g SAF required for compliance.

**3.4** The current SAF submarkets be retained and extended to ground fuels (replacing the development fuel sub mandate).

**3.5** The current HEFA and non-HEFA main obligation mandates be renamed to recognise the greater diversity of pathways and feedstocks. One option would be the Advanced SAF sub mandate.

## 4 Conclusion

Decarbonising aviation must be done. The development of a large-scale SAF market is critical. The UK is leading the way with a portfolio of demand and supply-side policies that are unmatched anywhere else in the world.

The UK mandate lays out clear targets. They are ambitious but balanced. It incentivises innovation and good practice in reducing emissions through the value chain. It provides clear markets for the products we will need in the future as well as the products we can use today. The penalty for non-compliance is high enough to reward investment but capped.

The SAF Clearing House, the AFF and the RCM are all robust supply-side measures.

We are building new markets, with new products. The current UK policy portfolio provides good foundations, but the journey from here to the destination still carries risk. This report calls out some of the main challenges and suggests some potential responses.

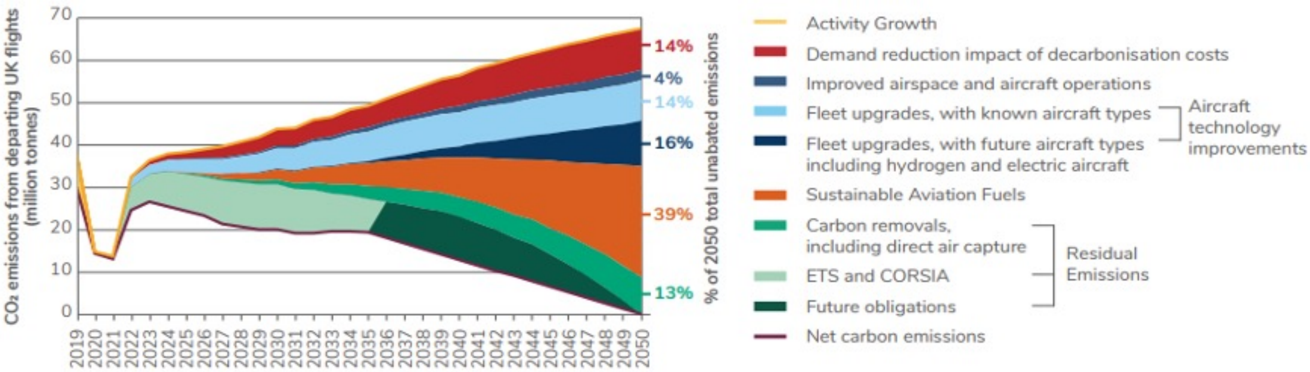
If these risks can be mitigated, not only will we avoid the serious downsides associated with missing the mandate targets. We will also see a lower emitting, more sustainable aviation sector. We will see cost exposures managed – avoiding buy outs and commodity price fly-ups. We will see new investment in new technologies and jobs created. We will see threatened legacy assets revived and jobs saved. We will see cost and emissions savings through various supply chains.

The SAF opportunity speaks directly to the UK Green Industrial Revolution. It is one of the areas where we still have potential for leadership. If this report helps at all in making that leadership possible it will have been worthwhile.

# Introduction

Aviation is fundamental to economic growth, connecting economies and communities. However, the CCC 7th carbon budget(1) suggests that – even with a 17% emissions reduction - it will be the largest source of UK emissions by 2040. This is in part because of continued growth in demand for travel, but also because it is among the very hardest and most expensive of economic sectors to decarbonise. Net Zero aviation can be achieved – but will require a range of interventions. The Sustainable Aviation pathway (2) illustrates a possible combination of levers; even allowing for a degree of demand destruction (a consequence of higher fuel costs and ETS) and a strong focus on efficiency and operational improvements, there will still be a heavy dependence on reducing fuel emissions. Even then the modelling requires offsets and carbon removal to deliver Net Zero.

**Figure 1: Sustainable Aviation Roadmap (2).**



Emissions are cumulative so doing nothing until other solutions emerge is unpalatable. There is significant uncertainty around when longer-term abatement technologies will deploy at scale. Optimism around the timelines for the adoption of hydrogen and electric aircraft has waned in recent years and while progress on climate engineering (carbon removal) is promising, the creation of appropriate international market, governance and institutional structures remains a complex challenge*.

Decarbonising aviation fuel is the most material lever that the sector has available to it for the next 10-15 years at least. Delivering SAF at scale, sustainably and affordably will require some trade-offs, but in aviation the range of available levers is even more limited than in other sectors.

An increasing number of countries have announced mandates or other measures to drive the deployment of SAF. The UK has led the way in many respects, establishing a thoughtfully designed and ambitious SAF mandate (with the support and encouragement of the wide range of industries associated with UK aviation).

Fulfilling the mandate is crucially important, particularly in the first decade or so of the transition, when credibility and confidence needs to be established. Meeting the mandate implies the emergence of deeper, fungible, balanced SAF markets, with robust competition between producers and suppliers enabling scale benefits to reduce costs.

If the mandate targets are not met for any length of time, and they become viewed as unachievable, the implications are profoundly unpalatable. There are three possible consequences. None of them are good:

1. Fuel suppliers are forced to “buy out” their obligation. The shortfall in supply will be met by fossil Aviation Turbine Fuel (AVTUR) so passengers will be paying a premium price for fuel with no emissions benefit.
2. The mandate is reduced – undermining investor confidence in developing and scaling the new technologies and businesses needed to deliver the next generation of lower carbon (and even negative carbon) fuels.
3. The targets are made more achievable by reducing demand – throttling back access to air travel (with the issues outlined above).

*SAF nomenclature can vary. This report uses the classifications introduced in the Department for Transport (DfT) – commissioned independent stakeholder review in 2023 (15) – 1g refers to SAF made with existing conversion processes (hydrotreating) but also - in this report - the distillation of C6 plant sugars into ethanol  (and then upgraded to SAF), 2g (or Advanced SAF) to emergent non-Power-to-Liquid (PtL) technologies and 3g refers to synthetic fuels (e.g. PtL).

Further consequences of the mandate not being fulfilled include:

- The impact on UK economic growth aspirations. Aside from the impact of any reduction in infrastructure investment plans - new runways and capacity expansions in particular - have been justified in part by the benefits from SAF. Failure to meet our targets risks delegitimising these proposals.
- Undermining the case and confidence for SAF mandates in other countries.

## Report Focus: De-Risking the UK SAF Mandate

A wide range of companies, and stakeholders in the future of UK aviation, have welcomed the SAF mandate and are anxious that it succeeds in driving the progressive reduction of emissions. The ambition is well supported, and the design principles are highly regarded. Successful fulfilment of mandate targets in the first decade or so is seen as particularly important.

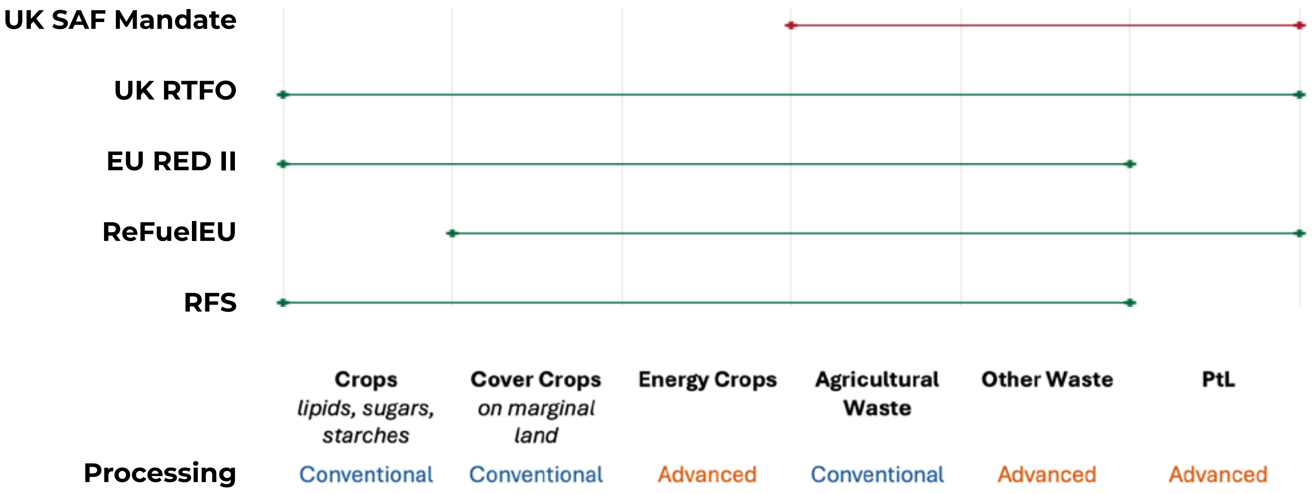
There are worries that delivering mandated targets may be challenging – and risk failure. The UK combines the tightest set of restrictions on allowable SAF feedstocks with the joint most ambitious targets for usage over the next 10 years of any jurisdiction with an announced SAF policy.

**Table 1: Comparison of the UK Mandate and ReFuelEU(14). Volumetric conversions based on forecasted demand total jet fuel demand for the UK and EU(3, 6, 7).**

| | | 2025 | | 2030 | | 2035 | | 2040 | |
|---|---|---|---|---|---|---|---|---|---|
| | | % | Mt | % | Mt | % | Mt | % | Mt |
| **UK** | Bio-SAF | 2 | 0.2 | 9.5 | 1.2 | 13.5 | 1.6 | 18.5 | 2.0 |
| | PtL | 0 | 0 | 0.5 | 0.1 | 1.5 | 0.2 | 3.5 | 0.4 |
| **EU** | Bio-SAF | 2 | 0.9 | 4.8 | 2.4 | 15 | 8.6 | 24 | 15.4 |
| | PtL | 0 | 0 | 1.2 | 0.6 | 5 | 2.9 | 10 | 6.4 |

The competition for the restricted range of feedstock required for 1g and 2g SAF, their availability, cost and sustainability credentials, and the importance of the timely availability of 2g SAF volumes are all causes of concern.

**Figure 2: Feedstock eligibility across legislative frameworks.**



This report has been commissioned to review the deliverability of the mandate targets, assess whether concerns are justified and – for those that are – to explore options to ease supply and improve availability.

The report starts with an assessment of the key risks to mandate fulfilment. The risk assessment:

- Covers demand drivers both in the UK and across other markets.
- Explores the relative competitiveness of the UK mandate in securing supplies.
- Frames the possible evolution of competitive dynamics in the emerging SAF market.
- Reviews the supply potential of qualifying feedstocks under current conditions.

This informs the conclusions of the risk assessment.

The second section of the report:

- Assesses potential risk mitigants, including an assessment of additional supply options and mechanisms to encourage investment in new capacity.
- Explores trade-offs, challenges and opportunities.
- Presents a set of recommendations for interventions or policy modifications.

## Types of SAF

Sustainable Aviation Fuel (SAF) can be made from a wide range of feedstocks utilising a diverse set of processes. All pathways and end products need to be ASTM approved. SAF can be categorised in many ways, but technology maturity and process pathway are useful.

Processing sugars and lipids from agricultural crops, co-products and wastes using relatively established processes to convert into intermediate products that can then be upgraded to SAF (usually through hydrotreating) is widely practised. Examples include the hydrogenation of lipids to hydro processed esters and fatty acids HEFA and the fermentation of C6 plant sugars (crop or “waste”) to ethanol which is then converted to SAF using a further ethanol-to-jet process.

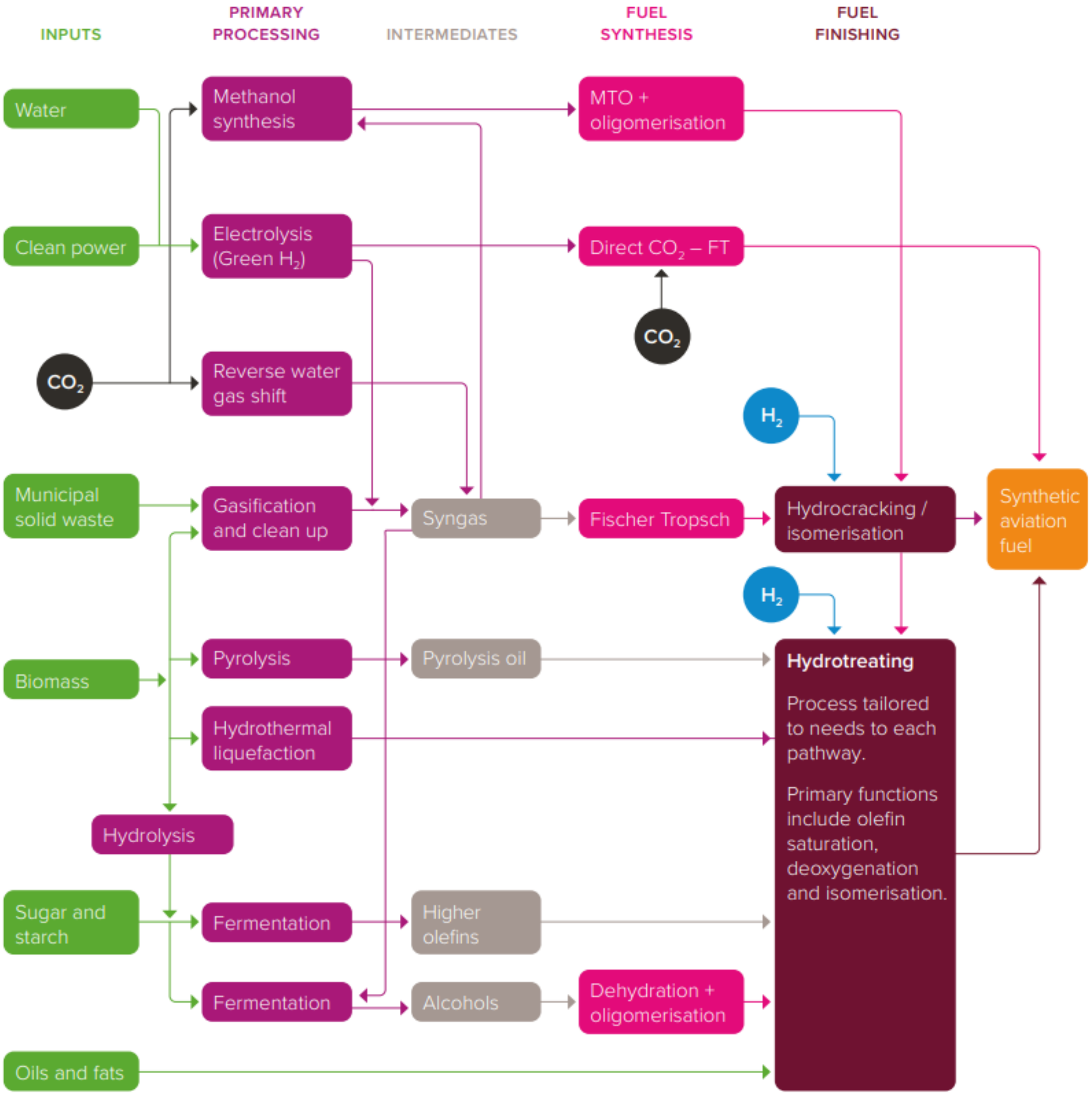
Second generation (or advanced) SAF involves more complex and less mature conversion processes. Examples include the gasification and catalysis of municipal solid waste (MSW) -including non-recyclable plastics, commercial waste and waste wood and the fermentation of plant lignocellulosic sugars into ethanol (requiring a further ethanol-to-jet process step). There are other potential pathways

– such as the production of tyre pyrolysis oil, the hydrothermal liquefaction of sewage sludge into bio-crude, and the pyrolysis of woody and other agricultural wastes into fermentable sugars - which are pending ASTM approval.

Third generation SAF is shorthand for synthetic e-fuel pathways (power to liquids, or PtL), typically with CO2 (ideally biogenic or atmospheric) reacted with hydrogen (ideally from renewable electricity).

Certain 1g and 2g SAF pathways can be combined with carbon sequestration technologies to further improve their emissions performance (often delivering net-negative emissions).

**Figure 3: SAF feedstocks and production routes(4)**



Although SAF is a “drop in” fuel, there are constraints on the proportion that can be blended into aviation fuel. This is because fossil jet contains aromatic hydrocarbons helping elastomeric seals to swell. In contrast, most forms of SAF have very low aromatic content, which can cause the seals to shrink in engines that have previously been operating on fossil jet, creating the potential for leaks. At the same time the high aromatic content of Jet Fuel has been associated with non- CO2 global warming impacts (from contrail formation). The potential for increased SAF usage to reduce both CO2 and other non- CO2 emissions that nonetheless have important climate impacts must not be overlooked. Although the science remains uncertain both HEFA and Fischer-Tropsch SAFs have been effective in early trials. “4th generation” SAFs are being explored that may overcome blending constraints while still delivering non- CO2 emissions benefits.

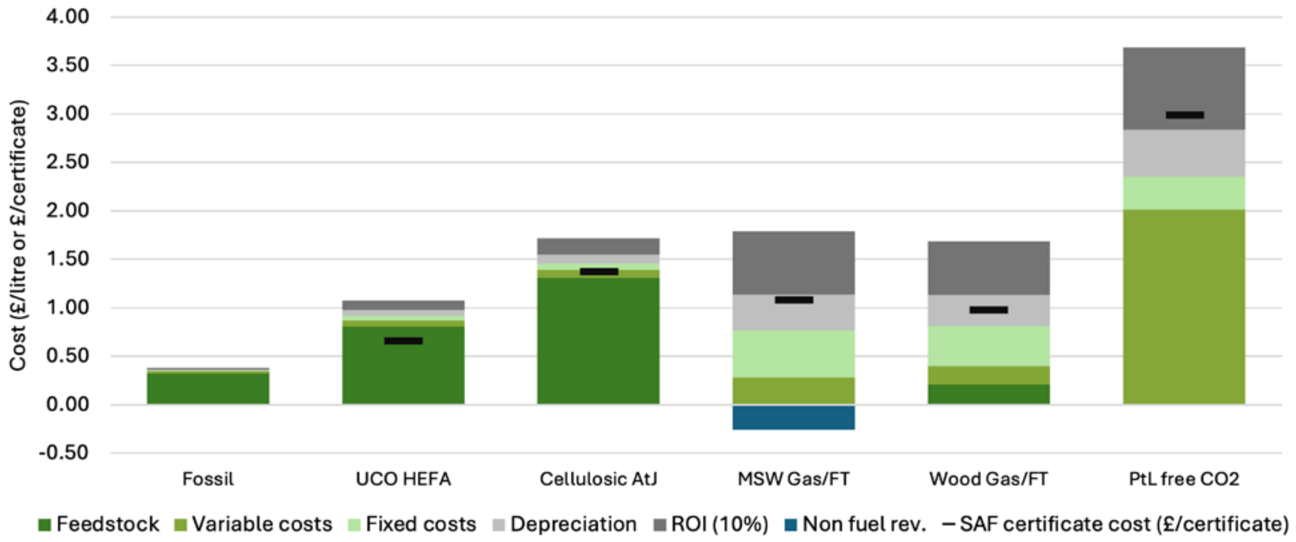
The UK SAF mandate has identified a sub-set of these pathway/feedstock combinations that qualify as compliance products against respective segments of the mandate obligation. The PtL mandate applies to qualifying PtL products (using only “green” hydrogen and zero-carbon CO2), while in the main obligation the HEFA cap differentiates between the hydrogenation of lipids and, “above” the HEFA cap, pathways that are not HEFA. Importantly, food crop, feed crop and energy crop feedstocks are completely banned, regardless of pathway, and any product must deliver at least 40% Greenhouse gas (GHG) savings vs fossil AVTUR to qualify.

## Techno Economic Modelling. SAF pathways and Market Sizing

This report assumes that liquid, transparent markets for SAF will emerge, and explores possible outcomes under such conditions (acknowledging that markets today are still forming).

To illuminate the likely cost differences between SAF pathways, techno economic modelling of some representative types of SAF has been completed. These are Illustrative archetypes based on nth of kind (so mature, scaled technology) costs and using a common set of input assumptions (Annexe 1) to support and inform a relative understanding of the landscape. Actual data will be project and technology specific – these archetypes do not reflect any specific individual project or proprietary technology – the model outputs should not be used to form judgement on any individual proposition (and in some cases are undergoing further validation).

**Figure 4: Cost build-up for key SAF production technologies (10% ROI, 25% discounted gate fee) (5). Full assumptions found in Annexe 1.**



The chart shows the relative cost per litre of SAF for some of the more prominent archetype pathways. Inputs are based on UK metrics, and the model includes capital costs, operating costs and a standard assumption on shareholder return.

An illustrative certificate cost, based on the modelled relative carbon intensity of each archetype, has also been provided.

As can be seen, pathways that are based on converting feedstocks (Alcohol to jet - AtJ - and HEFA) are highly dependent on feedstock price. MSW and PtL pathways can have effectively free feedstock inputs (electricity is modelled as an operating cost) but much greater financing cost – a reflection of relatively high capex intensity. In the archetypes shown here no carbon sequestration or capture has been included and the PtL pathway assumes a free source of adjacent CO2.

In assessing overall aviation fuel demand (and therefore modelling mandate fulfilment volumes), the Sustainable Aviation pathway has been used for the UK(2) and for other geographies the Boeing Cascade Climate Impact Model (6) default assumptions have been used.

# Risk Assessment

## Demand

**Market Fundamentals**

SAF is almost unique in the renewable energy ecosystem:

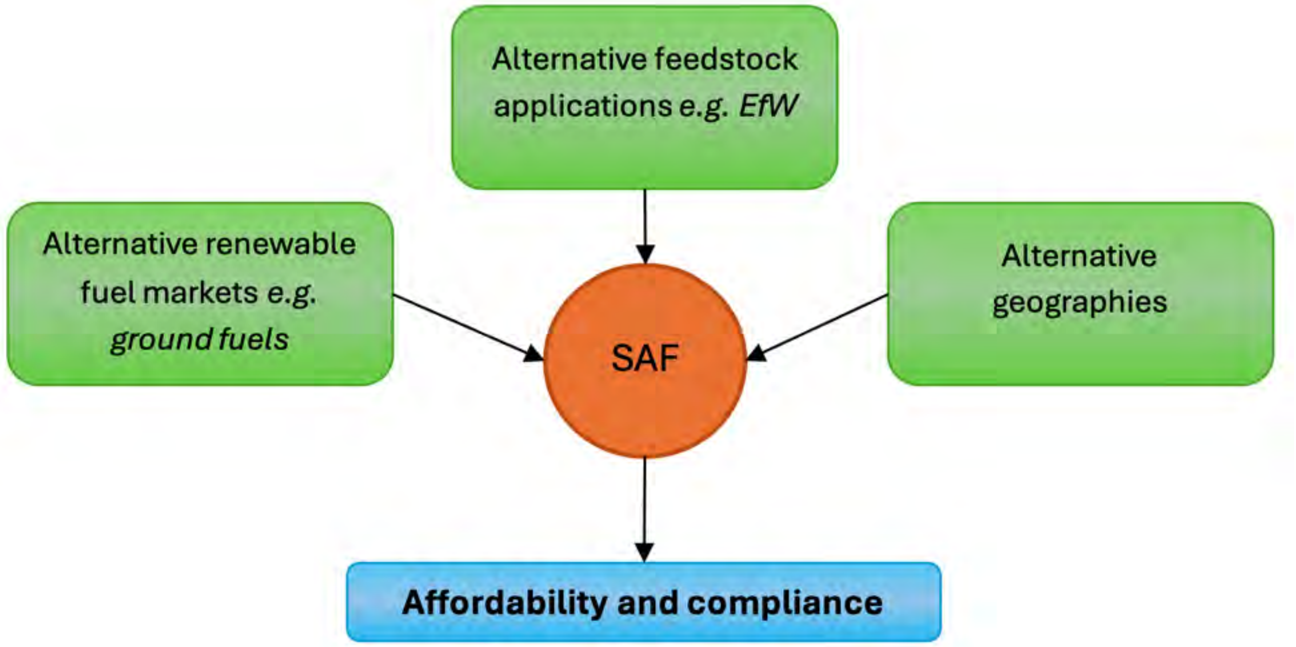
- A fungible liquid fuel, it is easily stored and easily moved. It can be made anywhere and consumed anywhere, with a potentially global supply envelope serving a potentially global market.
- Demand is less locationally fixed than any other energy type except marine fuels. Aircraft can choose whether to fuel at departure or arrival, unless it is a very long-distance flight.
- Most SAFs are made from feedstocks that have multiple other applications, and SAF itself shares many processes with ground fuels.
- So, production capacity needs to be competitive internationally, and bid feedstocks away from other applications, while markets need to offer attractive netbacks to secure supply in tight markets (while minimising demand destruction through uncompetitive end-user pricing).

The UK will be competing for access to SAF with all the other national or regional markets where mandates or other incentives are in place. SAF producers will seek to maximise margins, selling product into the highest-return markets. This applies as much to UK-produced SAF as it does to imports. The UK market arrangements therefore need to be understood in a relative context, comparing with other markets (and comparing domestic markets for like products – e.g. UK SAF mandate and Renewable Transport Fuel Obligation (RTFO) Hydrotreated Vegetable Oil (HVO) demand, or US Renewable Diesel vs SAF demand). The review of market arrangements, and the consequent regulatory arbitrage, underpins assessment of likely demand.

Feedstocks are also subject to competitive resource allocation pressures – whether domestic or global. Given the emphasis on waste feedstocks this will involve understanding the underlying activity that generates the waste and alternative outlets for the waste. Deep dives into international waste lipid and domestic MSW markets, with a brief survey of cellulosic ethanol and PtL prospects, provide an overview of supply options of UK qualifying pathways against the mandate.

Although we are already seeing renewable electricity competing with thermal power, the nature of SAF technologies means that it is difficult to see how the cost of SAF will match fossil prices – at least in the next 20-30 years. SAF will be a regulated, legislation-driven market for the foreseeable future.

**Figure 5: Multiple axis of competition.**



**UK Context**

The UK SAF mandate sets targets for the progressive reduction in emissions from aviation fuel. A mandate-based system, with the fuel supplier as the obligated party and the cost of compliance ultimately falling on the end user, it has three distinct defining characteristics:

1. It is based on emissions reductions rather than volume – although targets are expressed as an increasing share of total aviation fuel taken by SAF, compliance is achieved through delivering emissions reductions – so the better the carbon saving a litre of SAF delivers, the fewer litres of that SAF are required to fulfil the mandate. The carbon intensity of each molecule of SAF is therefore important in determining the volumes required for compliance.

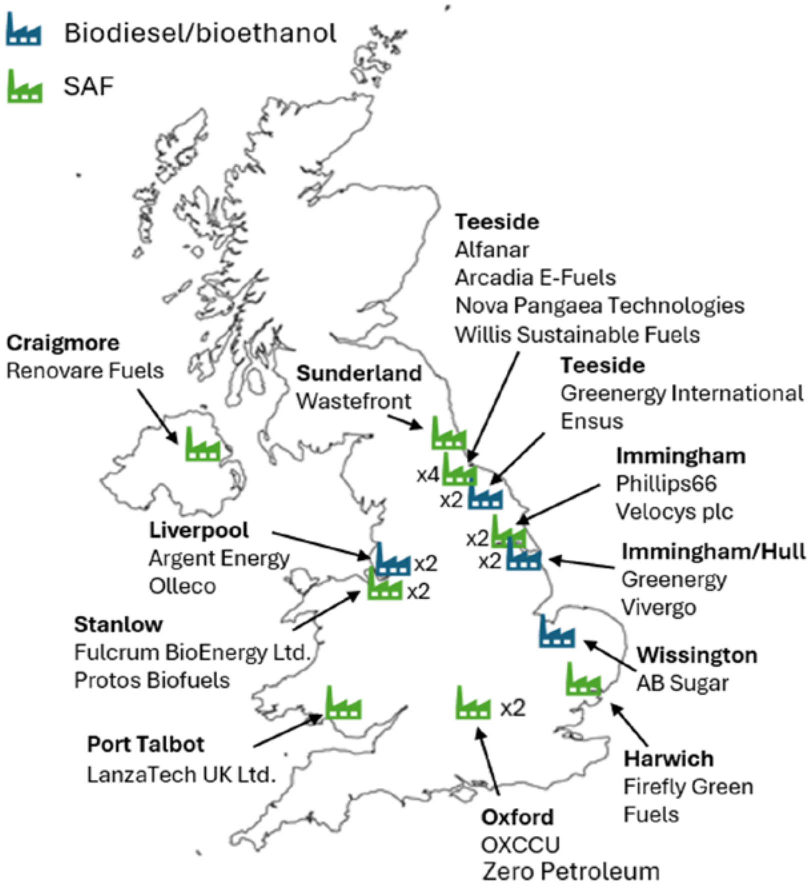
2. It has distinct sub-markets – a stand-alone market for PtL and a "main obligation" market that is further sub divided using a cap on the share taken by HEFA – in effect creating a further sub-market for 2nd generation products. The obligations in each market are expressed volumetrically, but the actual volumes required are a function of the Carbon Intensity (CI) of SAF sold.

3. For each of the main obligation and PtL markets there is a buy-out price (£4.70/litre in the main obligation, £5.00/litre for PtL), in effect providing a price cap in a short market. [Note – because of the use of certificates related to Carbon Intensity, in effect the buy-out price needs to be adjusted]

The UK SAF mandate operates alongside – but separately – from the long-established Renewable Transport Fuel Obligation. Because both HEFA SAF and RTFO HVO are made from the same types of feedstocks (waste lipids) and use similar processing pathways, they could be in competition with each other for supply. Both are certificate based – but while SAF certificates are based on emissions savings delivered, RTFO certificates are volume based with preferred feedstock and pathway combinations benefitting from "double counting". The RTFO covers all ground transport fuels – in theory the obligated party would seek to minimise compliance cost by maximising the volumes of the lowest-cost compliance fuel up to blend limits – so HVO volumes are potentially also driven by their cost relative to other compliance potions, such as ethanol. The RTFO also has a buy-out price mechanism (set at £0.50/litre).

The UK SAF mandate has much tighter qualification rules than the RTFO – in effect, for interchangeable feedstocks and pathways (e.g. HVO/HEFA) only those combinations which are double counted under RTFO qualify for SAF. No crop-based products are allowed. For the main obligation only, feedstocks defined as wastes qualify. For PtL low CI electricity is required (i.e. either renewable or nuclear) and there are further restrictions regarding "additionality" and temporal correlation.

**Figure 6: Current and planned SAF and biofuel facilities(13).**



The UK SAF mandate has relatively ambitious early targets but puts an increasing emphasis on the development of 2g SAF and relatively less weight on PtL than Refuel EU. It sets targets to 2040 only, reflecting the uncertainty around longer-term technology and market development.

There is limited SAF capacity in the UK today – HVO and SAF co-processing at the Phillips 66 refinery on Humberside, and potential for co-processing at the other four UK refineries (Fawley, Pembroke, Stanlow, Lindsay). There are some waste-based ethanol volumes that could be converted to 2g SAF and a handful of active 2g projects, all working towards Final Investment Decision (FID).

Domestically sourced waste lipids (tallow and Used Cooking Oil, or UCO) seem to be focussed on supply to the HVO market and are in any case small in volume. The UK is heavily dependent on imported waste lipids, and this is likely to increase with the introduction of the SAF mandate.

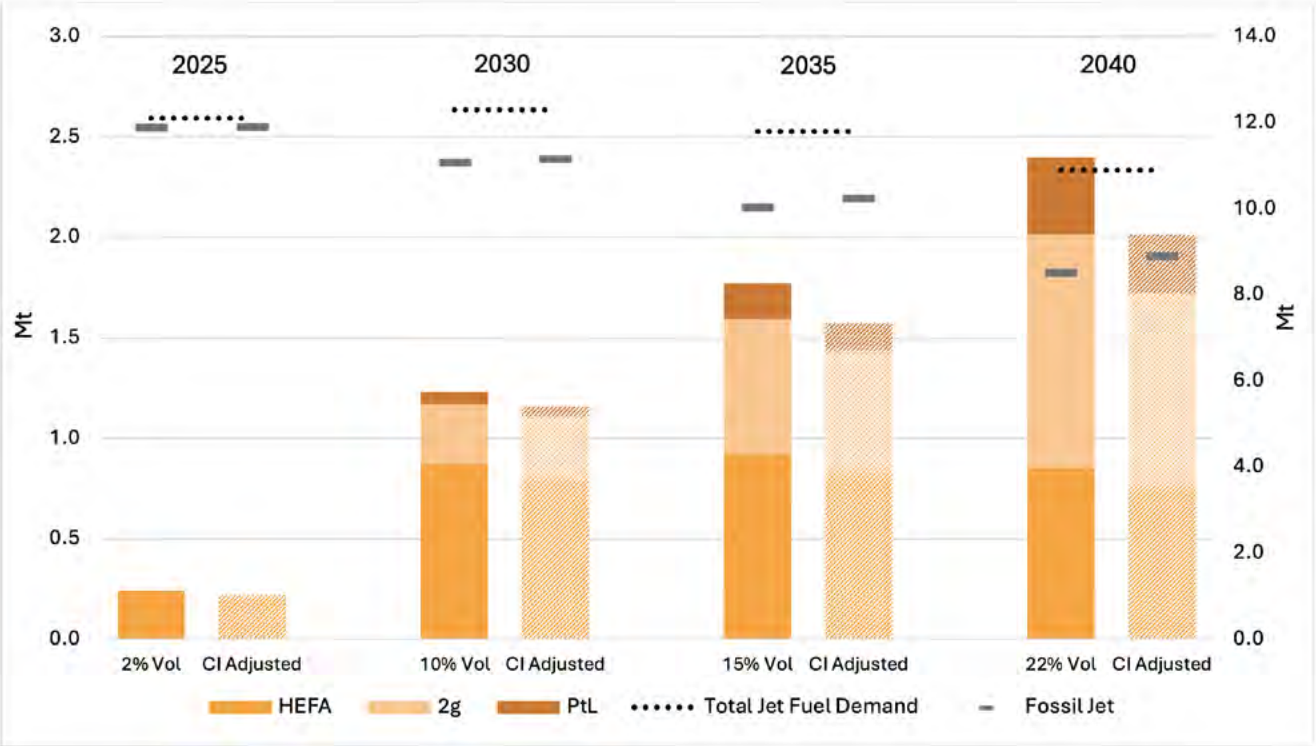
There is a range of associated measures intended to encourage the development of 2g SAF (necessary to fill the gap between the HEFA cap and the overall main obligation). Notable among them are:

- The Revenue Certainty Mechanism (RCM) – a market mechanism intended to remove revenue risk from new projects,
- The Advanced Fuels Fund (AFF) – providing financial support to technologies under development and
- The SAF Clearing House, tasked with providing technical guidance to developers around criteria for qualification and measurement.

The mandate defines not the absolute volume of SAF required, but the amount required to achieve equivalent carbon savings of SAF with a carbon intensity of 26.7g CO2e/MJ; a 70% reduction compared with AVTUR. Therefore, SAFs with a greater carbon reduction than the 70% default will discharge more than one certificate of obligation per litre, and hence a lesser volume is required to meet the mandate.

**In this chart and the following Cascade graphics, for illustrative purposes only HEFA is assumed to have a CI of 20g CO2e/MJ (78% reduction), and PtL a CI of 7g CO2e/MJ (92% reduction). 2g SAF is assumed to have a CI of 29.8g CO2e/MJ (67% reduction) until 2030, before decreasing to 13g CO2e/MJ (85% reduction) by 2040 as the technology is developed and processes are optimised.**

**Figure 7: Volumetric and CI adjusted implications of the SAF Mandate. Total jet fuel demand and fossil jet shown on secondary axis.**

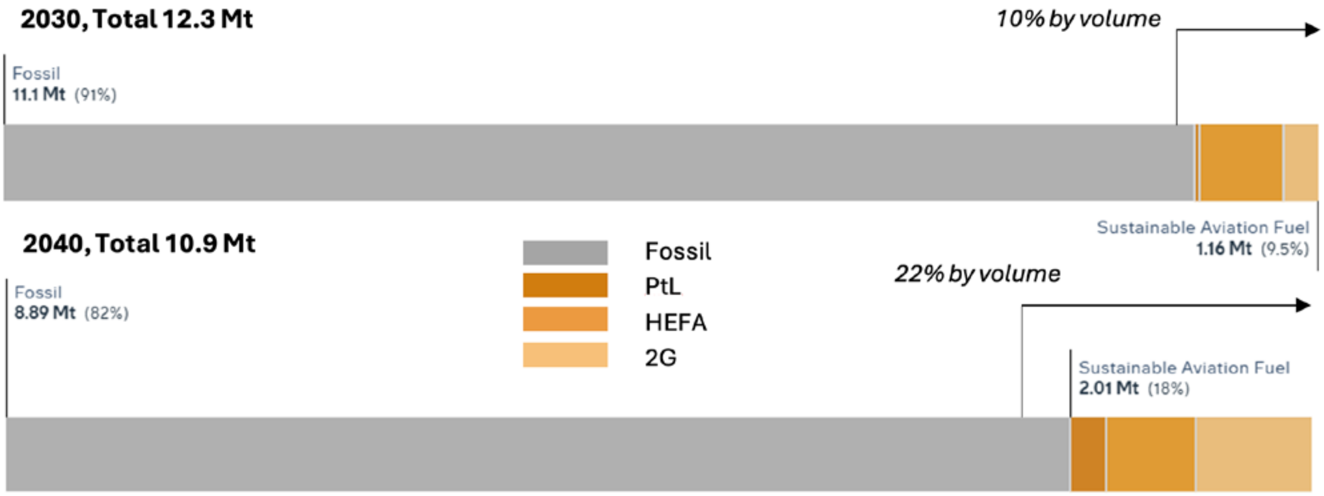


**This is an illustrative representation of the volumes of SAF required to meet mandate amounts.** This is critical. It means that in 2030, when the target is expressed as a 10% SAF volume target (split between HEFA (7.1%, 2g 2.4%, and PtL 0.5%) compliance is achieved not through simply delivering the volumes but instead delivering a 7% carbon intensity reduction. Carbon Intensity is established on a case-by-case basis, but if all HEFA is assumed to deliver an average 80% saving, 2g SAF an average 90% saving and PtL a 100% saving then rather than SAF representing 10% of total fuel volumes to deliver the mandate target in 2030 (7% carbon reduction), only around 8.4% of the physical volumes would need to be SAF.

Importantly, the mechanism allows negative emissions. SAF must demonstrate at least a 40% carbon saving to qualify.

This is central to an assessment of likely demand.

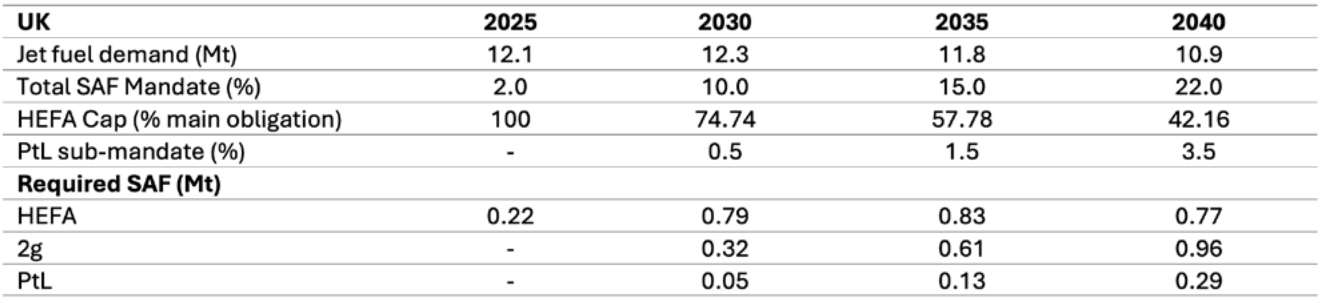
**Figure 8: Jet fuel mix to fulfil the mandate(6).**



The UK is not offering free Emissions Trading Scheme (ETS) allowances to airlines (but neither is it contemplating an AVTUR fuel tax). This aside, the competitiveness of UK fuel prices compared with EU will – in the short term - be a function of the aggregate effect of an overall higher UK mandate (partially offset by CI) combined with the need to include 2g against the more aggressive EU PtL mandate and a penalty scheme that, depending on SAF prices in short markets, could be more expensive than the UK buy out.

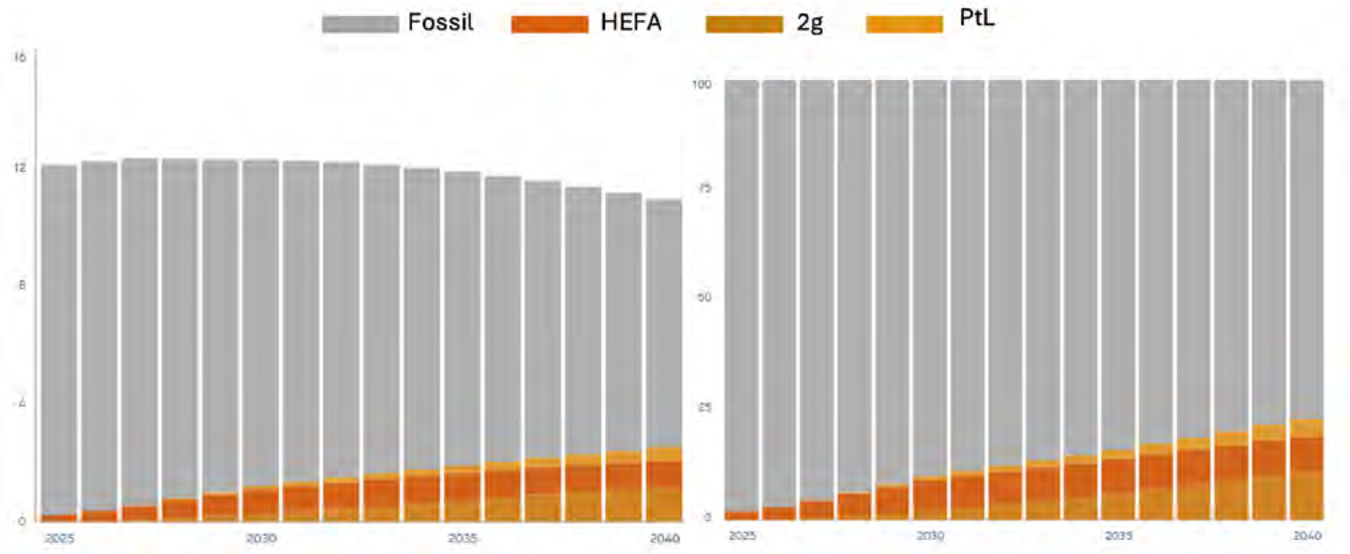
Unless the UK adopts anti-tankering measures there is a possibility that UK fuel liftings will decline-with tinkering risks both from non-mandate jurisdictions and with airlines utilising the EU ETS allowances and minimising fuelling in the UK for UK-Europe routes. Of course, this would have the unintended consequence of reducing the volumes required to fulfil the UK mandate.

**Table 2: UK demand summary(3, 7). SAF values in Mt are the CI adjusted values shown in Figures 7 and 8.**



| UK | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|
| Jet fuel demand (Mt) | 12.1 | 12.3 | 11.8 | 10.9 |
| Total SAF Mandate (%) | 2.0 | 10.0 | 15.0 | 22.0 |
| HEFA Cap (% main obligation) | 100 | 74.74 | 57.78 | 42.16 |
| PtL sub-mandate (%) | - | 0.5 | 1.5 | 3.5 |
| **Required SAF (Mt)** | | | | |
| HEFA | 0.22 | 0.79 | 0.83 | 0.77 |
| 2g | - | 0.32 | 0.61 | 0.96 |
| PtL | - | 0.05 | 0.13 | 0.29 |

**Figure 9: UK SAF Mandate volumetric requirements, absolute (left) and normalised (right) values(6).**



### EU Context

EU renewable fuels market regulations resemble the UK in some respects and differs in others:

- They operate through mandates (Renewable Energy Directive, or RED3 for ground fuels; Refuel EU Aviation or ReFuel-EU-A for SAF), with most of the cost of compliance borne by the end user. The RED mandates are met through the issue of certificates and achieved through the delivery of individual member-State targets.

- The mandates are the responsibility of different parts of the European Commission (DG Energy for RED, DG Move for ReFuelEU-A) which adds some complexity and uncertainty.

- The obligated party is the fuel supplier.

- For ground fuels there are caps on the use of crops and double counting of certificates for waste and advanced fuels. As in the UK there are blending limits for esterified biodiesels (e.g. FAME and used cooking oil methyl ester, or UCOME) and ethanol. Under RED there is an overall cap on the use of waste lipids (UCO, tallow) of 1.7% of total transport energy content. Based on 2022 data this equates to roughly 6.8 million tonnes . Targets are set by energy content. Non-compliance penalties are set at member-State level.

- For SAF there is an effective ban on all food crop-based products.

- The waste lipid cap does not apply to SAF. HEFA made from waste lipids, crops grown on severely degraded land and "cover" crops, advanced fuels from other wastes and PtL synthetic fuels all qualify for SAF. Any CO2 used must be biogenic.

EU SAF market arrangements differ from the UK in a few important respects:

- There is a single target for all 1g and 2g SAF and a separate target for PtL only (no HEFA cap). There is no double counting or other distinction between qualifying fuels within their respective submarkets. Targets are framed as volume share (rather than carbon intensity) of total fuels sold at a given airport (but with a transition period allowing for compliance averaged across the EU until 2034).

- Targets corresponding to the UK main obligation are lower, targets corresponding to the PtL obligation are higher. The PtL target has some flexibility in the early years of the mandate. The targets increase in steps.

- Rather than applying a fixed buy-out price, non-compliance is penalised by a fine levied on the fuel supplier that is at least twice the difference between the average cost of fossil AVTUR and the average price of SAF in its respective sub-market. The supplier must make good the supply shortfall in the following year – so in effect the penalty could be roughly three times the price delta. Revenue from penalties is intended to be hypothecated and reinvested in SAF research and development.

- The range of allowable feedstocks has recently been expanded to include feedstocks grown on severely degraded land and intermediate (often described as “cover”) crops.

- Anti-tankering regulations are in place (although apparently with implementation challenges), intended to restrict the opportunity for aircraft travelling from non-mandate jurisdictions to avoid refuelling with SAF when leaving an EU airport.

- The EU intends to narrow the price difference between SAF and fossil AVTUR through a range of mechanisms. Like the UK fossil AVTUR is no longer granted free ETS allowances, thus raising the effective price of fossil AVTUR, but the EU will also allow airlines to claim a number of ETS allowances to offset SAF costs on flights that are ETS liable, so reducing the cost of SAF (currently set at 20 million free allowances, with an estimated value of €1.6bn). There are also proposals to tax fossil AVTUR use on internal EU flights.

- The EU appears to favour subsidies to support new technologies (particularly PtL) and double-sided auctions to encourage offtake and price discovery.

The electrification of cars, and continued improvement in engine fuel economy, will reduce demand for diesel (and therefore biodiesel) but trucks and buses (and to a degree vans) will take longer to move to fuel cell or battery power trains. They take a significant share of the diesel market (approx. 40% in the UK). Potential biodiesel demand destruction will be more than offset by growth in SAF mandate volumes.

**EU Market: Implications for UK SAF Supply**

Feedstocks: RED and ReFuelEU favour wastes as compliance options, although cover crops and crops grown on marginal soils are now permitted in principle – the practicalities require a lot more work. RED has been instrumental in driving demand for waste lipids: 80% of the UCO/POME (palm oil Mill Effluent) used for EU biofuels (HVO and HEFA) is imported, mostly from China but also from Indonesia and Malaysia (8).

The EU will likely drive PtL demand – the significant volumes in the sub target, combined with broader incentives around green hydrogen should advantage development in Europe. Whether the volumes will be there to meet the 2030 targets remains to be seen…

The absence of a sub-market for 2g pathways means that these products will be competing with HEFA in the EU. This is potentially problematic for the EU:

- On the one hand holding back investment and development of EU 2g technologies until either HEFA supply is close to maxing out or the cap on the use of waste lipids is hit and demand for the more expensive, higher risk 2g products is clearly visible. (Double counting of advanced ground transport fuels under RED might mitigate this risk to a degree).

- While on the other effectively creating a premium for HEFA once the marginal tonne is 2g, resulting in higher aggregate fuel prices for EU consumers (and increasing HEFA prices in the UK).

This creates a potential opportunity for the UK - a market for the 2g production pioneered thanks to the HEFA cap.

In a short market, where accessing sufficient product to meet mandate obligations is problematic and there is a risk of a SAF price spike, the EU penalty structure will be more punitive than the UK.

At 2024 EU reference price levels (pre mandate and with uncertain price discovery) the price differential between AVTUR (734 eu/te) and HEFA (2715 eu/te) would need to grow from 1981 to 2510 eu/te before the UK would lose the marginal tonne of HEFA to the EU.

The higher the SAF premium, the more likely it is that EU willingness to pay will bid outbid the UK (of particular relevance to the PtL mandate).

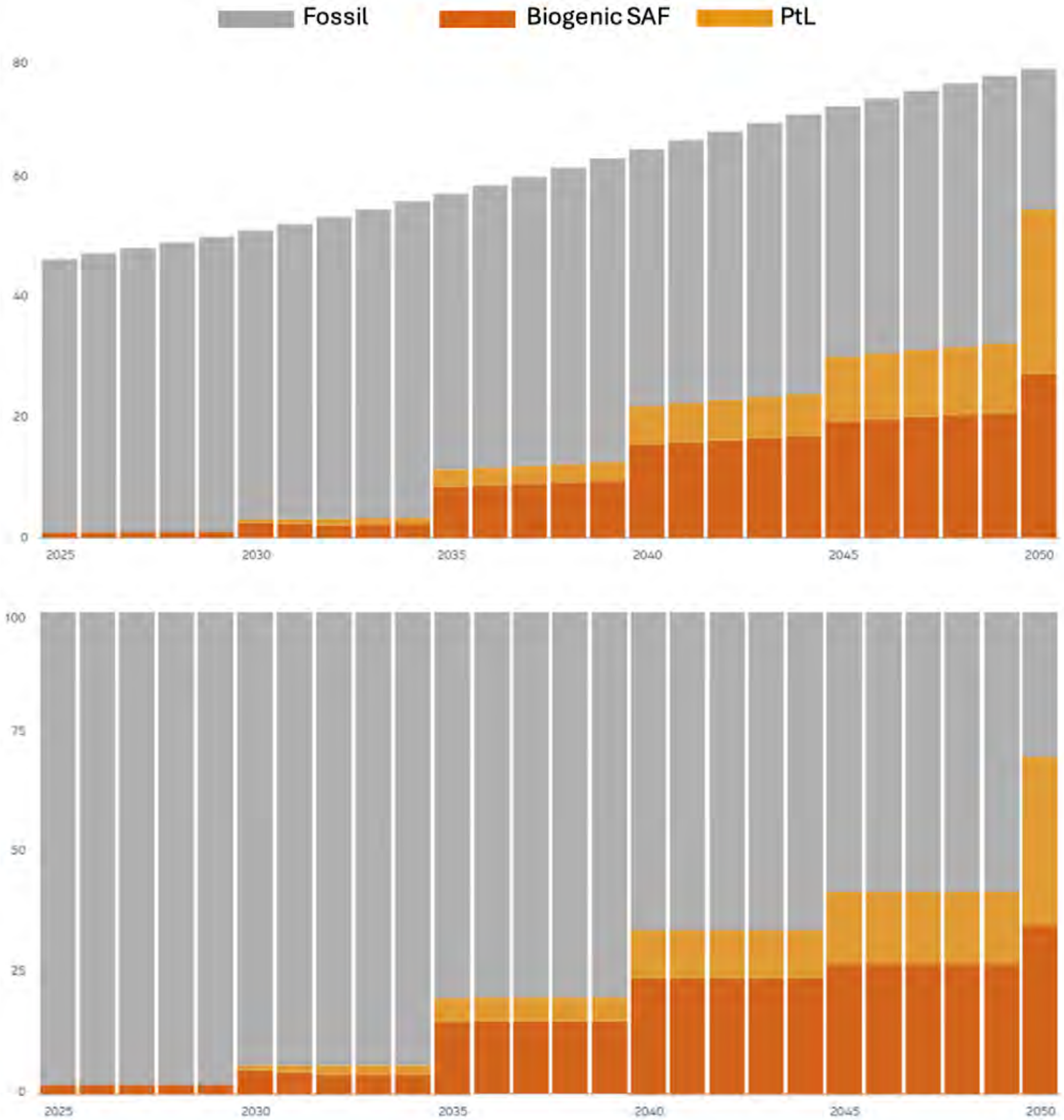
At 2024 reference levels it suggests that a supplier would, in extremis, pay up to 5940 eu/te to avoid non-compliance penalties (the UK default buy-out price of £4.70/litre converts to £5.27 for HEFA with Carbon intensity index of 1.11, or a cap at about 7530 eu/te

In a well-supplied market HEFA will price around the marginal cost of supply – which will itself be based on the value of the marginal tonne of waste lipid. In practice the HEFA price will be established by a published Argus/Platts quote.

**Table 3: EU demand summary.**

| EU | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|
| Jet Fuel Demand (Mt) | 45.4 | 51.1 | 57.2 | 64.1 |
| Total SAF Mandate (%) | 2 | 6 | 20 | 34 |
| Total SAF Mandate (Mt) | 0.9 | 3.1 | 11.4 | 21.8 |
| PtL Mandate (%) | - | 1.2 | 5 | 10 |
| PtL Mandate (Mt) | - | 0.6 | 2.9 | 6.4 |

**Figure 10: ReFuelEU mandate volumetric requirements, absolute (above) and normalised (below) values[(6)].**



**US Context**

In the US renewable fuels market, the price difference between renewables and fossil fuels is funded by both the taxpayer and the end user.

This is effected through a series of stackable credits - in all states the Renewable Fuel Standard (RFS) applies, issuing tradeable RINs (Renewable Identification Numbers - credit certificates) to qualifying renewable fuels through a waterfall system of classification against an obligation (RVO) as does the Producer Tax Credit, which includes a sliding scale mechanism rewarding the production of qualifying renewable fuels depending on their carbon intensity. The Producer Tax Credit (PTC) applies to exports – although HVO exports are currently subject to UK anti-subsidy and dumping investigation.

In some states there are additional incentives for renewables (Low Carbon Fuel Standard in California, Oregon, Washington and additional SAF credit in Illinois, Washington and Minnesota). Other states are considering options.

This is against a backdrop of relative oversupply of both biofuel production and crop processing capacity alongside strong yield improvements in corn and soy production.

The direction of travel is the rebalancing of domestic markets through a combination of expanding demand (increasing the RVO and raising renewable blend levels, such as E15) and restricting imports (limiting access to PTC to products made and grown in the US (NAFTA for feedstocks).

US SAF allows for crop feedstocks – with better carbon saving pathways rewarded through the PTC. Waste lipid HEFA, soy oil HEFA and cellulosic and corn ethanol to jet are the most likely pathways. The IRS uses a version of the GREET model to determine carbon intensity – this tends to have less punitive treatment of land-use change than European models (and recent changes to the PTC have removed Indirect Land Use Change ( ILUC ) factors entirely).

Production costs are typically lower compared with Europe. Aside from greater diversity in feedstocks, energy and construction costs are lower, and crop yields higher (in part because of genetic modification).

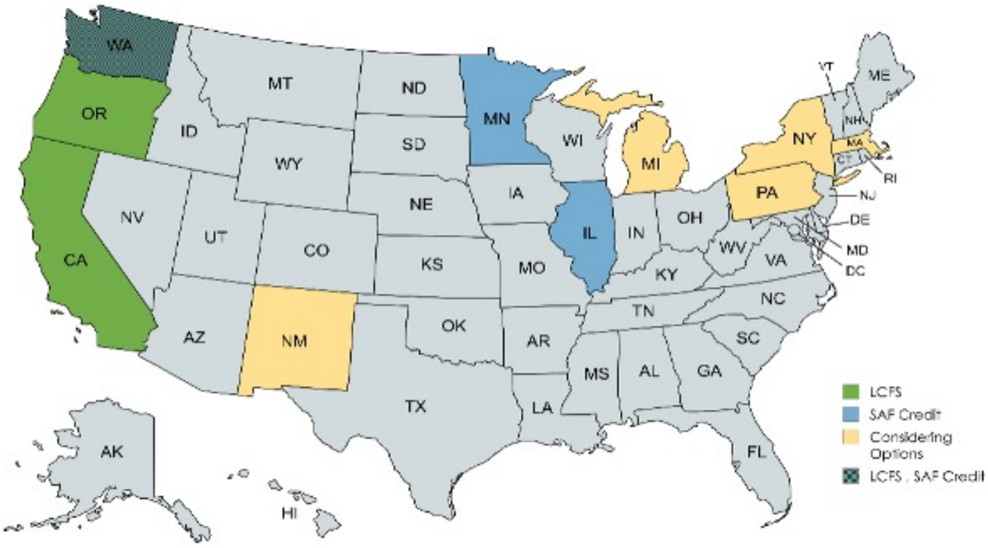
SAF usage is not mandated. SAF demand will therefore be a function of any SAF premium/discount to fossil AVTUR. The question is whether the combined value of PTC and RINs is sufficient to offset the additional cost of production for SAF. In most States (non-low carbon fuel standards (LCFS) + Ill), under current market conditions, it isn't.

In LCFS markets there is a clear advantage in prioritising Renewable Diesel sales over SAF, although LCFS markets offer higher premia for SAF than other States (except Ill and Min). Everywhere else the incentive to produce SAF rather than renewable diesel is marginal – especially since the reduction of the SAF PTC premium in the recently passed "Big Beautiful Bill". It is now treated the same as Renewable Diesel.

**Table 4: US demand summary.**

| US | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|
| Jet Fuel Demand (Mt) | 76.8 | 86.3 | 96.5 | 108 |
| SAF Target (%) | - | 10 | - | - |
| SAF Target (Mt) | - | 9.0 | - | - |

**Figure 11: Map of US incentives.**



**US Market: Implications for UK SAF Supply**

Feedstocks: The denial of PTC support to any product containing imported UCO effectively closes the export of UCO from China, Indonesia and Malaysia to the US – freeing up UCO volumes for use elsewhere. In 2023 the US imported over 2 million tonnes of UCO.

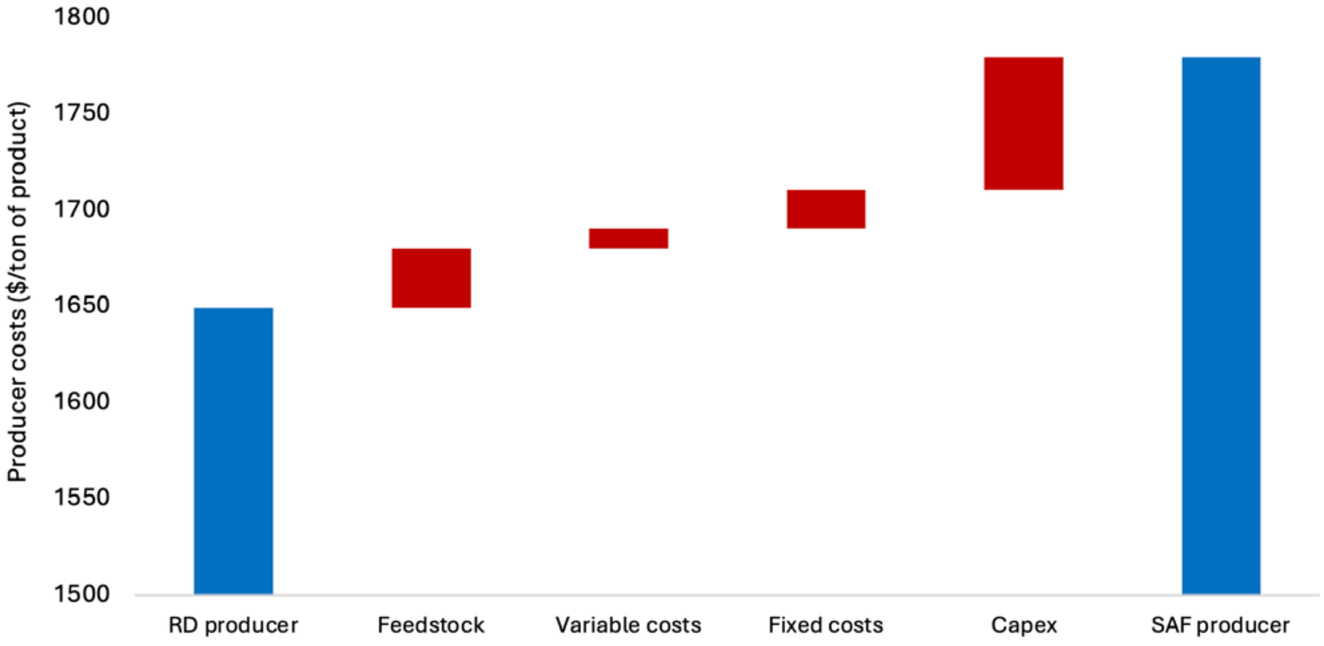
Post-PTC implementation NAFTA-sourced UCO and tallow is an advantaged feedstock for renewable diesel (HVO) and HEFA plants – but will likely be bid into LCFS markets that strongly reward low CI feedstocks.

The possible expansion of the RVO for biodiesel (both renewable diesel (HVO) and FAME) will absorb some of the current supply overhang (as will the need to substitute imported UCO). The eventual size of the RVO is uncertain – it could tighten global lipids markets and would certainly underpin RIN certificate values (possibly restricting export opportunities further).

It is not obvious that SAF production will ramp up significantly – for producers that can switch between renewable diesel and HEFA production the additional cost in producing HEFA (fig 12) and lack of premium in selling HEFA (fig 13) prioritises ground fuels - renewable diesel costs less and makes more - it is simply more profitable (at current values around $200/te). In 2023 around 8.8

million tonnes of RD were produced but only 19,000 tonnes of HEFA SAF (In 1q 2025 SAF production grew 77% year on year to 140,000 tonnes - it will be interesting to see whether the lower SAF support in the new Big Beautiful Bill means that this marks a high point).

**Figure 12: Incremental costs for SAF producer vs. renewable diesel producer (USA)(5).**



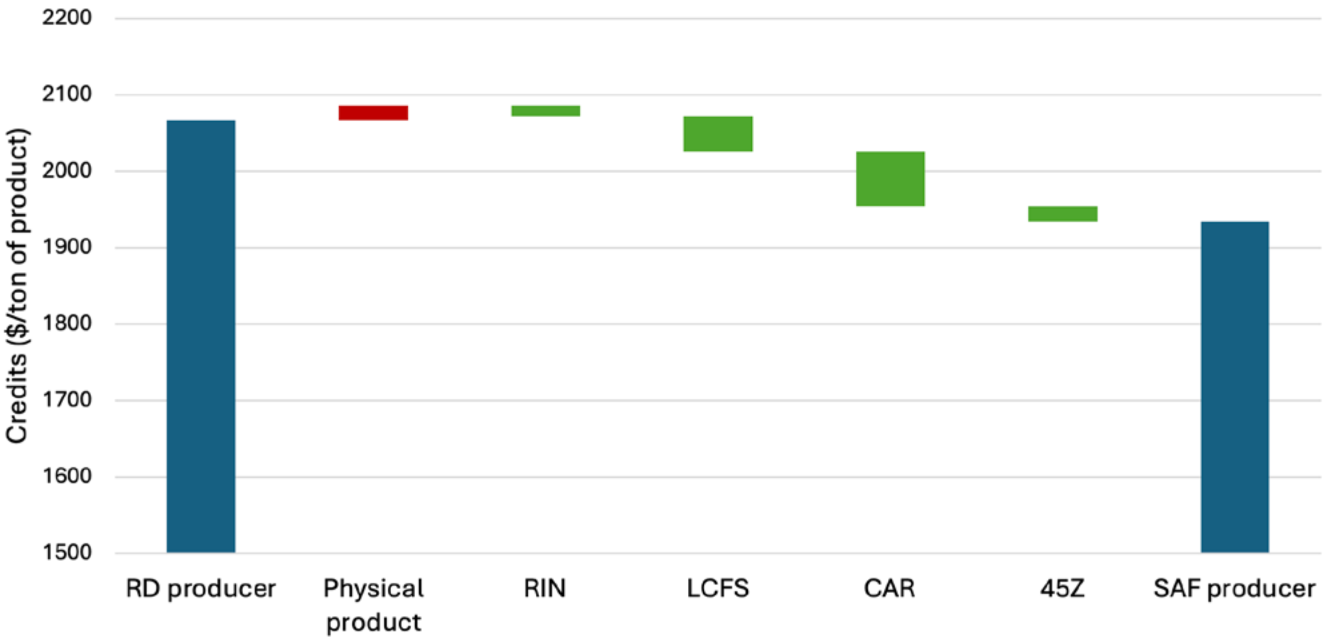
Corn ethanol to jet is a potential pathway (and potential beneficiary of carbon sequestration if the “carbon pipeline” is built) but the cost difference to HEFA will not be recompensed under current conditions. In any case it is not permitted under the UK mandate.

There is no compelling mechanism that specifically supports advanced SAF production.

Voluntary sales excepted, absent a mandate offtake is likely limited to those airports in States where SAF will be available at fossil AVTUR prices – where LCFS or SAF-specific support applies (so Pacific Coast and Illinois).

The risk of “tankering”, especially on East Coast–UK routes, is clear – airlines will be tempted to avoid UK SAF price premia by loading with fossil AVTUR for the round trip.

**Figure 13: Credit revenue for SAF producer vs renewable diesel producer (US)(5).**



Export-dedicated plants are a possibility - we have seen already that corn retentate (Unrefined liquid dextrose ultrafiltration retentate (ULDUR)) ethanol processing is now in place, targeting UK RTFO double-counting certificates as a sole market (it accounted for 28% of UK ethanol in 2024). Although regarded as corn ethanol in the US, under current UK legislation this could become a source of 2g SAF supply, if upgraded with ethanol-to-jet processing (this status is currently under review). Otherwise, exports would likely be limited to more expensive 2g pathways (such as cellulosic ethanol to jet), but the absence of a clear domestic market clearly adds to investment risk. Several RD producers and at least one HEFA SAF producer are based on the US Gulf Coast (and a new, first-of-kind, PtL plant has been announced) and so are well placed to export to the UK, however…

In order for the UK to bid away US capacity from renewable diesel it would (due to the combination of the new PTC and LCFS) need to be able to set a price that would give better profits than the LCFS States offer for product made from US-sourced waste lipids. We estimate that this would imply a UK HEFA price of around £1750/te if the exporter does not receive the PTC on exports. The UK/EU PtL mandate will be attractive to US PtL producers, leveraging lower energy costs and a specific incentive (if they can access it before it is withdrawn).

Overall, however, the key point is that, ULDUR excepted, the UK should not bank on volumes of advanced SAF becoming available to meet any supply shortfall. The incentive to invest in advanced SAF capacity to meet US domestic demand has been undermined by the absence of a mandate and the lessening of support for SAF. Investing in export-only facilities is a significantly riskier proposition.

### China Context

China has been a major player in UCO markets – it is a significant importer of palm oil and soybeans (which are then crushed in-country) to meet its own cooking oil needs. It has been diligent in maintaining cooking oil quality standards for domestic consumption (so there isn't a tradition of upgrading used oil for human consumption). Volumes are a function of population and per capita income – population is declining, and consumption has plateaued. It also imports grades of UCO for blending purposes – bringing domestic UCO output to export standards. It is therefore a significant producer of UCO, most of which has been exported to the US and Europe (23% of all renewable fuel used in the UK in 2024 was from Chinese used cooking oil), although (confusingly) volumes are also exported to Malaysia for bulking up for on-exporting. The US export opportunity has been largely closed with the recent introduction of the PTC, freeing significant further volumes for alternative applications (US imports amounted to almost 2 million tonnes in 2024).

A phased mandate, applicable to Chinese airlines, is starting to come into force on selected domestic routes starting in 2024. This year the blend rate at the pilot airports will be set at 1%, with cumulative consumption predicted to be around 50,000 tonnes of HEFA. This is expected to grow to up to 3 million tonnes in 2030 (a 5% blend rate) under the next five-year plan. Alongside this a range of incentives and financial support mechanisms across the value chain have been introduced.

The proposed expansion of Chinese demand has several potential impacts:

- If restrictions on allowable feedstocks are not applied, Chinese mandate volumes will use the lowest-cost source of lipids – whether palm /soy or domestic UCO. This creates new demand that will offset the volumes freed up by the loss of the US export market.

- China is developing new HEFA capacity. The first new plants are already operating. They will have material domestic supply markets that exports will need to bid supply away from. Export volumes are anticipated to be at least 300,000 tonnes this year, increasing to 500,000 tonnes in 2026. These will likely use material UCO volumes - so taking 450,000 tonnes this year and 750,000 tonnes in 2026.

- The trajectory of the possible mandate is aggressive, and the supply-chain support mechanisms feel familiar – there is potential for Chinese capability and capacity in SAF to mirror what has already been seen in other aspects of renewable technology development – solar panels, batteries (and EVs), wind turbines and electrolysers. The mandate should perhaps be viewed as a stimulus to industrial strategy in a potentially important new market rather than simply a step towards decarbonisation. It opens the question whether we might see Chinese cost and scale leadership in 2g and 3g SAF technologies develop by the mid-2030s.

If the mandate doesn't happen, China will have a substantial surplus of both UCO and HEFA production capacity.

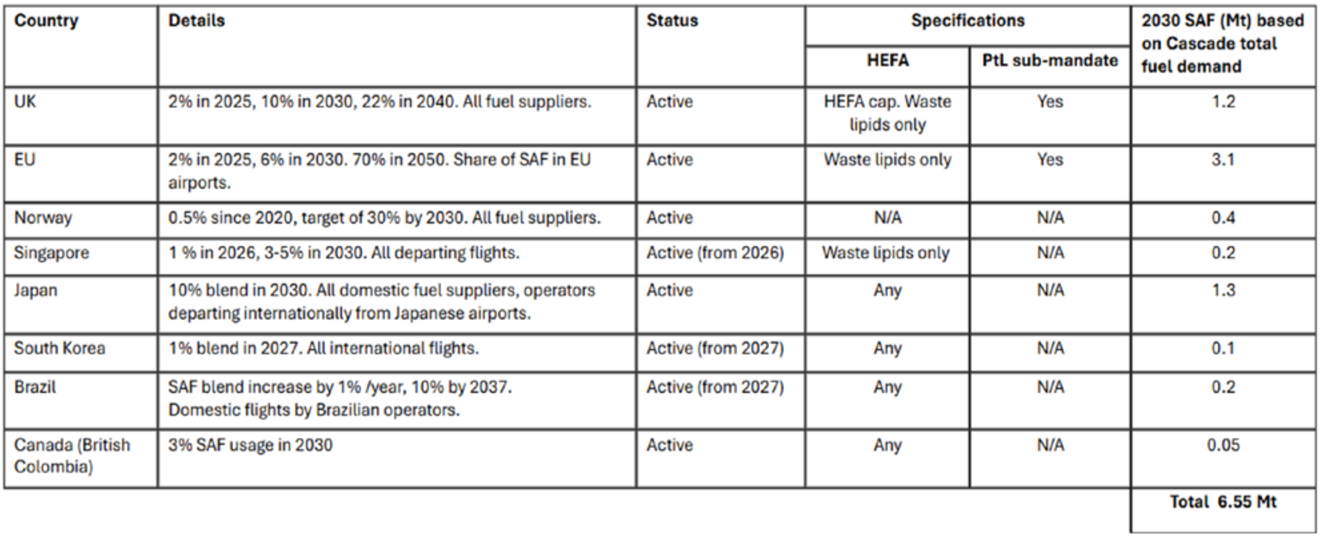
**Table 5: China demand summary. SAF targets apply only to Chinese operators.**

| China | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|
| Jet Fuel Demand (Mt) | 45.4 | 51.2 | 57.1 | 63.7 |
| SAF Target (%) | 1 | 5 | - | - |
| SAF Target (Mt) | 0.3 | 1.7 | - | - |

### Other Demand Centres

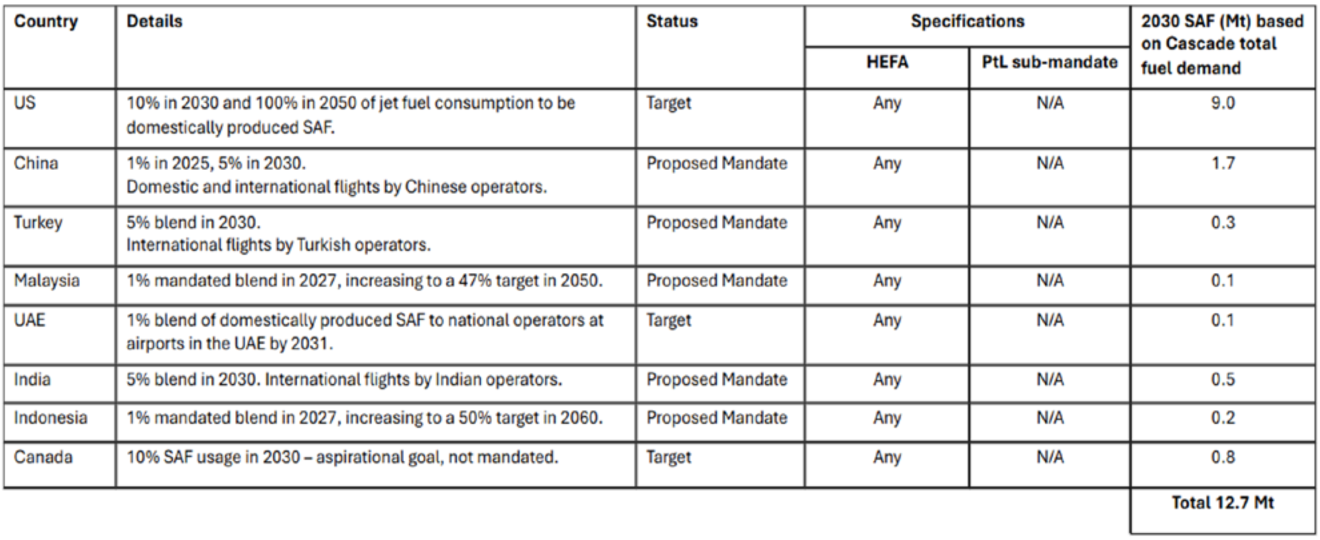
Several jurisdictions have biodiesel mandates already – creating demand for both waste and crop lipids. As table 6 shows, a few jurisdictions have announced or are moving towards SAF mandates. British Colombia is adopting US-style incentives and others have hybrid approaches. A few have long-term targets with no current compliance mechanism. That said, beyond the UK, Norway and the EU progress is somewhat tentative. In most cases key design details – including compliance mechanisms, penalties and feedstock requirements are still unresolved.

**Table 6: Active SAF mandates[17].**



| Country | Details | Status | Specifications | | 2030 SAF (Mt) based on Cascade total fuel demand |
|---|---|---|---|---|---|
| | | | HEFA | PtL sub-mandate | |
| UK | 2% in 2025, 10% in 2030, 22% in 2040. All fuel suppliers. | Active | HEFA cap. Waste lipids only | Yes | 1.2 |
| EU | 2% in 2025, 6% in 2030. 70% in 2050. Share of SAF in EU airports. | Active | Waste lipids only | Yes | 3.1 |
| Norway | 0.5% since 2020, target of 30% by 2030. All fuel suppliers. | Active | N/A | N/A | 0.4 |
| Singapore | 1 % in 2026, 3-5% in 2030. All departing flights. | Active (from 2026) | Waste lipids only | N/A | 0.2 |
| Japan | 10% blend in 2030. All domestic fuel suppliers, operators departing internationally from Japanese airports. | Active | Any | N/A | 1.3 |
| South Korea | 1% blend in 2027. All international flights. | Active (from 2027) | Any | N/A | 0.1 |
| Brazil | SAF blend increase by 1% /year, 10% by 2037. Domestic flights by Brazilian operators. | Active (from 2027) | Any | N/A | 0.2 |
| Canada (British Colombia) | 3% SAF usage in 2030 | Active | Any | N/A | 0.05 |
| | | | | | Total 6.55 Mt |

**Table 7: Proposed SAF mandates and targets[17].**



| Country | Details | Status | Specifications | | 2030 SAF (Mt) based on Cascade total fuel demand |
|---|---|---|---|---|---|
| | | | HEFA | PtL sub-mandate | |
| US | 10% in 2030 and 100% in 2050 of jet fuel consumption to be domestically produced SAF. | Target | Any | N/A | 9.0 |
| China | 1% in 2025, 5% in 2030.<br>Domestic and international flights by Chinese operators. | Proposed Mandate | Any | N/A | 1.7 |
| Turkey | 5% blend in 2030.<br>International flights by Turkish operators. | Proposed Mandate | Any | N/A | 0.3 |
| Malaysia | 1% mandated blend in 2027, increasing to a 47% target in 2050. | Proposed Mandate | Any | N/A | 0.1 |
| UAE | 1% blend of domestically produced SAF to national operators at airports in the UAE by 2031. | Target | Any | N/A | 0.1 |
| India | 5% blend in 2030. International flights by Indian operators. | Proposed Mandate | Any | N/A | 0.5 |
| Indonesia | 1% mandated blend in 2027, increasing to a 50% target in 2060. | Proposed Mandate | Any | N/A | 0.2 |
| Canada | 10% SAF usage in 2030 – aspirational goal, not mandated. | Target | Any | N/A | 0.8 |
| | | | | | Total 12.7 Mt |

Of the many biofuel mandates in place, the Indonesian biodiesel mandate is noteworthy – targeting 50%. Indonesia also has an energy-security motivated SAF goal – potentially utilising purpose-grown palm. These will most likely be met with palm oil as the feedstock.

### Demand-Side Headline Conclusions

Overall, mandates count. SAF is expensive and the airline industry is very competitive. Targets and ambitions without mandates cannot be relied on. Business to business (B2B) sales enabling airline corporate customers to reduce scope 3 emissions are optically useful, but marginal. Confirmed mandates amount to 6.55 million tonnes in 2030. Although some estimates go as high as 15 million tonnes the unlikelihood of the US SAF Grand Challenge aspirations being met suggests that the 5-10 million tonnes range is more realistic. In the UK/EU waste-lipid based HEFA will be the preferred supply outside separately mandated submarkets – at least until waste HEFA supplies are stressed. Elsewhere it will be the cheapest feedstock – often palm or soy oil.

The US is the biggest market for AVTUR. Under current (and currently developing) regulations, with no mandate and incentives slanted to favour Renewable Diesel production, it is unlikely to be a major user of SAF – it is possible that offtakes will not be much higher than “voluntary” B2B sales by airlines to corporate customers. More aggressive support from individual states may change this.

The US will therefore not be a major rival to the UK/EU for access to UCO or HEFA supplies from China and SE Asia.

US HEFA SAF exports will occur only if the transatlantic arb opens wide enough to either bid NAFTA produced UCO/Tallow from LCFS states and/or imported UCO is viable.  If the RVO is significantly increased (as is possible) then the value of biodiesel and advanced diesel RINs may grow significantly, which would require an even greater expansion of the arb (this assumes that the UK translates the current (but under legal challenge) acceptance of imports of US subsidised HVO across to HEFA).

US non-HEFA SAF exports could be material if the supply of ULDUR ethanol increases. Otherwise, it is likely to be limited given the lack of domestic demand, although we might see some PtL. The US will not fill an advanced SAF UK supply gap in the short to medium term.

The development and enforcement (or not) of Chinese and other Asian SAF mandates is a major swing factor. If it happens, the export length created by the near elimination of the US UCO export opportunity for China could be significantly offset. Absent clarity on the confirmation and then design of the many new mandate markets, the emerging Chinese (and other Asian) HEFA production capacity will clearly be EU/UK bound.

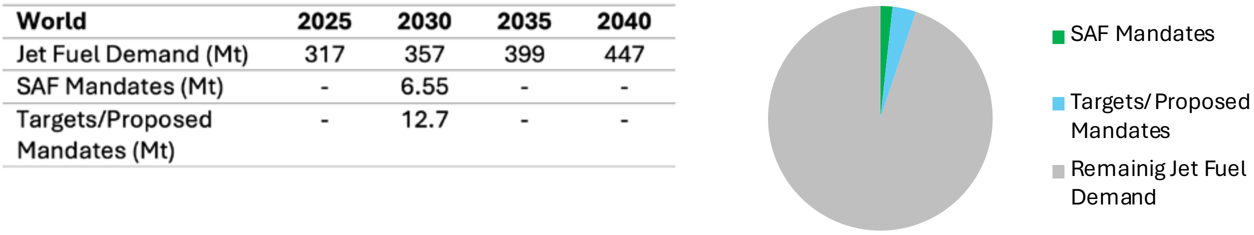
RoW demand is likely to be muted – the most material competition for volumes and feedstocks will arise from national biodiesel mandates, impacting HEFA feedstock costs.

The EU will be the largest market for waste-based HEFA but is unlikely to compete for 2g SAF until HEFA supply is constrained. Based on current prices in a short market the UK would bid away the marginal tonne, but this would change if the AVTUR/HEFA spread expanded significantly (which it would likely do in an undersupplied market.

- The relative compliance cost of ethanol vs HVO in ground transport, and between HVO and HEFA in their respective markets, will influence volume allocation. For as long as markets are well supplied, competitive intensity across respective (ground fuels and aviation fuels) supply chains will be the ultimate determinant of value and volume allocation.

- EU will drive PtL market demand, UK 2g SAF demand.

**Figure 14: Global jet fuel demand, mandates and targets.**



| World | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|
| Jet Fuel Demand (Mt) | 317 | 357 | 399 | 447 |
| SAF Mandates (Mt) | - | 6.55 | - | - |
| Targets/Proposed Mandates (Mt) | - | 12.7 | - | - |

## Market Reflections

### Regulatory Arbitrage: Broad conclusions

The UK mandate creates a unique market for 2g SAF. The opportunity is to create early-mover advantage for UK-based or developed technologies, a broader and potentially very material market for which may emerge should the supply of HEFA feedstocks become constrained (whether on physical or sustainability grounds) and the development of PtL technologies take longer and cost more than the more optimistic forecasts predict.

The creation of a distinct market space for 2g should enable the UK to attract any early mover 2g SAF developed in other markets, where today it would be forced to compete with cheaper HEFA. The RCM mitigates the risk of margin erosion should this happen.

The short-term challenge for the UK is the mobilisation of sufficient capacity to meet the early non-HEFA volume targets. The longer-term challenge is ensuring the availability of appropriate feedstocks to assure scale up, the fulfilment of mandate targets into the 2030s and the opportunity to lead a global industry.

The competitive challenge is whether the opportunities created via market design in the UK will outweigh potential supply-side subsidy in other jurisdictions. In the short term it is probable that EU focus will be on developing PtL and the US will be driven by a mix of farmer support and energy security drivers. The unknown is China.

In a long market the UK will be a price taker for HEFA, with prices a function of global UCO balances and HEFA capacity, based off market indices. SAF will always need to bid away capacity from ground fuel markets – which have a greater diversity of supply options.

In a short market, at current prices, the UK SAF buy out - even when adjusted to account for CI certificate value - would be less expensive than the open-ended EU penalty scheme. The marginal tonne will be bid away by the EU. In such conditions the pecking order would be EU SAF, UK SAF and thereafter ground fuels – order dependent on relative member State/ UK buy outs. This is even more pronounced in the PtL markets.

At buy-out prices supply of waste-based HEFA would likely be bid away from US market.

The EU penalty mechanism establishes the potential premium an EU-based supplier could pay to bid 2g SAF away from the UK.

Within the UK SAF should outbid RTFO for HEFA/HVO when the market is tight (by virtue of the much higher SAF buy out).

The threat of the non-compliance penalty (EU) /buy out (UK) might provide a significant incentive for suppliers to invest in new technology (PtL in EU, PtL and 2g in the UK). However, there is always the likelihood that penalty prices will, if market-wide, be simply passed on to customers. If suppliers feel that they are uniquely at risk, there is a possibility that rather than seek to invest in compliance solutions they choose to reduce their participation in aviation fuel markets.

The US is starting to look like a more self-contained market, with SAF development held back by the absence of a mandate and the relatively greater profitability of domestic renewable diesel markets. Export-driven capacity could emerge should net back margins exceed domestic returns, but current UK feedstock restrictions mean that the UK would need to price significantly higher than LCFS markets (we estimate at least $2300/te) to attract product made from US domestic waste lipids or cellulosic ethanol from the Pacific Coast market.

All these new markets will add demand pressure for lipids, whether waste or otherwise (as will biodiesel mandates and tax regimes in feedstock supply markets). Under current conditions, vegetable oil and tallow prices should be expected to increase.

The UK HEFA and EU main SAF mandates will likely be the among last of the (non US) UCO markets to be affected in a global supply crunch (the eventual design of some of the more recently announced mandates may change this) – the penalty and buy-out prices mean that the willingness to pay is very high and in competing ground fuels markets there is a broader range of relatively competitive substitutes.

## UK Market Operation: Hypothesis

The SAF market is very immature. Although SAF has been sold for over 5 years there are limits to the lessons that can be taken from the operation of the voluntary markets that came before the mandate markets – which have only been in operation since the start of 2025. Clear evidence will have to wait until the completion of a full year of activity under the mandate.

The mandate has three key elements that frame price setting:

1. The creation of distinct submarkets, each with annual targets (shown as percentages of total aviation fuel volumes).

2. The use of carbon intensity as the certificate metric.

3. The buy out prices.

On the basis that the obligated party will normally seek to minimise their cost of compliance, they will (for as long as SAF costs more than fossil AVTUR, even with ETS), preferentially purchase products that generate the most carbon savings – they will earn more certificates per litre and so reduce the number of litres of SAF they need. This obviously has value - the question is how the potential value of SAFs of different carbon intensity might be allocated across the supply chain. The strong will crowd out the weak – but will it be rewarded by price as well?

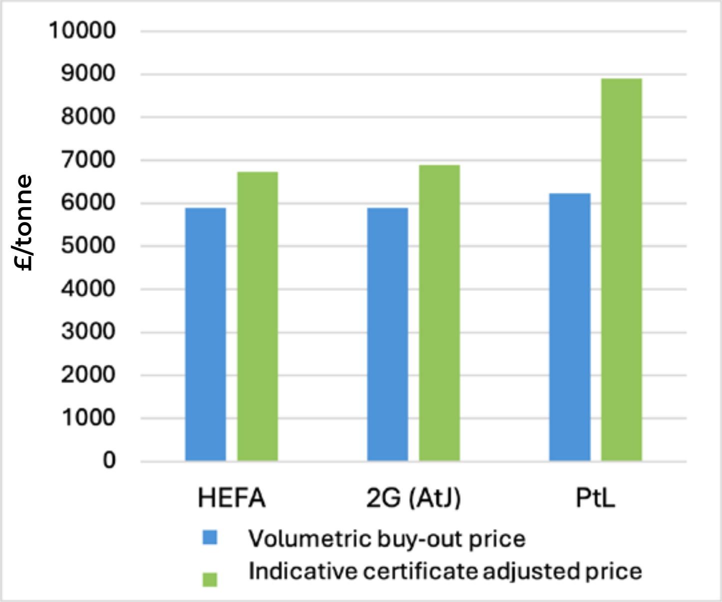
The RTFO market for renewable ground fuels has been operating for over a decade. Although it has some different design features it does offer some pointers on what might be expected with SAF – particularly when looking at the pricing of double-counted products.

Under the RTFO the experience has been that when the market has been well supplied the value accrues downstream – the market clears at the marginal cost of mandated product. This reflects the very competitive and relatively transparent nature of most ground fuels markets. The obligated party in effect buys a physical tonne of product with one or two certificates attached. The certificates themselves are valued at the difference between the relevant fossil fuel price and the price of the marginal tonne of renewable fuel. Although certificates can be traded the certificate market is relatively shallow as might be expected in a market that is well supplied with physical tonnes.

In the early days of the SAF mandate, with shallow, illiquid markets and a prevalence of bilateral supply arrangements this experience will likely not be replicated immediately.

For HEFA the limited variations in carbon intensity combined with the presence of larger and deeper markets in Europe for like products means that the UK will be a price taker – HEFA will price off a Rotterdam quote. In the short to medium term there should be more HEFA/HVO than SAF mandates require – so double-counting ground fuels will underpin the price. The CI of HEFA is expected to be slightly better than the default CI and will create value by requiring fewer litres than the headline mandate quantity – so reducing overall fuel costs versus a default CI counterfactual.

**Figure 15: Short Market Pricing.**

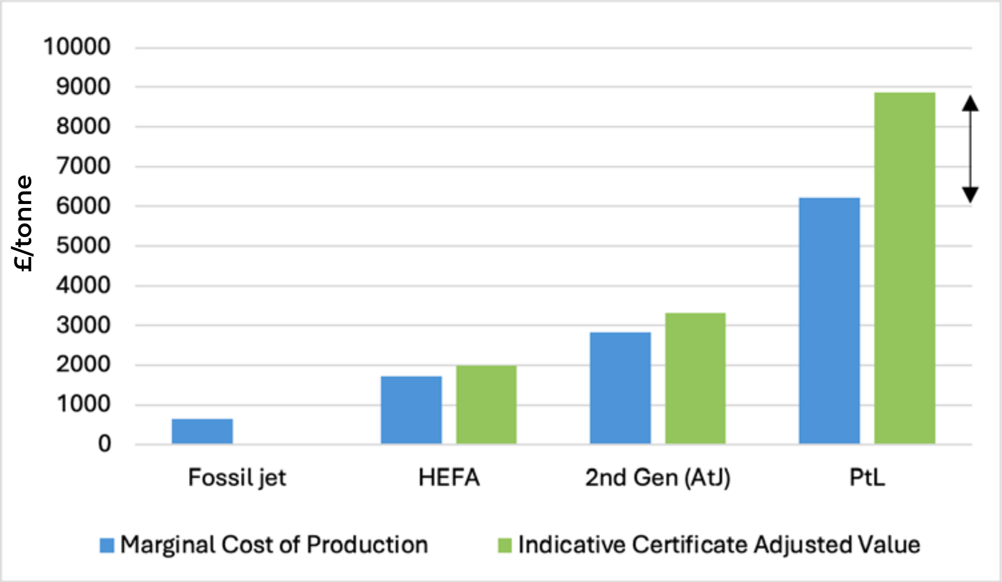


In a short market – where there are insufficient volumes of qualifying products to meet the obligation - the buy-out price will be triggered. The spot price of products should be expected to match the buy-out price, and the full value of the scarce product should flow to the producer. Because the certificates are based on carbon intensity this value will not be a simple volumetric read-across. Only if a product has the default CI index value of 0.7 (a GHG saving of 70% vs fossil AVTUR, one litre generating one certificate), will the buy-out price be £4.70/l (main obligation). A product with a greater than 70% saving will generate more than one certificate and so should command a higher price (for example, assuming a litre of HEFA at, say, 80% emissions reduction this would push the effective spot value to £5.37/l).

In more balanced markets the value of the extra certificates created by virtue of a better CI than the default value could in theory be converted into value. How this is shared between producer, supplier, airline or passenger is a function of the competitive dynamic in the market. The longer the market, the more likely the value will flow downstream.

In a very well supplied market, the value will definitely flow downstream – prices will clear at the marginal cost. However, even in such a market an advantaged CI still has value.

**Figure 16: Long Market Pricing.**



*Delta reflects the fuel value which will be shared throughout the supply chain between producers, airlines and consumers.*

In Figures 15 and 16, the CI reductions relative to fossil jet are assumed to be 0.8, 0.82, and 1, for HEFA, 2g and PtL respectively.

Because the mandate rewards CI rather than volume or energy content in awarding certificates the cost of the marginal certificate is the key driver - the obligated party will seek to generate certificates at the lowest cost. The cost of a SAF certificate for a given product is – at its simplest - the incremental cost of supplying that product (over a litre of fossil AVTUR) multiplied by the CI factor.

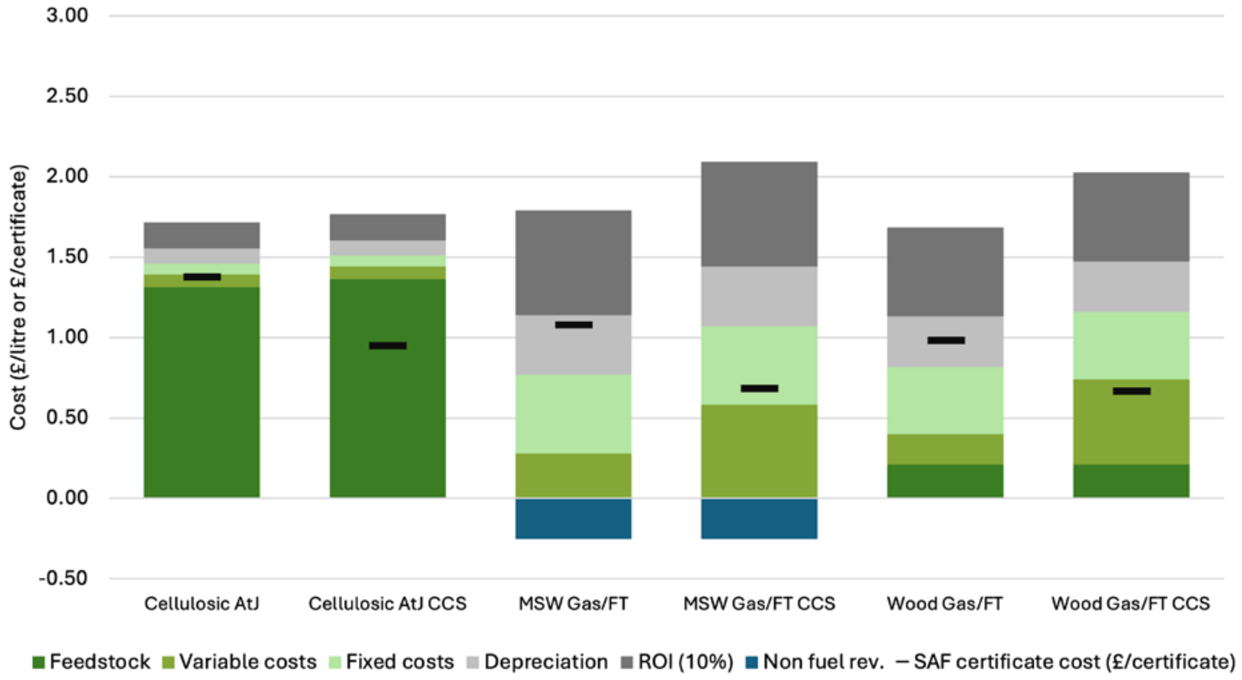
Given that the mandated demand is growing, and investment in new capacity will be needed, products in the non-HEFA sub-market should price at the fully built-up cost of the marginal certificate plus the price of a litre of fossil AVTUR.

Producers with lower certificate costs should accrue additional margin – they are cost advantaged. Products with higher certificate costs will struggle to compete (as we have seen in the RTFO market).

At its simplest, the cost of generating a SAF certificate will be the difference between the price of a litre jet fuel and the cost of a litre of SAF divided by the carbon intensity index of the SAF (so the carbon saving relative to the default certificate value). A SAF with a better carbon performance will generate more than one certificate per litre, and one that delivers less than a 70% carbon saving will produce less than one certificate per litre of product. In the report's more sophisticated techno economic modelling, account is also taken for the credits for any co-products that are produced alongside the SAF, which adjusts the outcome to a degree.

But the basic principle is that the cost of a certificate is a function of the cost of production and the relative carbon intensity. The better the carbon intensity and the lower the cost of a physical litre, the lower the cost of a certificate. A clear example of this is how the Carbon Capture and Storage (CCS) pathways, although more expensive per litre, yield cheaper certificates by virtue of the negative emissions.

**Figure 17: Cost build-up for SAF production technologies with and without CCS (10% ROI, 25% discounted gate fee)(5). Full assumptions found in Annexe 1.**



The price of a certificate, on the other hand, is the difference between the market price of SAF in the respective submarket (we assume this will be set by the cost of a litre of the marginal certificate product) and the price of a litre of fossil AVTUR.

## Supply

### 2g Potential Supply

2g SAF will come from a variety of waste-based pathways – all of which are emergent. Ligno-cellulosic, flue gas fermentation and agricultural waste ethanols to jet, solid waste gasification and catalysis are among the leading current pathways allowed under current regulations (with tyre oil pyrolysis and sewage sludge to bio-crude awaiting ASTM qualification).

Developing a robust UK 2g SAF industry is a UK Government preference – evidenced by the unique non-HEFA mandate sub-market, the AFF and now the introduction of the RCM. The UK mandate remains globally unique in its encouragement – through market design – of the development of an advanced SAF fuels capability.

Technology and finance risk are still major problems. None of the key technologies have yet been fully demonstrated at scale – although some individual steps (such as the LanzaTech and Raizen cellulosic ethanol processes) are in commercial operation in other countries and others are close. On the whole however technology readiness levels (TRLs) are still in the 6-8 range.

UK-based projects cover the range of possible pathways, but none have yet got to FID.

Potential supply of 2g SAF will be a function of the timing of the successful pathways coming on-stream (and overcoming initial integration problems) and the extent to which scale-up is constrained by feedstock availability.

For each pathway cost, carbon intensity and scalability need to be considered. A mix of technologies could contribute to mandate fulfilment in the next 5-7 years, but as mandate volumes grow scale will become central.

Feedstock availability is a necessary (but not sufficient) condition for scale. Most pathways are waste-dependent. Reliance on imported waste will in most cases create a significant regulatory arbitrage risk and potentially political pressure as well – it is prudent to assume that a UK industry will need to rely primarily on UK-sourced feedstock.

Most feedstocks of interest to 2g pathways have other outlets – they will need to be bid away for application in SAF. MSW is a leading example, as is sewage slurry, which today has value for anaerobic digestion plants - producing biogas for the gas grid. Waste-based ethanol would need to be bid away from the RTFO double-count market.

Although nowhere else in the world offers a discrete advanced SAF market space, it is possible that the UK advanced SAF sub-market could attract potentially competitive and scalable products from other countries. Leading examples include sugar cane bagasse-based ethanol to jet from Brazil and, building on the success that this product has had in dominating the RTFO ethanol market, corn ULDUR ethanol to jet from the US (assuming it retains its status).

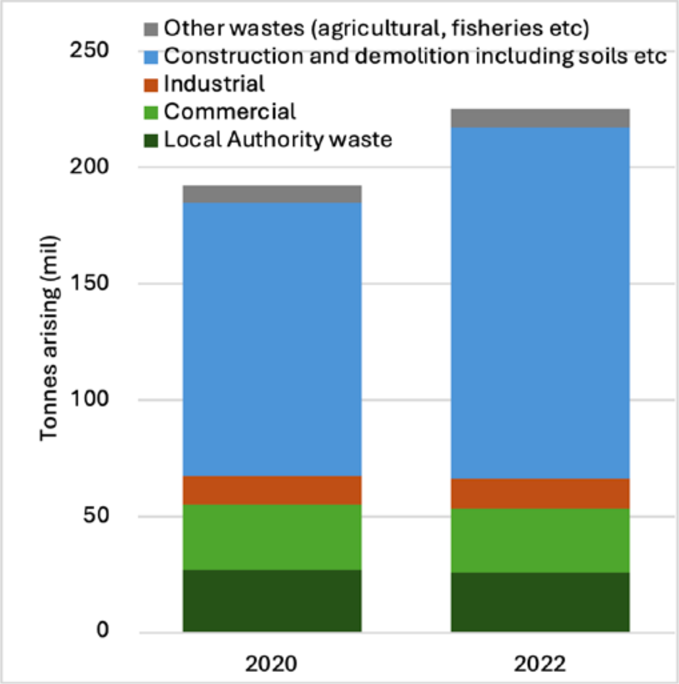
These potential sources increase the likelihood that the mandate will be fulfilled (and at a potentially lower cost) but also reinforce the importance of the RCM (and other supportive interventions) if a UK-based industry is to be successfully developed.

While some pathways will clearly be limited in terms of scale more work needs to be done to complete a full picture of realistic supply potential of the more emergent technologies. To test whether one of the more me of the questions around advanced SAF scale up a deep dive into the MSW and waste wood Fischer Tropsch pathway has been undertaken.

**F-T Gasification pathway feedstock supply (MSW and waste wood): Deep dive**

Pending a breakthrough with cellulosic ethanol production the MSW Gasification and/or waste wood FT pathway could, at face value, be one of the most scalable domestically produced 2g options over the next 10 years, if only because of the quantity of waste arisings in the UK.

**Figure 18: UK waste arising from all sources[(9)].**



Of the 220 million tonnes of waste that the UK produces some 30 million tonnes are potential feedstocks for SAF (2.6 million tonnes of waste wood and 26 million tonnes of residual municipal solid waste (aka black bag waste) after recycling. However, the UK is targeting residual waste reduction – through tightening packaging regulations, introducing ETS and encouraging higher recycling rates. These measures are forecast to reduce residual waste by up to 3 million tonnes p.a. by 2035 (even allowing for 1% growth in annual overall waste).

In the past this would have gone to landfill. Today, residual waste is mostly sent to energy from waste incinerators, an industry that was supported by the introduction of the Landfill Tax. A local authority pays to dispose of waste in a landfill, currently around £160/te. The EfW company can secure the waste by charging the local authority less than the landfill tax to dispose of their waste – the "gate fee" - typically around £90/te on a term contract, or £120/te spot. This is now a material industry, with 17 million tonnes of operational capacity, delivering 15% of UK renewable electricity and with a further 5.5 million tonnes under construction or at financial close.

Overall, the 26 million tonnes of potential feedstock will likely decline year on year as recycling and other initiatives take effect with 22 million tonnes of current or potential EfW capacity competing for the balance.

A significant proportion of MSW is under long-term contract with EfW facilities – assets financed with only a small amount of merchant capacity exposure. EfW is a known technology. MSW SAF is yet to demonstrate viability at scale. Risk-averse local authorities will understandably favour the known offtake from EfW plants over much less certain SAF projects – which will likely be more restricted in the range of waste they can take than the local authority might like. However, the market is now more balanced, and local authorities may feel more confident in encouraging competition among a more diverse set of off takers. Much of the MSW market is managed by "first tier", or vertically integrated, companies who collect and process MSW – they have an interest in retaining control of the full value chain. This is a further challenge for SAF projects if, rather than contracting directly with local authorities, they seek to contract with tier 1 operators for supply. Non vertically integrated contractors may be open to providing supply, but they are typically smaller operations.

Each tonne of residual waste treated in this way typically releases around half a tonne of fossil CO2 – in aggregate amounting to around 5% of UK total emissions. The introduction of ETS to waste processing is a partial response to this issue.

EfW plants that can access CCS capacity are likely to remain competitive (although applying CCS to an EfW plant will be more costly than with a gasification technology (like MSW FT SAF). EfW plants without access to CCS capacity may start to look more exposed – the electricity they produce will (at least for the non-biogenic element) be the highest carbon of a renewables/nuclear electricity system in the 2030s and around 2 million tonnes of current capacity is over 20 years old and relatively inefficient - if SAF processing does emerge as a viable pathway the case for investment in refurbishing these assets will be fragile.

The application of ETS to the waste market will likely create a strong incentive for the EfW sector to extract as much plastic as they economically can. This could make between 1.2 and 2.4 million tonnes (likely reducing to 0.9 - 1.9 million tonnes by 2035) of hard to recycle plastics available as a feedstock for either the SAF or chemical recycling (into plastic) technologies. There are two possible drawbacks to this potential source - if the counterfactual (incineration) is changed then it is difficult to see how these plastics will continue to attract the current favourable CI treatment they enjoy under the Recycled Carbon Fuels (RCF) provisions of the SAF mandate and in any event the sustainability case for the chemical recycling of these plastics rather than burning them as fuel is intuitively strong. That said, in the short term there are more plastics than recycling offtake - the plastics will need an alternative outlet – and there will probably be some volumes that are not suitable for chemical recycling.

Another possible source of waste is Commercial and Industrially derived "MSW-like" waste. This is typically on shorter contracts than local authority MSW, but individual contract volumes are smaller, adding complexity to the supply chain management of a SAF plant.

The aversion to technology risk of both local authorities and commercial and industrial waste producers creates a Catch 22 dilemma for SAF projects - suppliers are unlikely to commit beyond initial Heads of Terms until the plant is operational, but to secure financing investors will likely look for feedstock supply security.

If SAF plants are to secure the feedstocks needed to scale this technology beyond the first handful of plants, they will need to compete with the EfW sector for access to non-contracted residual waste and agree short-to medium term contracts with waste aggregators.

The most direct approach will be through the gate fee - offering a big enough discount to attract waste from EfW plants or offer enough margin to aggregators to secure supply, particularly as existing contracts to EfW plants conclude. Initial analysis suggests that early SAF plants will need to offer significant discounts to EfW to overcome the diffidence of local authorities and Tier 1 contractors to supply them. Once the technology is established it is likely that supply contracts could be agreed at a lower discount to EfW. The nth of a kind techno-economics in this report reflect this assumption (applying a 25% discount), but we have also modelled the economics for an early plant (with a 100% discount).

The lower CO2 process emissions from SAF production may offer a competitive advantage once waste processing pathways (whether EfW or SAF) fall under ETS, but MSW transport costs may be higher, given the likely location of MSW plants. Neither of these effects have – for the sake of simplicity - been considered.

The key issue is technology risk and market confidence. If the initial plants succeed in proving the technology later plants will benefit from gate-fee revenue as well as other scale and learning-curve benefits. This adds to the risk for the first-of-a-kind plants – and reinforces the importance of the RCM.

**Waste Wood**

The UK waste wood market could potentially be a significant source of feedstocks for the SAF sector (almost 100% biogenic and easier to process).

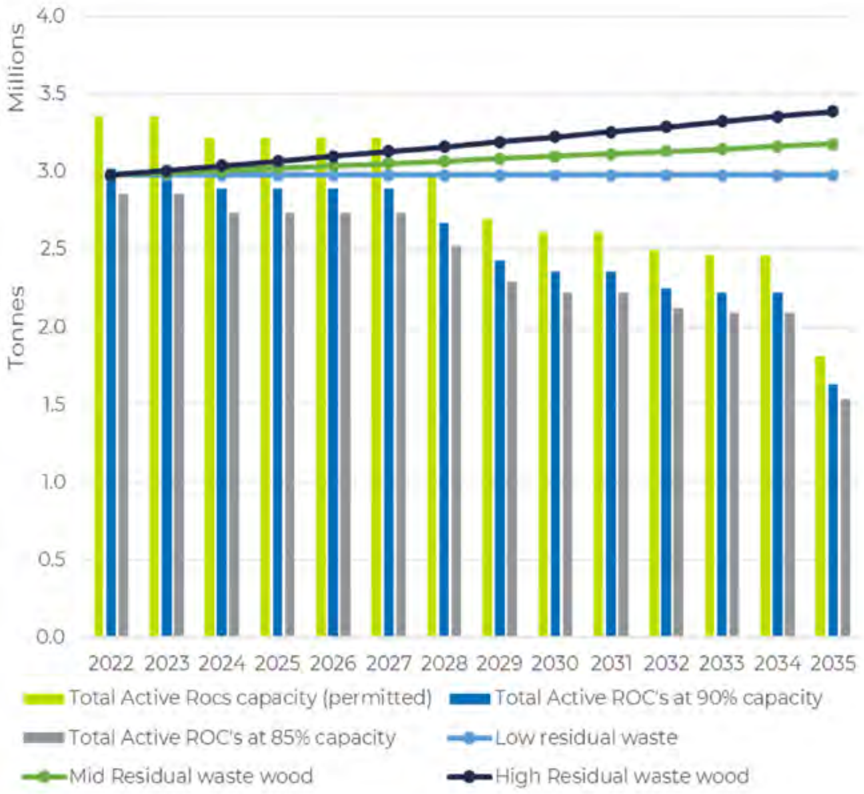
The total market size is 4.3 to 4.5 million tonnes of waste wood of which 1.4 million tonnes is recycled, leaving 2.9 million tonnes, of which 0.2 million tonnes is landfilled or exported.

Biomass energy generators buy around 2.6 million tonnes to produce low carbon heat and power. They pay for waste wood (unlike the MSW incinerators which are paid a gate fee to take the MSW). These facilities are all supported by the Renewables Obligations scheme and able to claim Renewables Obligation Certificates (ROCs) which provide financial incentives for each MWh of electricity produced from low carbon feedstocks.

The ROC scheme is winding down. The earliest plants will lose ROCs in 2027/8 which could “free-up” 0.2 million tonnes of waste wood, growing to 0.6 – 0.7 million tonnes by 2030. After 2036, all plants lose ROCs income. 2.6 million tonnes of waste wood could be available to the SAF sector as, without ROCs, these facilities would no longer be competitive in the electricity market. To compete they would need to move from paying for feedstock to a gate fee model.

Fig. 19 shows the potential supply of waste wood (low/medium and high residual waste wood) versus ROC-driven demand from generation. From 2036 onward there will be no further ROC demand.

**Figure 19: Waste wood and ROCs, 2022-2035(9).**



The waste wood market will likely experience a period of commercial change as ROCs for some plants loosen the market. However, even if this is the case waste wood will remain a higher value waste feedstock than residual waste streams due to its biogenic nature.

Aside from ongoing support of ROCs, the Wood Recyclers Association (representing all users of waste wood) is lobbying Government to recognise that biomass will remain a key part of the UK's renewable energy generation capacity. One option is the application of Bioenergy with carbon capture and storage (BECCS) to biomass sites, creating negative emissions and replacing the revenue from ROCS with new revenue streams from carbon-derived financial instruments.

SAF may be able to access some waste wood within the market as ROCs facilities lose incentives. Scale will likely depend on the ability for SAF processors to bid away waste wood from BECCS, which may depend on whether the SAF producers are able to sequester emissions.

### 2g MSW Supply and Demand

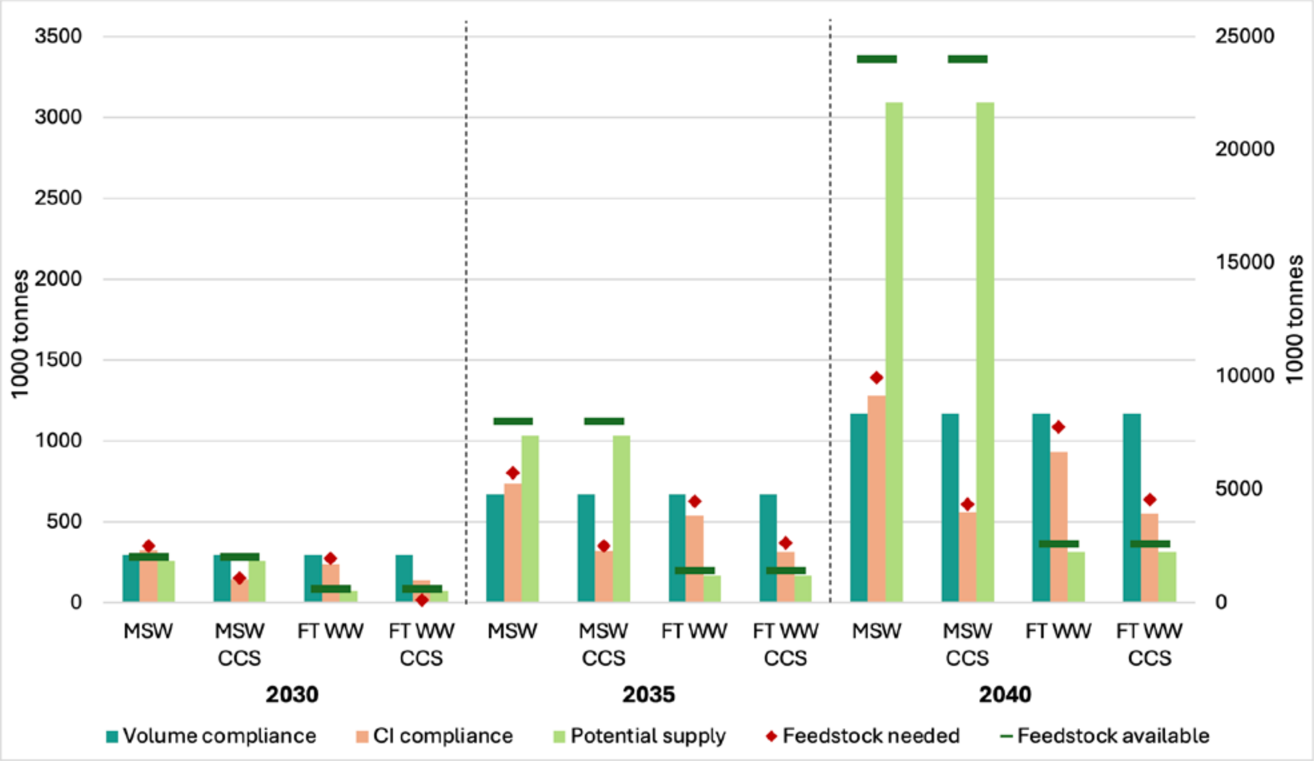
Actual volumes necessary for compliance will depend on the mix of technologies used and their carbon intensity relative to the default value.

On the basis that the MSW gate fee and wood purchase prices are set at levels sufficient to bid material away from electricity generation the entire feedstock pool is potentially available. Actual availability will be a function of contract length with current users. We assume a 15-year contract for EfW offtakes and ROC elimination timings for waste wood.

Taking a relatively prudent view of contract expiry timing, potential MSW feedstock availability is expected to be 2 million, 8 million and 24 million tonnes in 2030, 2035 and 2040 respectively. Waste wood feedstock availability is expected to be 0.6 million, 1.4 million and 2.6 million tonnes for the same years.

This chart looks at four process archetypes (MSW FT, MSW FT with CCS, waste wood FT and waste wood FT with CCS) across three reference years, compares the volume needed to meet all the non-HEFA mandate if it was a simple volumetric target with the CI adjusted volumes, shows the feedstock needed to meet the mandate and the potential supply if all available feedstock was utilised.

**Figure 20: MSW FT pathways – mandate demand and supply potential. Feedstock available and feedstock needed on secondary axis(9).**



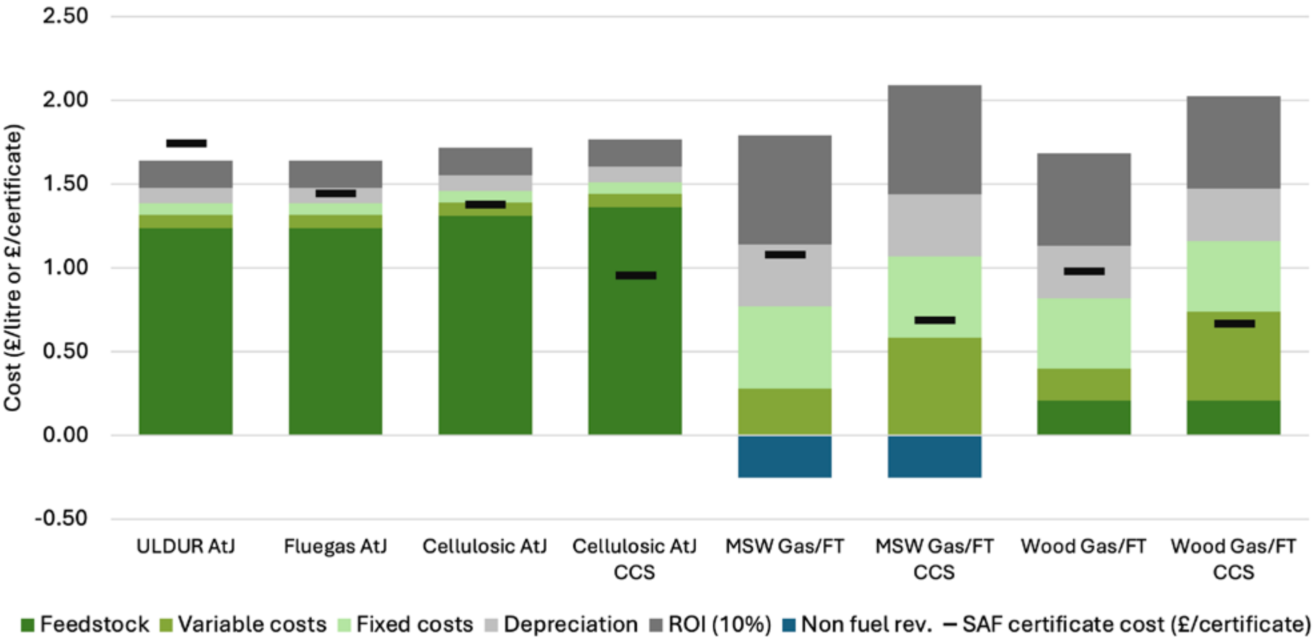
The analysis indicates that while MSW availability is just short of the volumes needed to meet all the 2g mandate in 2030 there could be surplus feedstock in 2035 and beyond. This is even more pronounced if the SAF plant has CCS (a single plant could potentially meet the entire mandate requirement in 2030). If waste wood were combined there would be sufficient feedstock to support compliance in 2030.

Once the MSW FT pathway is proven to work at scale, and assuming that the archetype modelling is broadly reflective of actual performance, the implications are that:

1. Feedstock availability is not an obvious long-term constraint This single pathway/feedstock combination has the potential by itself to fulfil mandate volumes in the mid-to-late 2030s – and leave surplus feedstock for 2g SAF export opportunities and/or EfW + CCS assets.
2. The FT MSW pathway therefore could be the marginal compliance product. Actual FT MSW volumes will of course depend on the capacity of other, more competitive pathways with lower cost certificates than FT MSW.

This is illustrated below.

**Figure 21: Cost build-up for 2g SAF technologies (10% ROI, 25% discounted gate fee)$^{(5)}$. Full assumptions found in Annexe 1.**

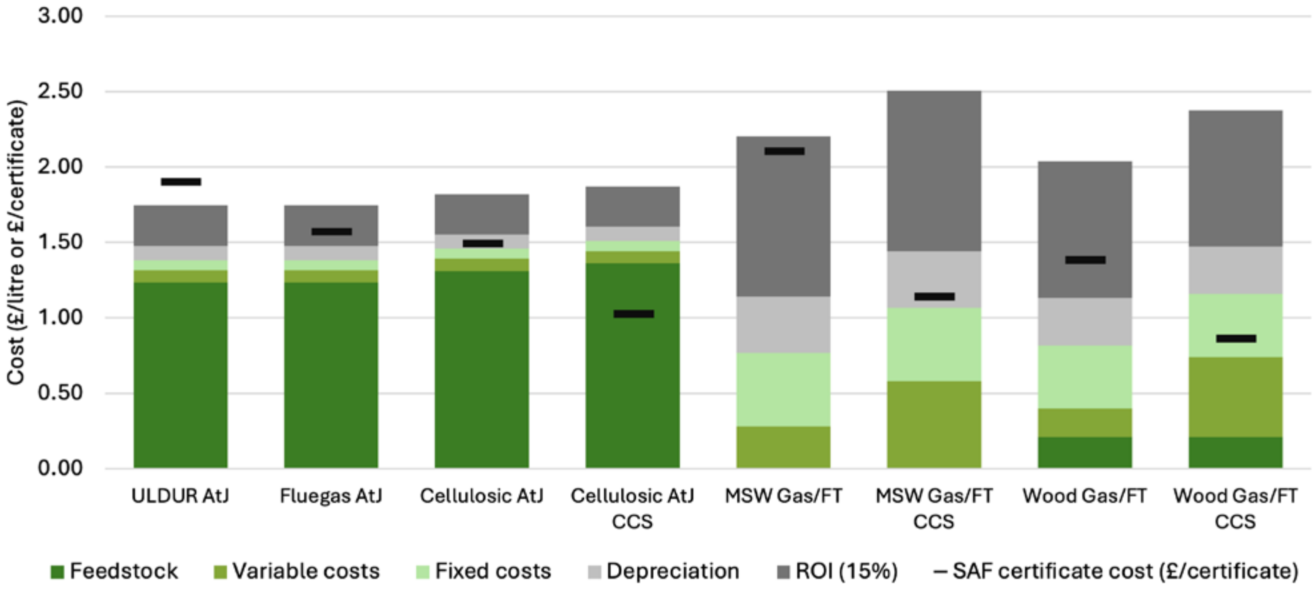


On this basis, and just using the modelled archetypes (which are themselves illustrative), IF (and this is a huge caveat) MSW gasification with Fischer-Tropsch can overcome remaining technology integration and investibility issues, and that feedstock is accessible at the gate fees modelled , any other 2g technologies with lower certificate costs that manages to reach commercial scale should enjoy superior returns, and be “crowded in” to a compliance product mix.

This is however based on nth of kind technology. In the early years MSW pathways will have to offer deeper discounts on gate fees to secure feedstock supply – and all pathways will likely have to offer higher returns to investors. These effects impact the more capital-intensive pathways, and the MSW pathways the most, as shown below (the cost of certificate from a first of kind MSW FT facility is roughly double that from a mature asset).

The cellulosic/double count agricultural waste ethanol-to-jet pathways are less likely to scale, unless the ULDUR penetration increases significantly. Even then the ULDUR still be valued at a double-counted ethanol value.

**Figure 22: Cost build-up for early key SAF technologies (15% ROI, no gate fee)⁽⁵⁾. Full assumptions found in Annexe 1.**



## Hydrotreated Esters and Fatty Acids (HEFA)

HEFA is today the most mature, largest scale and lowest-cost form of SAF. It is therefore the default choice for mandate fulfilment outside specific submarkets (PtL in EU and UK, 2g in UK). Global HEFA sales were estimated at approximately 1 million tonnes in 2024, with demand forecast to increase to between 5 and 10 million tonnes by 2030 (10).

HEFA is made from fatty acids – typically vegetable oils and animal fats. The animal fats (tallow) are usually waste products from the meat processing industry (rendering plants). Vegetable oils are available from food crops (soy, palm, rapeseed), “cover” or intermediate crops (camelina) and “waste” oils – used cooking oils, distillers corn oil, crude tall oil (CTO) and products produced as part of edible oil milling or refining processes (e.g. POME).

Qualifying feedstock varies from jurisdiction to jurisdiction. The UK allows waste only, the EU waste and cover crops. The US allows everything except CPO and palm fatty acid distillate (PFAD) (although waste attracts more support than crops in LCFS states), and other markets do not place any limits on feedstocks. Many countries indicate that they will likely adopt CORSIA GHG metrics – but absent a GHG-driven obligation demand will go to the marginal physical tonne. Today that often means Palm Oil.

HEFA is made by hydrotreating, hydrocracking and hydro-isomerising refined oils and fats. Compared with HVO processing for ground transport applications it requires more intense treatment (and therefore has a higher cost and a slightly increased carbon intensity).

HEFA can be made in dedicated facilities or co-processed with fossil fuel production in an oil refinery. Standalone plants will typically have higher production volumes – co-processing is limited to around 5% of process hydrotreater throughput. Most HEFA plants can switch to HVO production, and not all HVO plants can make HEFA.

Mandates will drive demand – and because of the close overlap between HVO and HEFA SAF production any analysis of capacity and feedstock availability needs to cover both fuels. The EU and UK in particular will play a major role in shaping the market – their ground fuel mandates are material, they are front-runners in SAF, and they both place specific emphasis (for ground fuels, but particularly for SAF) on waste oils and fats.

The maturing of SAF mandates will grow demand for HEFA (compensating for possible electrification – driven reductions in ground transport HVO demand). The structure of the EU mandate provides a strong incentive to maximise waste-based HEFA before developing higher-cost alternative technologies (except PtL).

As the table below shows, HEFA manufacturing capacity has expanded significantly in the past few years. Today there is about 3.0m tonnes of stand-alone HEFA capacity out of around 5 million tonnes of total HEFA/HVO capacity, with co-production at least 9 refineries worldwide, including Phillips 66 at Immingham.

**Table 8: SAF Supply Capacity(10).**

| Region | Country | City/ Province/ State | Company | Operational (tonnes) | 2025/26 (tonnes) | Status |
|---|---|---|---|---|---|---|
| Asia Pacific | China | Jiangsu | EcoCeres | 168,000 |  | Operational |
| Asia Pacific | Japan | Sakai | JV btw JGC, Cosmo Oil and Revo |  | 23,000 | 2026 |
| Asia Pacific | Thailand | Bangkok | Bangkok Corp. |  | 278,000 | Q4 2024/25 |
| Asia Pacific | Malaysia | Johor | EcoCeres |  | 210,000 | 2025 |
| Asia Pacific | Malaysia | Pengerang/ Johor | JV b Petronas, ENI, Euglena |  | 275,000 | 2028 |
| Asia Pacific | Singapore | Tuas | Neste | 1,000,000 |  | Operational. |
| Asia Pacific | Australia | Kwinana | BP |  | 130,000 | Project now mothballed |
| Europe | Finland | Porvoo | Neste | 100,000 |  |  |
| Europe | Netherlands | Rotterdam | Neste | 400,000 |  | Expected production in 3Q24, assuming ramp up in 2025 |
| North America | US | Texas | Diamond Green Diesel | 693,000 |  | Expected production in 4Q24, assuming ramp up in 2025 |
| Asia Pacific | China | Puyang | Junheng Industry Group | 150,000 |  | Started producing in Dec 2023/early 2024, ramping up |
| Europe | Sweden | Gothenburg | ST1 & SCA |  | 200,000 | Opened in April 2024, optionality for output, so not 100% SAF, assuming ramp up in 2025 |
| Europe | Italy | Gela | ENI | 150,000 |  | Expect to be online in 3Q/4Q 2024 |

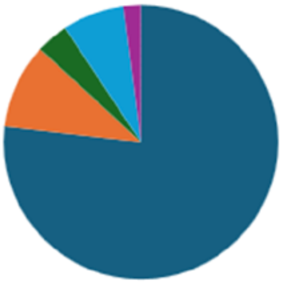
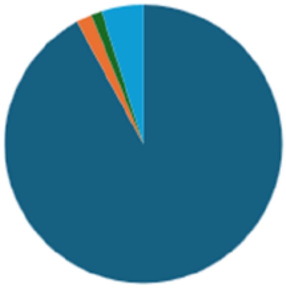
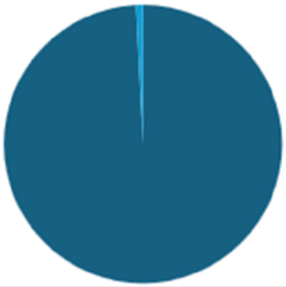
| | | | | | | |
|---|---|---|---|---|---|---|
| Europe | Italy | Livorno Taranto | ENI | | 10,000 | |
| Europe | Netherlands | Delfzijl | Sky NRG & SHV Energy | | 100,000 | |
| Europe | Spain | Cartagena | Repsol | 125,000 | | Started producing in 2Q24, ramping up |
| North America | US | Reno/ Nevada | New Rise Renewables/ XCF | 112,000 | | 38m gal SAF, completion expected end of 2024 |
| Asia Pacific | Indonesia | Cilacap | Pertamina | 41,000 | | Not running well |
| North America | US | Soperton/ Georgia | LanzaJet | 30,000 | | Production from 2025 |
| Asia Pacific | Thailand | Bangkok | JV Bangchak, Thanachok, BBGI | | 290,000 | Start producing SAF from 2025 |
| Europe | France | Grandpuits/ Paris | TotalEnergies | | 210,000 | Start producing SAF from mid-2025 |
| Europe | Portugal | Sines | Galp | | 193,000 | Expected to begin near the end of 2025, with commercial operations due to begin in 2026 |
| Asia Pacific | Malaysia | | EcoCeres | | 130,000 | Expected to start in 2H25, 130,000 tonnes of SAF |
| Europe | Poland | Plock | PKN Orlen | | 60,000 | Start producing SAF from 2025 |
| North America | US | Rodeo/ California | Phillips 66 | | 442,000 | Rodeo SAF capacity assumptions, first production in 4Q24 |
| North America | US | Great Falls/ Montana | Montana Renewables | 100,000 | | |
| **SUM** | | | | **3,054,000** | **2,551,000** | |

### Vegetable Oils, Waste Oils and Fats

Waste oils dominate the UK/European supply picture, thanks to the strong incentives provided by the RTFO and RED regimes. In the UK, crop-based biodiesel (from rapeseed or soy) has almost disappeared from the picture.

Of the waste oils and fats distillers corn oil (DCO), Tallow and CTO are supply constrained by the fact that they are only produced as a co-product. Supply is a function of ethanol processing volumes, beef or pulp production, not a function of the demand for waste lipids. Supply is therefore constrained. Waste vegetable oils - used cooking oil and increasingly POME oil – now dominate HEFA and HVO supply markets as is illustrated by the UK.

**Table 9: UK biofuel feedstocks(16).**

| | FAME | HVO | SAF |
|---|---|---|---|
| Feedstock (%)<br>🟦 UCO<br>🟧 POME<br>🟩 Tallow<br>🟦 Other Wastes<br>🟪 Crops |  |  |  |
| **Total (mil L)** | 647 | 716 | 255 |

UCO does the heavy lifting in the UK renewable diesel markets (89% of all UK biodiesel and SAF volume in 2024 was UCO derived). Across Europe as a whole (including UK) UCO derived products amounted to just over 7 bn litres in 2023. Domestically sourced UCO was around 126,000 tonnes in 2023, alongside 798,000 tonnes in the EU. Although there is more UCO theoretically available Europe is probably approaching the limits of economically and behaviourally feasible collection. (source Stratos Advisory). In 2024 only around 38 ml of UK renewable fuels consumption was made from UK-sourced UCO – less than 2.5% of all UCO-based production.

Used cooking oil in the UK and Europe is a limited, well-defined market. It is collected primarily from commercial sources (food processors and restaurants) as a low-value waste product and restricted in supply by the economics of collection (and if not collected there is a risk of fatbergs if the waste oil is disposed of irresponsibly).  It is understandable that European-based observers might worry about a finite global supply of waste oils putting mandate delivery at risk.

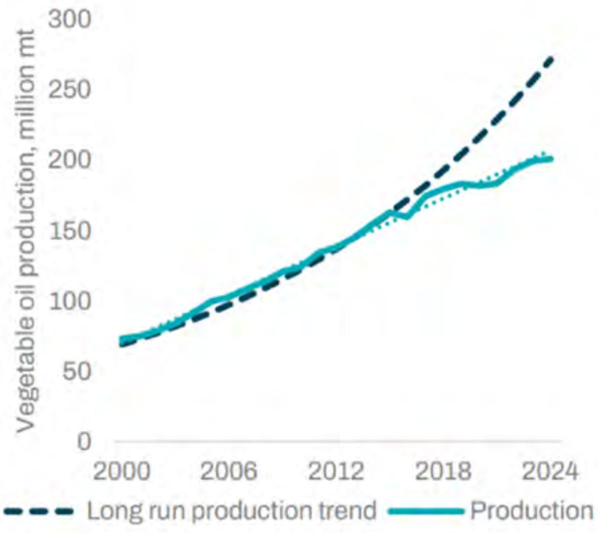
This is probably true of much of the world – scalable waste oil collection requires the development of market mechanisms, infrastructure and consumer behaviours that are unlikely to respond quickly to likely price signals.

However, the dynamics of the waste vegetable oil market in SE Asia and China are fundamentally different. These markets are dominated by palm oil (and to a lesser extent, in China, by soy oil).

Vegetable oils are largely interchangeable. Their prices are linked. Palm was historically the cheapest of the vegetable oils, and until recently the fastest growing in production. It is the largest in volume of all the vegetable oils, with over 80% of production concentrated in Indonesia and Malaysia. Historically, increased demand was met with area expansion – especially in Indonesia – giving rise to significant sustainability concerns, particularly in the West.

Since 2020 prices for all vegetable oils have risen. Supply has lagged increases in demand - primarily due to stagnation in palm oil output driven by a major reduction in the rate of increase of the area under cultivation and flat yields. The Indonesian biodiesel mandate has almost quadrupled domestic demand for palm oil since 2010. Palm is now trading at a premium to other oils, and soy planting is increasing in response to the price signal created by the imbalance between palm oil demand and supply.

**Figure 23: Annual vegetable oil production vs. long run trend[(10)].**



### Asian Waste Vegetable Oils

The Asian palm oil market sets the context for global waste oil supply. Just as there is interchangeability between oils, the market offers oils of varying quality at varying prices – including oils now characterised in EU and UK legislation as "waste". The critical distinction between other sources of waste oils and fats and the palm-based waste oil market in Asia is that in these markets, because of:

- Their depth
- The ability to blend different qualities of oil to meet different end-use specifications
- The dynamics of the cooking oil sector and the way palm oil is produced

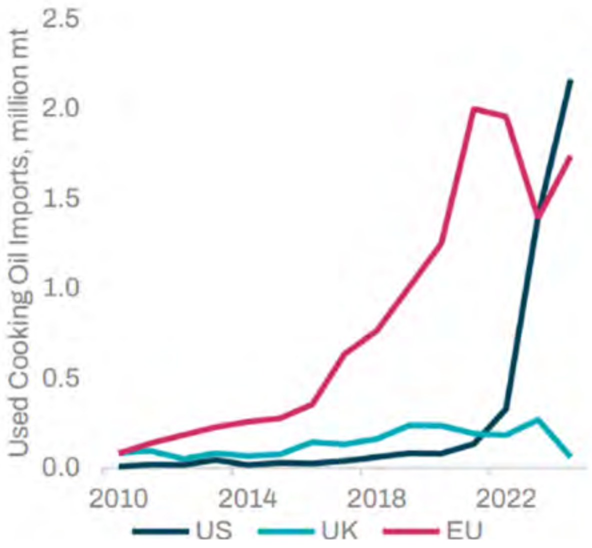
waste oils have emerged not as a finite resource but rather an integral, integrated component of the broader vegetable oil matrix, with remarkable supply responsiveness to price signals.

Malaysia and China are the leading suppliers of UCO, Indonesia (until very recently) the leading supplier of POME oil. China imports oils (CPO, POME and UCO) from Malaysia and Indonesia and exports UCO (and now HEFA/HVO) to Europe and until recently the US.

Oils of lower quality have always been part of the market - whether POME oils made from oil in mill waste water, oils made from fresh fruit bunches processed more than 24 hours after harvesting (after when the quality declines) or used cooking oils - which are regarded as lower-quality oils rather than as a totally separate product.

This is important – UCO in the context isn't only used oil – it covers a broad range of off-spec oils. It is collected, transported, traded and blended across SE Asia and China.

**Figure 24: Imports of UCO(10).**



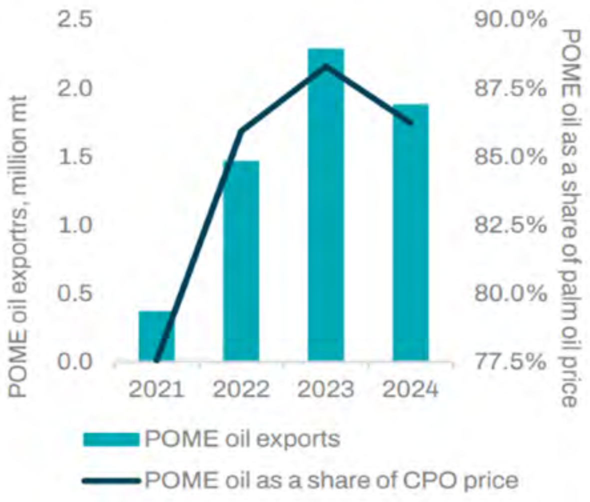
This makes accurate UCO price analysis difficult - it covers a range of products traded and blended in a variety of ways. Price benchmarks are not very accurate, although the SEA UCO benchmark has been trading at a premium to the CPO price for all but 9 of the last 36 months. POME oil price is easier to track (because it more strongly relates to palm oil price) and therefore provides the basis for illustrating market dynamics.

Historically, strenuous efforts were made to minimise the production of lower-quality oils, which traded at a significant discount to premium oils. It made sense to blend residual oils with higher-quality oils (or "polish", sometimes illegally, used cooking oils) to achieve higher specifications and prices. There was little waste oil – almost everything was repurposed. So any additional call for waste oils doesn't access previously untapped resources – it simply redirects products which previously would have gone into other applications.

As EU and UK mandate-driven demand for UCO and POME oils has grown, the relative value of all lower-quality oils has increased – for example POME oil was trading at around 70-75% of Crude palm oil but is now trading at more than 85% of the price. The historic discounts for higher free fatty acid oils have almost entirely disappeared.

POME oil production – which had been held at less than 1% of crude palm oil production – has significantly increased in both Malaysia and Indonesia. POME exports from Indonesia and Malaysia have increased more than fivefold in the last four years, to 1.8-2 million tonnes. UCO imports into the US, EU and UK have soared - from a few hundred thousand tonnes in 2010 to around 4 million tonnes in 2023. This has been exacerbated by local fiscal measures - in Indonesia an export tax was placed on CPO in 2022 further encouraging the classification of lower-quality oils as POME (to benefit from the resulting tax differential). This diversion of domestic capacity away from cooking oil has since led to a ban on all Indonesian POME exports.

**Figure 25: Annual POME oil exports against POME oil as a share of CPO price[10].**



The surge in supply is a consequence of responses to the clear price signals that have been created, made possible because of the fungibility of vegetable oils of all qualities. Now that waste oils are not heavily discounted to CPO (and frequently achieve a premium) actors across the value chain are predictably modifying behaviours – increasing oil usage in food processing, in some cases relaxing waste management protocols in palm oil milling, etc. An anecdote brings this to life: A noodle manufacturer historically produced nine batches of noodles with one batch of palm oil, seeking to minimise input costs. As the manufacturer started to see increased value in the used oil from this process, he realised that this was a potential profit pool. He now uses one batch of oil for each patch of noodles. This is not fraudulent behaviour but an entirely rational response to price signals as biodiesel mandates in Europe and the US strongly incentivise the use of these waste oils over virgin products. It does, however, mean that while the oil directed into the UCO market is indeed used, it is not end-of-life waste as intended by the mandates. Figure 23 shows that exports of POME are a consequence of the POME price relative to CPO – the closer the price, the greater the POME volume.

This suggests that the mandates are simply redirecting product that otherwise would have been part of the mainstream palm oil resource base – whether by dint of waste minimisation or blending and upgrading efforts. The effect is difficult to distinguish from the consequences of allowing the direct imports of CPO in the first place. The demand for UCO is increasing the demand for palm oil and is contributing to the increase in vegetable oil prices.

The conventional view is that there won't be enough UCO to meet the demands of the EU and UK mandates. In 2035 if the main EU SAF mandate were to be met by HEFA alone it implies demand of around 15 million tonnes of UCO. Thanks to the HEFA cap the UK only adds a further 1 million tonnes to demand. The current effective withdrawal of the US from the demand pool eases some of the pressure, but even if UCO/POME is completely bid away from the ground fuel market (which would lead to significant supply challenges given the crop cap limits) a further fourfold increase in supply is indicated. Because all vegetable oils (including waste oils) are highly correlated, this must be viewed primarily through the lens of aggregate vegetable oil supply and demand.

In 2020 demand for all biodiesel applications was around 32 million tonnes of a total vegetable oil supply of around 200 million tonnes. Adding the growth in EU SAF demand and other new mandates (on both SAF and ground fuels), and accounting for some softening of diesel demand through electrification and fuel economy improvements, fuel vegetable oil demand of 52 million tonnes in 2035 feels reasonable.

It is very unlikely that material new sources of waste oils will emerge – cooking oil is too valuable in most markets outside Asia to be downgraded, and collection, blending and bulking infrastructure is almost non-existent. The increase in UCO demand can only be met through the diversion of more CPO to waste. An increase in CPO production of 10 million tonnes in the next ten years is at the high end of assumptions (as we have seen, supply expansion is already lagging despite a strong price signal), so supply pressure will increase on other oils (most likely soy) with implications for the future value of grain crops. If nothing else changes, there would be significant upward pressure on HEFA prices – vegetable oil prices overall would continue to increase and the premium for UCO over CPO would grow as well. There is a strong possibility of a governmental response on the supply side (as we have already seen in Indonesia with CPO export taxes and POME export bans).

Of course, the central problem is that in selecting waste oils as the preferred pathway for 1g SAF (and ground fuels) the fact that all oils – whether waste, lower quality or perfectly on spec – are all part of a highly integrated, interdependent whole. In this sector at least, waste becomes a false distinction. There isn't a clear delineation between the two categories. Consequently, many of the hoped for benefits of avoiding oil crops are lost – the outcomes are, in the long run, the same.

So, unless the supply is limited by much more effective certification practices in the future, we won't run out of UCO. The market will find a way. At some stage HEFA prices could rise to the level where 2g SAF is priced in for the EU mandate. The problem is that by then (if not already) the emphasis on waste oils will have had entirely the opposite impacts on markets and demand than policy makers intended.

The current construct is close to failure. A tipping point is approaching. We need to assess alternative pathways to delivering SAF, looking afresh at the cost/emissions savings/sustainability balance.

**A Note on PtL**

Power to Liquids, or E SAF, is frequently cited as the only really scalable SAF option. Made by reacting hydrogen (ideally zero carbon hydrogen made from renewable electricity) with CO2 (ideally biogenic point source or atmospheric, captured by direct air capture (DAC), it produces a fungible drop-in liquid fuel.

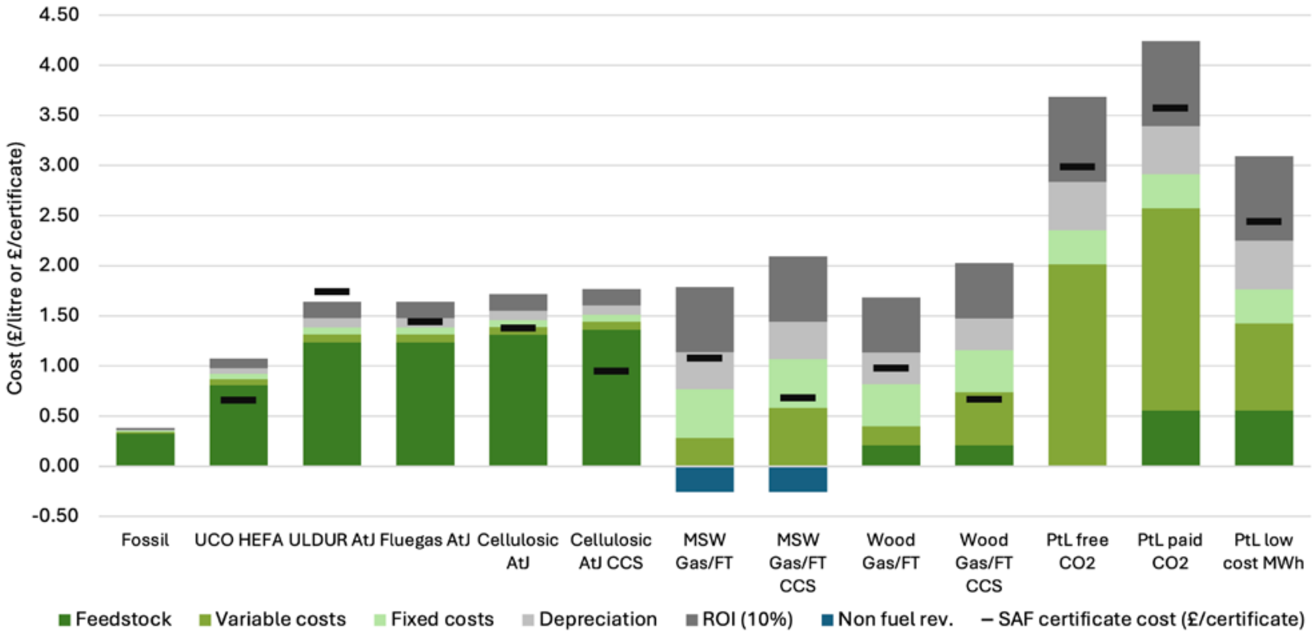
The UK and EU mandates encourage PtL – with separate markets and, in the UK, a higher buy-out price. The UK PtL sub mandate starts in 2028 and targets 0.5% of total fuel demand by 2030, rising to 3.5% by 2040. Based on the Sustainable Aviation demand curve this equates to ca 80m SAF certificates initially, rising to around 480m. Assuming a carbon intensity of 7g CO2/ml this would be delivered by 47,000 tonnes of PtL, rising to 290,000 tonnes. The UK mandate requires that PtL is made from renewable or low carbon sources, excluding bioenergy but including nuclear energy.

Electricity demand is very high (particularly if the CO2 is from DAC): Based on assumed 2030 electrolyser efficiency, power consumption is ~25 MWh/te of liquid product, plus perhaps a further ~5 MWh/te associated with direct air CO2 capture. Renewable power price is therefore a key determinant of cost. This implies that the plants will be based in the most competitive locations for wind or solar generation, with the SAF then shipped to customer destinations.

Plants will likely need to combine dedicated renewable electricity capacity with electrolysis, a source of CO2 and conversion and upgrading capacity.  This is where scale up could be a challenge – it demands an ever accelerating roll out of zero carbon electricity capacity that will need to be bid away from other uses (data centres, for example) to both power the DAC process and make the green hydrogen that itself will be in high demand for the plethora of applications for which it is touted as the net zero answer. Some commentators are now raising the question of whether it makes sense to simply capture the carbon rather than go the added step of converting it to fuel. (CCS 7th Carbon Budget)

As the chart below highlights, even with low-cost electricity and adjusted for carbon content PtL SAF, is far from being competitive with any of the other pathways (although this is based on commercially acquired CO2 –which may understate the competitiveness of the low electricity cost archetype if this had CO2 from a dedicated DAC unit).

**Figure 26- Cost build-up for key SAF technologies (10% ROI, 25% discounted gate fee)(5). Full assumptions found in Annexe 1.**



That there will be PtL is not in doubt. How much, by when and at what cost remain highly contested questions, with significant dependencies.

A central problem for the new green hydrogen facilities that PtL depends on is the absence of clear offtakes and uncertainty about the formation of market prices. State-managed competitive Contract for Difference (CfD) and power purchase agreement (PPA) mechanisms have been required to enable the first assets to start development.

This is where the deployment of mandated demand for SAF is a potentially powerful enabler – the demand is clear, and the buy out sends a clear price signal.

Offtake agreements with airlines seeking to meet mandate obligations may be instrumental – although there are many competing demands for green hydrogen (and renewable electrons) it is possible that the mandate structure will enable SAF to bid capacity away from other uses.

Infineum have announced a plant in Texas that plans to come onstream in 2027 producing 23,000 tonnes of liquids of which ca.70% is likely to be SAF (16,000 tonnes). It is supported by offtake agreements.

This also underlines a potential UK opportunity – the development of hybrid assets where gasification and catalysis units (such as MSW FT pathways) access green hydrogen and are able to produce PtL alongside advanced SAF.

## Risk Assessment: Summary

In most respects the UK SAF mandate is a well-designed policy tool that balances risk and opportunity and stands up well to international comparison:

- The HEFA cap reduces exposure to the waste oils market and creates an opportunity for 2g SAF to emerge.
- The price cap is high enough to encourage investment without exposing suppliers to uncapped risk, and potentially passengers to extreme fuel prices, if the mandate isn't delivered.
- The GHG certificate metric, while making market operation a bit more complicated, provides a real incentive to producers and suppliers to improve emissions performance and mitigates volume delivery risk.
- The relatively modest scale of the PtL mandate looks prudent given the profound uncertainties around the scale, cost and timing of the development of the green hydrogen economy, let alone the extension to PtL production and the competition for supply of such PtL product that is made.

Current UK market design takes a very precautionary approach to sustainability – going beyond Corsia feedstock neutrality to impose absolute bans on the use of all crops and placing a heavy emphasis on the use of wastes. Even the EU is slightly less restrictive. Other mandates and mechanisms so far announced at most differentiate on emissions performance, and in some cases have no feedstock requirements at all.

The central question is whether this exposes mandate fulfilment to risk of failure against three key criteria:

**Emissions** – will there be enough qualifying physical product available when needed to meet mandate requirements?

**Cost** – can these products be supplied at a price that balances investability, affordability and international competitiveness?

**Sustainability** – can these be supplied within acceptable sustainability criteria?

So far, the report has explored feedstock and production costs, emissions and availability, demand drivers and mandate targets. It also considers the market mechanisms that inform price setting within the current sustainability requirements of the UK mandate.

This informs a risk assessment against the first two criteria (emissions and cost). It also supports enquiry into unintended consequences that may impact sustainability goals.

**Key Risk 1: The HEFA Tipping Point**
This relates to our dependence on waste vegetable oil feedstocks to meet the mandate, and the risk that this will be increasingly challenged – on economic, supply access and reputational grounds – until a tipping point is reached.

Hydrotreating – which is what a HEFA plant does - is an efficient and proven way to produce non-fossil AVTUR.  On a like-for-like basis it costs less, scales more easily and emits fewer process emissions than other non-fossil SAF pathways. It is inherently flexible – if it can make HEFA it can also make (at slightly lower cost) HVO. The challenge is the feedstock.

Global vegetable oil markets are already tight. Supply has lagged demand, and prices overall have been on a rising trend. In part this is due to the growth in demand for lipids for biodiesel. Vegetable oils have been depicted collectively as having high ILUC risk (an asserted, but unproven, concern that the use of crops for energy causes the conversion of high ecological value land elsewhere to be converted to agricultural use). There is a very high degree of interchangeability between different types of vegetable oil – prices are therefore highly correlated.

Policy makers have turned to waste lipids with the intention of minimising both ILUC and broader price risk. By far the largest source of waste lipids is palm oil-derived used cooking oil sourced from SE Asia and China. This embraces a spectrum of lower-quality oils; unlike other forms of waste (such as MSW, waste wood, tallow etc.) used cooking oil may be used, but it is very often not end-of-life. Because of this the UCO market is not finite and can expand considerably to meet demand. Efforts to define UCO as a separate class of product, with potential supply subject to estimates of collection rates, struggle in a SE Asian context.

UCO supply is an integral element of the broader vegetable oil system. UCO already trades at a premium to palm, and palm oil itself has moved from being the cheapest to the most expensive of the main types of vegetable oil. If a premium for waste oils exists, demand for UCO will be met. The implication is that an unintended consequence of specifying and incentivising waste vegetable oils pathways is increased demand for oil crops.

By 2035, even on the relatively conservative aggregate demand assumption we use, increased demand will significantly outstrip palm production growth and have a knock-on effect on soy demand.

The tipping point could be reached through one of two routes:

1) If nothing changes and heightened monitoring and verification efforts have little impact on underlying behaviours, waste oils continue to price at parity or better with crude palm oil (CPO), it is unlikely that we will "run out" of UCO. The mandate will increase UCO/POME premia over CPO, but the additional demand pressure will also be diluted across the broader vegetable oil supply base (so premia will widen – but over an increasing underlying vegetable oil price). Or,

2) The most recent attempts to tighten UCO certification really do work, in which case the likelihood is that supply will tighten as supply is restricted to genuine, end-of-life waste. A supply shortfall could emerge. There is a risk that this will inflate the waste oil premium at point of sale to the processor even more

In either case there is the further risk that supplying countries will act to tax or ration exports of UCO and/or POME to control domestic food prices and/or enable their own SAF and biodiesel mandates to be met at lower cost. Indonesia is already doing this with POME and UCO. This will clearly inject significant additional volatility and price risk into the waste lipid HEFA market.

It raises the prospect of price convergence between HEFA and advanced SAF. Should UCO prices increase by more than around $600/te advanced SAF could become competitive in volume-denominated markets like the EU while UK HEFA certificate costs will be more expensive than those from the more competitive advanced SAFs.

As things stand, only the development of a large-scale advanced SAF market (itself highly conditional) could cap waste lipid demand and dilute price inflation risk.  Until then, we are very exposed to this feedstock class.

Given the fungibility of vegetable oils as a whole, at least as far as waste oils sourced from the SE Asia/China supply complex is concerned, "waste" is at risk of becoming a false distinction. The effective definition and verification of genuine waste vegetable oils is a challenging conundrum.

**Unless the "waste" conundrum is resolved the legitimacy of waste lipids as preferred, incentivised feedstocks on sustainability grounds will diminish, risking a backlash. If it is resolved, supply will likely fail to meet demand.**

**Key Risk 2: Advanced SAF – too little, too late?**
The analysis indicates that UK supply of advanced SAF need not be feedstock constrained. This is very positive – it means that a key barrier to the scale up of non-HEFA SAF is mitigable and possibly offers an alternative to both overdependence on 1g SAF and the risk of PtL volumes not appearing at the time, scale and cost hoped for.

There is enough MSW for the MSW-FT pathway to have sufficient capacity by itself to meet the mandate, other pathways may emerge that can contribute to mandate targets at lower certificate costs – and there are pools of feedstock (waste wood, sugar beet process waste) that could be very competitive. Once the technology is demonstrated and market confidence is built costs will reduce (both cost of capital and, slightly counter-intuitively, the costs of certain feedstock types). The application of CI denominated certificates can mitigate supply risks – fewer molecules of better CI product will be needed.

The key challenge is overcoming technology risk and reducing barriers to investment. The AFF and the RCM are both very important interventions. The concern is that they are necessary but not sufficient. It is crucial that the final design of RCM supports the development of a vibrant non-HEFA sector that can offer returns to future new investments.

**The risk is that while previously proposed interventions – around “Icebreaker” programmes and the prioritising of feedstock allocation to the hardest to decarbonise sector (where the feedstock conversion technologies generate lower emissions anyway) remain unaddressed the emergence of the advanced SAF sector will be at best faltering.**

There may also be risks associated with the definition of qualifying sources of electricity and CO2 for PtL/Renewable fuels of non-biological origin (RFNBO) that may obstruct the development of promising integrated production models that could both improve overall advanced SAF certificate economics and underpin delivery of the PtL mandate.

The consequences of a failure to urgently mobilise investment are serious – the non-HEFA mandate will not be met (and/or will rely on expensive imports of advanced ethanol), scaling will lag, and feedstocks will find other homes. Meanwhile, dependence on 1g pathways will increase (as the opportunity to lower the HEFA cap is lost) and the opportunity for UK leadership, innovation and inward investment created by the mandate design will slip through our fingers.

**Key Risk 3: Regulatory Misalignment**

Although ground fuel and SAF market structures are better coordinated in the UK than in the EU, the exposure of identical or similar products (HVO/HEFA, cellulosic or advanced ethanol) to different market structures – single or double-counted certificates in the RTFO vs carbon intensity denominated certificates in SAF is a concern. The risk is the unintended consequences for the operation of both ground fuels and aviation markets, creating resource allocation inefficiencies. An example is advanced ethanol which attracts a double-counted certificate under the RTFO, forcing an ethanol-to-jet producer to bid the ethanol molecule away from the RTFO, potentially resulting in higher overall compliance costs.

The successful implementation of the SAF mandate touches on many sectors of the economy and many policy areas, including waste management, agriculture, carbon capture and storage, the development of green hydrogen, regional development, planning and permitting, skills development, power pricing and supply. Although some progress has been made, such an emergent sector is very vulnerable to mixed policy messages and inadequate communication and coordination across Government.

# De-Risking The SAF Mandate: Part 2. Risks

The report has identified three key risks to mandate fulfilment: The issues with UCO supply, the challenge of establishing advanced (non HEFA) SAF and regulatory misalignment.

## Risk 1: The HEFA Tipping Point

HEFA from vegetable oils and lipids is the most established, most competitive pathway for SAF. To reduce pressure on crude palm oil the UK and EU have placed a reliance on waste oils and lipids, with the unintended consequence of creating a premium market for waste oils in SE Asia. Rather than limit the use of palm oil in biofuel applications, it has increased it. This will likely result in a series of regrettable outcomes – increased vegetable oil prices, a reaction from governments in producing countries, and challenges to the legitimacy of waste-oil based SAF products undermining the credibility of the SAF mandates themselves.

If it is possible to restrict waste vegetable oil use to only demonstrably end-of life or low-value by-product sources a supply gap will emerge. The UK is leading the way in creating markets for advanced biofuels – but barriers remain before they are going to be available at sufficient scale to offset any shortfall. Access to alternative SAF products, quickly and at scale, to meet the mandate requirements is necessary.

Two short-term mitigations are required:

1. A definition of waste that reinforces confidence that the unintended consequences of creating premium markets for wastes are minimised.

2. The diversification of qualifying feedstocks to mitigate the risk of over reliance on waste lipids in general and to substitute higher impact “waste oil” based SAF in particular.

If the issue is to be resolved both are necessary, but neither one is, of itself, sufficient.

### Defining Waste

Whenever waste attracts a premium over the product from which it is derived, perverse outcomes follow. For those waste products that are in effect “manufactured” (such as Asian UCO) the incentive is to create more of the waste (or by-product when the by-product is as or more valuable - such as POME oil), rather than to minimise it.

The premium for waste products is a consequence of demand generated by mandate requirements. A redefinition of mandate requirements – on economic terms – might offer a solution to the waste conundrum.

This is now recognised in the latest ISCC (International Sustainability and Certification System) UCO certification systems documentation (ISCC is a leading independent certification body, recognised by many governments, including the UK and the EU): https://www.iscc-system.org/wp-content/uploads/2025/04/ISCC_EU_202-5_Waste_and_Residues_v4.2.pdf

Which covers many of the potential hazards in waste production, including the following attempt to define an economic test:

> “As the existence of a market or an alternative application for a waste or residue material may be difficult to assess during an audit, the economic value of a material is a feasible criterion which can be assessed. If the economic benefit for the point of origin is insignificant, it can be assumed that the main goal of the point of origin is to reduce the amount of waste or residue in favour of the main or primary product(s). Therefore, the risk for deliberate production or intentional contamination can be considered to be low. The economic benefit of a material generated at a point of origin can be regarded as insignificant if the economic value of the material is 15% or lower than the economic value of the main or primary product(s). This only applies if the material in question is used for non-bioenergy purposes. This means, if only bioenergy applications are relevant to be considered as “further use of the material”, the economic value in this case is not relevant to determine if a material meets the definition of a processing residue. In the case of two or more main or primary products, the average economic value of those products shall be used.”

The inclusion of an economic test is very welcome, but the conventional response to the challenge - increasing the rigour of testing regimes, is not a panacea. The question is whether this can be relied on to change market behaviours in the specific context of the east Asian UCO market. The dependence on the ISCC auditor on the ground, on whom the burden of enforcement rests, represents a stark single point of failure. There will possibly be other complexities and nuances – for example the tax treatment of different products in originating jurisdictions may also need to be considered. Incidentally, how ULDUR is treated may offer an insight into how the latest standards will be interpreted.

Of course, it is to be hoped that it does prove effective – and if it does it will address many of the broader concerns about the credibility of the current imported UCO market. However, it would then likely result in a shortfall of supply to both the EU and UK ground fuels and SAF markets (the historic capacity of the market to expand supply of “waste” oils in response to a price signal will be eliminated).

The impact of any supply shortfall will be magnified by the fact that UCO is currently treated as a doubled counted feedstock for ground fuels in the EU and UK – the value of remaining double counted supply might be expected to grow, and the demand for more single-counted, crop based biodiesel feedstocks increase.

The good news is that there is no evidence that the UK used cooking oil market is exposed to the same risks. It would continue to be a reliable source of feedstock. Any supply crunch would be mitigated by diversifying feedstocks and pathways:

- If supplies of cover crop and marginal land-derived vegetable oils that are now allowed in principle under EU regulations can scale,
- Ethanol to jet, if allowed, offers short-term source of volume for the SAF market (and around 20% of the ethanol-to-jet process output is biodiesel).

Should the changes to the UCO certification standards not have the desired impact, **consideration should be given to simply applying a cap on imports of UCO and other waste lipid products from Asia.** If that is unachievable the other option would be to **reduce the HEFA cap and establish a fourth sub mandate to reduce UCO dependence and allow for feedstock diversification** (see below).

**In any event, the necessary precondition for any effort to mitigate the consequences of waste UCO dependency is to increase the diversity of allowable feedstocks.** If enhanced monitoring works it will create a supply -side exposure – especially if the economic test condition is effective, because not only should absolute supply be limited but the price of waste oils should be below virgin oils in the main exporting countries (China, Malaysia, Indonesia). This will make these products attractive for use in fulfilling local mandates. If it doesn't there is a growing reputational and credibility exposure. In either case the governments of the supplying countries will have their own plans, which may not align well with our current regulatory needs.

### Feedstock Diversification

There are two potential responses to the supply pressure created by the UCO dilemma while avoiding further dependence on mainstream crop vegetable oil:

- Follow the EU's lead by expanding the available lipids pool using vegetable oil cover crops and crops grown on marginal land, and
- Exploiting the development of alcohol to jet pathways that enable access to a very deep potential supply pool of UCO HEFA alternatives.

### Cover Crops

The EU has added intermediate crops and crops grown on severely degraded land to the list of allowable SAF feedstocks. The rationale is that if these crops can be shown to have been grown without impacting food crop harvests and without reducing soil health (cover crops are normally grown to improve soil quality and reduce run off) they are a viable and sustainable addition to the feedstock mix. The risk (that this provision is intended to mitigate) is that adapting cover crop species grown and harvested for SAF may impact their intended beneficial function within a food production system, for example, removing the benefits of increased soil carbon, nutrient cycling, or erosion protection, as well as access to environmental subsidies.

In the short term the focus is on oil cover crops – adding to the permitted feedstock pool for HEFA (some crops will be suitable as cellulosic ethanol or gasification processes – but are technology dependent). Oil crops include Camelina, Carinata and Pennycress. Despite relatively low yields, advocates claim significant volume potential (up to 5 million tonnes HEFA) and so a useful contribution to resolving the UCO dilemma. However, while theoretical volumes look appealing, the challenges of establishing a new cash crop, especially with still forming sustainability criteria, unclear market models and pricing structures and without robust harvesting, collection and bulking infrastructure should not be underestimated. The UK may have some particular issues; our climate does not favour double cropping (as there is insufficient day length in winter for high yield) and harvesting in wetter months is also problematic, so constraining potential even more.

It is therefore unlikely that cover crops are the silver bullet solution to the UCO supply conundrum. ***They could make a helpful contribution to sustainable HEFA feedstocks and should therefore qualify for UK SAF (particularly as most UK HEFA is currently imported from EU-based producers)*** but they cannot be relied on as a sufficient response to a likely shortfall should UCO supply be limited.

### Sugar and Starch Ethanol to Jet

Under current conditions only ethanol from non-crop sources – (i.e. excluding energy crops) – is permitted, so ethanol from food processing residues, non-crop based cellulosic ethanol or the biological conversion of flue gases. These are relatively expensive pathways, yet to scale and highly incentivised in some other countries (e.g. the cellulosic RIN in the US). They have the potential to play an important role in delivering the advanced biofuel sub mandate but will not scale fast enough to substitute a reduction in the availability of HEFA feedstock if steps to reduce the use of UCO are taken or the HEFA “tipping point” occurs.

Diversification of SAF ethanol feedstocks is going to be necessary. If the mature and material 1g ethanol pool – using sugars and starches – could be accessed:

- a scalable substitute for HEFA will be available to de-risk mandate supply at least until advanced and synthetic SAF pathways are able to scale up and reduce cost.

- Inclusion of crop-based ethanol will enable the ethanol-to-jet technology platform to scale up and shake down earlier, partially de-risking the introduction of 2g ethanol-based pathways.

The production cost per litre is competitive – although the higher certificate cost (a function of the increased CI when ILUC is included) reduces the likelihood that this pathway will be an enduring feature (at scale) of a SAF regime – it could be outcompeted by the lower carbon intensity 2g pathways should they scale and their costs reduce.

**It is vital that the dedicated market for advanced SAF, above the HEFA cap, is preserved – these products should not crowd out and threaten the development of other advanced SAF pathways. This might be resolved by either:**

- **If certification works and/or supply of low credibility UCO is restricted: maintain the current sub-market volumes but redefine the HEFA cap as a cap on 1g pathways (and naming the non-HEFA SAF sub mandate "the advanced SAF mandate"), otherwise either**

- **Reduce the HEFA cap and allow crop-based AtJ SAF to compete with other 2g pathways in a much larger addressable market, or**

- **Develop a fourth, crop AtJ, sub-mandate market, carved out of the current HEFA mandate.**

Timing is important. It is important that mitigations are in place ahead of any supply shortfall happening. On that basis the early development of a crop carve-out looks attractive.

**Factors affecting expansion of crop biofuels for SAF**

In the mid-2000s, as the biofuels sector was starting to develop, concerns around the impact of diverting crops – and by extension crop land – into energy applications emerged. Although life cycle direct emissions for crop-based fuels were being measured (inputs including fertiliser use, diesel and process energy) this new concern was centred on the fear that Indirect Land Use Change (ILUC) would result in the otherwise avoidable extensification of farmland, especially if this might encroach on land with high climate and/or biodiversity value. The potential emissions effects from such expansion should then be added (as an "ILUC factor") to measured direct emissions. This was popularised by Timothy Searchinger in his 2008 report and started to influence UK policy thinking when it was referenced in the Gallagher Review of the indirect effects of biofuels production(11).

This was written at a time before there was any real confidence in the development of electric cars, with biofuels presenting as the only viable ground transport decarbonisation pathway and ambitious renewable fuel targets were being developed (the EU Fuels Quality Directive implied a 15% biofuels penetration (by energy) by 2020 – or about 20% by volume). The Gallagher Review acknowledged that the evidence base and science behind the theory of ILUC was highly uncertain. However, it advocated the adoption of a precautionary approach to the use of crops in biofuel production, pending further evidence:

> “The introduction of biofuels should be significantly slowed until adequate controls to address displacement effects are implemented and are demonstrated to be effective. A slowdown will also reduce the impact of biofuels on food commodity prices, notably oil seeds, which have a detrimental effect upon the poorest people.”

It went on to propose a wide range of steps to build confidence in the development of a sustainable biofuels sector – many of which have been adopted.

Over the 17 years since then a blizzard of academic studies have been published, with various depictions of ILUC. The only point of consensus seems to be that there is no consensus on how to measure ILUC, how to model ILUC or whether it is actually real. Its application has been contested legally by producing countries. **However, if there is a discernible trend at all it is that modelling has tended towards decreasing ILUC values over time, and that sugars and starches are held as having significantly lower ILUC risk than oilseeds.** This is reflected in the UK’s default ILUC factors, with grains (regardless of origin) at 12 g CO2e/MJ and oilseeds 55 g CO2e/MJ.

These factors are used only in an advisory sense today in UK regulation. The EU and UK response to ILUC has been to use it to justify the applications of restrictions on crop use (crop caps and, for SAF, outright bans) and the heavy incentivisation of feedstocks with very low or no perceived ILUC risk (double counting for wastes). In the US ILUC factors have been utilised in determining tax credits and LCFS certificates. ILUC factors are included in CORSIA standards.

As a result of the policies adopted in the wake of these reports, biofuels penetration has been far lower than forecast – and crop use in biofuels lower yet. In between 2018 and 2023 the implied total UK crop area used for biofuels production (predominantly wheat and rapeseed) was 35,000 ha, about 0.6% of total UK arable land. In 2023 oil seed rape was grown on 391k ha and wheat on 1,720k ha(12).

The US has removed ILUC considerations altogether from the producer tax credit scheme. Although several other countries are referencing CORSIA standards in developing their own mandates, there is little evidence that this will be enforced though qualification or measurement mechanisms (most seem to be happy to include the lowest-cost source of SAF without differentiation on sustainability or emissions grounds).

Whether ILUC is real or not, it remains mystifying that it only features in the policy debate when land use for biofuel is considered. To be consistent, all land use (particularly land used for emissions reduction purposes) should be subject to this, including land set aside or rewilded for environmental reasons.

**Food vs Fuel, or is it more nuanced?**

A second consideration has recently become more prominent – food security. The combination of import reliance, food price inflation and exposure to disruption caused by climate change driven weather events has led some to challenge the diversion of any land to energy use. It is often characterised by bioenergy sceptics as a question of "food versus fuel".

The production of biofuels is often framed as a trade-off between food, energy and other land uses (e.g. biodiversity) with the underpinning assumption that land is a finite entity and therefore there exists a zero-sum trade-off around its productive use; a use which in addition is often assumed singular (i.e. land is either in food or energy).

Most debate and referenced studies take this angle and reflect some response variable (e.g. food prices) to a set singular independent driver or in response to a singular event, presenting confirmatory analytical econometric approaches based on pre-existing expectations around the perceived impact of biofuels. Food poverty is complex problem and often in response to local circumstances. It is generally the case that there is sufficient food production globally to supply the current world population.

Recent evidence is starting to suggest a significantly more nuanced situation in which a particular landscape or farm business presents an opportunity to optimise for multi-use, in which there exists a set of conditions in which each activity benefits and enhances co-activities (e.g. income from energy/fuel production allows farming businesses to invest and become more productive in food production; regenerative farming both enhances food production while investing in and developing the natural capital in that geography).

Key here is a transparent policy environment which actively seeks and encourages co-benefits from multipurpose farm businesses in which the relative impact of each activity (e.g. CI, biodiversity) is transparent, but the businesses are allowed to develop and innovate to achieve optimal co-benefit results.

Successful farmers are agile in their decisions on planting and will react to market conditions (which includes subsidy levels). Therefore, in the current situation where we have excellent food security, farmers could switch to non-food crops with little risk to food supply. The evidence from the switch to oilseed rape for biodiesel in the late 1990s demonstrated this. At the time there were also arguments about displacing food production. Although at its peak in 2012 OSR occupied about 10% of land, there wasn't a dramatic fall in the production of food crops. The farmers used this new income to upgrade machinery and improve efficiency. It drove economic recovery in arable farming.

However, even taking the food versus fuel binary at face value, it is difficult to conclude that a major trade off is happening. Globally, sugar and starch crop production has adapted to a continued – and growing - biofuel use without long-term inflationary consequences; the global wheat marker price today (Chicago Board of Trade) is ca. $525 a bushel. It has traded in the $400-$600 (nominal) range for most years since 2016, spiking – as did most global commodities – in early 2022. Allowing for inflation in real terms (2016) the price would be at the very bottom of the range. The same is true for corn prices (indeed the price is roughly where it was – in nominal terms – in 2007. In real terms it would of course be much lower).

As the electrification of ground transport increases, demand for liquid fuels will decline. Even if biofuel blend rates increase overall demand growth will be limited (the United Nations Food and Agriculture Organisation FAO-OECD estimate a 14% global growth in sugar and starch use for biofuel production to 2033).

According to FAO and the OECD, from a 2025 base where 1.08% of wheat production, 15.4% of corn, 3.5% of sugar beet and 20.8% of sugarcane was used for biofuels this demand growth will translate into 1.07% of wheat, 14.8% of corn, 3.2% of beet and 25% of sugarcane. The overall share of sugars and starches used for fuels is 15.1%, growing to 16% in the next 8 years. The area under cultivation grows by 1.6% for wheat, 3.8% for corn, beet is flat, and cane 3.7%. In all cases yields improve (Annexe 3).

**Therefore a 14% increase in demand results in a less than 1% increase in the share of crops used for biofuels. Price, production and land use change fundamentals seem to suggest that fears of unacceptable trade-offs have been averted.**

There is a theoretical counterfactual – how much lower might prices have been without biofuel demand? Any attempt to quantify that would also need to account for potentially higher input costs (higher refined fuel prices) lower farm incomes and reduced investment in productivity improvements.

Agriculture is not just about food production or food security. Land use choices must be viewed in a more sophisticated, whole systems context. In the context of the deep global sugar and starch market food versus fuel is a binary that is at best unhelpful in developing responses to a complex mix of drivers and factors and at worst a mischaracterisation of agricultural production and market systems.

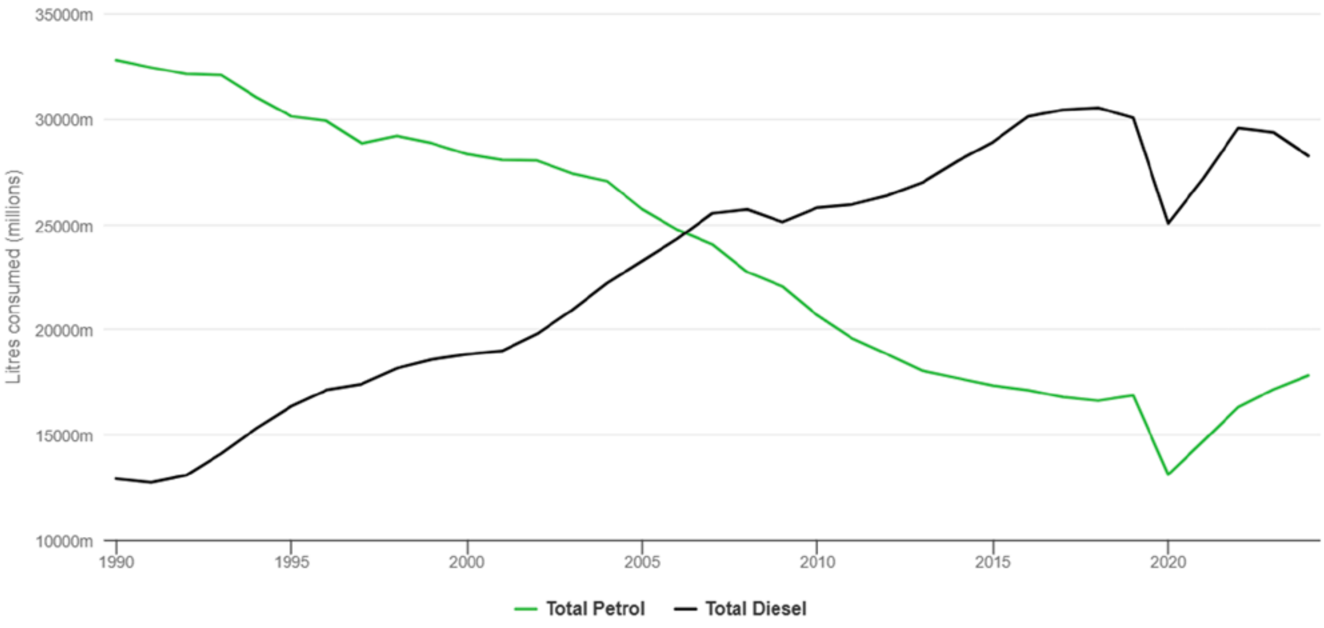
### UK Context

UK bioethanol is made from several crops, including wheat, sugar beet and maize (corn), although it is primarily wheat-based. The wheat used for ethanol is typically feed wheat – not normally used for milling into bread flour and instead used as animal feed. The feed wheat market is essential for the milling wheat market to operate. Reaching milling wheat (human consumption) specification is dependent on several variables such as soil type and weather conditions throughout the growing season - often out of the control of the farmer. If a farmer did not have access to a fungible feed wheat market, they would be highly unlikely to be able to take on the risk of growing milling wheat.

Historically the UK imports much of its milling wheat from Canada and exports surplus feed wheat to continental Europe. Farmers can grow industrial crops under contract with ethanol producers and can re-purpose non-milling wheat into ethanol. It is important to note that the UK bioethanol production facilities supply animal feed (and industrial CO2) as co-products. In effect, only a portion (the starch content) of the feed wheat goes to ethanol. The protein is retained as animal food. A tonne of wheat produces about 0.38 m3 of ethanol. It also makes 0.33 tonnes of high-protein food and feed co-products, and 0.28 tonnes of biogenic CO2, as well as other co-products.

The UK has removed all import tariffs on up to 1.4 billion litres of US ethanol following the June 2025 UK-US trade deal, roughly equivalent to the entire UK market (which goes into E10 petrol). Domestic producers (Vivergo and Ensus) have warned that this will result in plant closures – US corn ethanol is typically less expensive to make and the US domestic market for ethanol is over supplied and benefits from producer tax credits. Given the maturity of the UK economy and pace of electrification of the car fleet, demand for petrol is expected to decline (it has been roughly flat since 2015 (lockdown excepted), potentially leaving a tariff-free corn ethanol supply overhang.

**Figure 27: UK petrol and diesel quantities consumed[18].**



The loss of domestic supply to the UK ethanol market will likely depress UK feed wheat prices further as more output will need to find markets in the EU animal feed system.

**The mandate bans the use of crop-based ethanol as a SAF feedstock. It is worthwhile laying out the implications should the ban be lifted.**

Based on a forecast total aviation fuel demand of 12.3 million tonnes in 2030, under the mandate 7.1% of that must be met by neither advanced nor PtL SAF. At default CI savings values this equates to 873,300 tonnes of first generation SAF (1.1 million m3).

Including DfT default ILUC assumptions and using UK wheat actual direct emissions (as reported in the 2024 RTFO statistics), a litre of wheat ethanol derived SAF delivers a 45% GHG saving (and so qualifies for use as SAF) and generates 0.64 of a certificate. We estimate it takes about 1.65 litres of ethanol to make a litre of SAF.

Therefore about 1.72 million m3 of wheat ethanol SAF (1.1m m3/0.64) would be needed to fulfil this part of the mandate, which would use about 7.4 million tonnes of wheat (1.72m m3/ (0.38/1.65)).

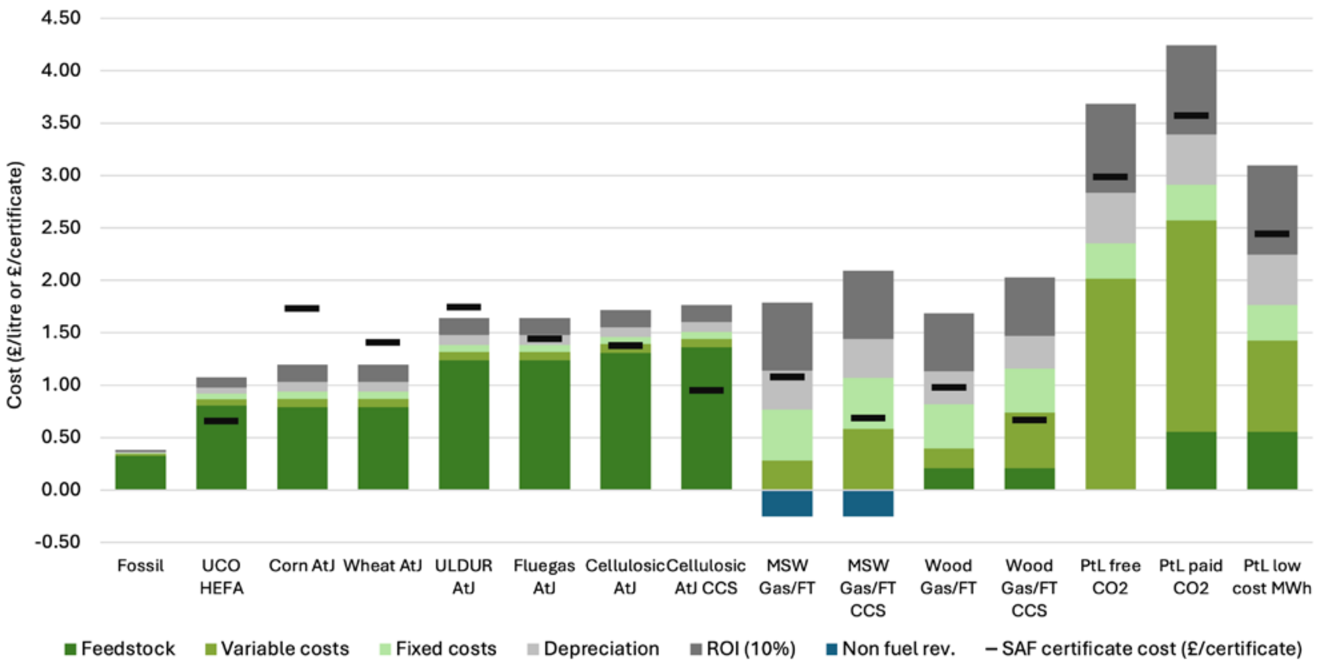
The 5-year average feed wheat yield is 8 tonnes per hectare. This suggests that 925,000 hectares of UK agricultural land would be required to meet the total sub-HEFA cap mandate in 2030.

**Current UK manufacturing capacity (Vivergo and Ensus) can deliver around 500,000 m3 of physical SAF volumes. This would generate 320,000,000 certificates and meet about 30% of the mandate target. The two UK plants would use about 2 million tonnes of wheat to do this (about 0.24% of global wheat production). Supplying current UK capacity would require about 250,000 hectares.**

The UK Agricultural and Horticultural Development Board (AHDB) forecast UK feed wheat production in 2025 at around 13 million tonnes, suggesting ca. 1.65 million hectares of UK agricultural land is used for feed wheat. Total UK arable land is about 6 million hectares. **Supplying current UK ethanol production would use just over 4% of our total arable land.**

As the chart below shows, wheat and corn A to J pathways are roughly comparable with UCO HEFA on the cost of a physical litre. However, the higher direct emissions of corn (on last year’s data) and the inclusion of ILUC for the two crop-based pathways increases the certificate cost. **However, wheat ethanol SAF remains a relatively competitive option (especially if compared with a first of kind advanced SAF pathway).**

**Figure 28: Cost build-up of SAF technologies (10% ROI, 25% discounted gate fee)(5). Full assumptions found in Annexe 1.**



## Dropping the Crop Ban: Responding to potential concerns

The case for diversifying the range of feedstocks for SAF, so broadening the range of alternatives to waste-vegetable oil HEFA, appears strong. The question is whether crop sugar and starch-derived ethanol should be a part of that mix, especially if there are uncertainties about the potential for cover crops to scale effectively. Starches are recognised as having low ILUC risk, and are in large, deep, liquid markets which appear to have shown great resilience in responding to demand for biofuels. UK food security concerns are offset by the flexibility and responsiveness of farmers and the fact that the alternative use of the marginal tonne of UK feed wheat is to be exported to feed Europe's cows.

That said, while many of the risks that informed the original precautionary policy approach do not appear to have materialised, simply declaring an end to all constraints or conditions on the use of crops may still raise some concerns, and, just as importantly, may forego an opportunity for the SAF mandate to be a driver of improved agronomic practice.

The opportunity is based in the potential provided by the central role carbon intensity plays in the valuation of certificates. For the first time we have a mechanism that potentially rewards efforts to reduce emissions through the supply chain. The fact that the UK SAF market is relatively small and emergent is also helpful.

A potential pathway to including sugar and starch-based crops in the UK “sub HEFA Cap” mandate could start with:

1. Identifying the unintended consequences that we are seeking to guard against.
2. Implementing appropriate controls and monitoring and measuring methods.

Should unintended consequences start to materialise corrective action could be initiated early – and in any event a stronger evidence base around the consequences of using such crops for energy would be established.

This approach would clearly lend itself best to geographies where there is a high level of trust and sophistication in the application of monitoring – perhaps lending itself to a UK trial period before deciding whether to extend the removal of the crop ban to imported feedstocks. Such an approach could not only guard against downside risks but also support improvements in direct agricultural emissions.

**Monitoring and verification technologies**

We would need to ensure the environmental impact of the crop used is verifiable and was similar or better than our own standards. The US, EU and UK have strong environmental policy around crop production, with transparency in the food supply chain. This is not the same in other countries. The EU has introduced regulations such as the deforestation regulation (EUDR) to ensure that food commodities like coffee, cocoa and soy are sustainably sourced from farms without recent land use change from primary forest. Satellite imagery is used to enforce the EUDR by enabling real-time monitoring of land use changes, ensuring commodities are sourced from deforestation-free areas. High-resolution images from satellites such as Copernicus Sentinel-2 allow for precise detection of deforestation activities, while GNSS data provides accurate geolocation of production sites, facilitating traceability and compliance verification. This integration of satellite data supports due diligence processes, risk assessments, and the generation of necessary documentation to demonstrate compliance.

Similar systems could be used to remotely monitor crops used for SAF production and detect new arable fields (direct land use change) where there were concerns about Indirect Land Use Change (ILUC). For example, the previous cropping history of any field used for SAF can be assessed using satellite remote sensing, to quantify GHG emissions for different land-use trajectories. It could then be used to verify the use of marginal lands and to detect environmental improvements.

Key metrics include:

- Land-use efficiency (yield per hectare, energy yield per hectare) .
- Carbon intensity accounting (C stocks and improvements from agricultural practice) .
- ILUC risk status (is it marginal land, is it improving yield) .
- Land conversion (avoid high risk or protected areas) .
- Economic modelling (e.g. demand vs land use change).

Other technologies such as blockchain could further enhance the traceability of crops grown for Sustainable Aviation Fuel by creating a secure, tamper-proof ledger that records every step of the supply chain.

Farm-Level Data on crop type, planting dates, agricultural practice environmental compliance, and certifications can go directly into the blockchain, to ensure that only crops meeting sustainability criteria move forward in the supply chain. Then the end-users can trace SAF back to their agricultural origins, supporting sustainability claims.

### Responses to the SAF Mandate carbon incentive: Novel cropping systems, climate smart and regenerative agriculture

Current agricultural technology solutions have focused on improving large-scale arable production and high-value crops. The commercial applications have seen vast improvements in the quantity and quality of data collected using satellite technologies, UAV and in-field sensors, and growers are already realising economic and environmental benefits. However, to meet future demand for food and fuel more radical thinking is required.

In the carbon cycle, crops remove CO2 from the atmosphere and partition this throughout the plant including the roots, and leaf litter decomposition adds to soil organic carbon (SOC). Some of the CO2 is lost naturally to the atmosphere via respiration and soil gaseous exchange. In a (well-functioning) natural environment plants will increase SOC (net gain).

However, the post-war increase in the use of artificial fertiliser and agrochemicals (themselves energy intensive and releasing several GHG (CO2, CH4, N2O)), coupled with improved plant genetics, and better agricultural mechanisation, has resulted in intensive cropping which is depleting SOC each crop cycle and degrading the land. Food crop residues are permitted as a SAF pathway, as they are often considered by-products, the assumption is that their emissions are already accounted for in the primary use. However, this source of carbon (e.g. straw) will no longer be re-incorporated into the soil, reducing SOC further.

Regenerative agriculture hopes to reverse the impacts of high-input agriculture by building resilient ecosystems, through a combination of crop choice (ones which can increase SOC quickly) and farming practices, such as under-sowing and mixed cropping and novel use of alternative fertilisers (such as digestate from the SAF process by-products). Reductions in greenhouse gas emissions from UK regenerative agriculture practice have been estimated to be 1 to 3.5 t CO2e/ha/year (Farm Carbon Toolkit, 2024). In contrast an intensive arable system emits >4 t CO2e/ha/year.

Regenerative agriculture will also improve wheat (or beet) yields in the longer term through improved soil health and water retention, practices that help mitigate climate change, which also indirectly supports longer-term wheat viability.

Farmers are also interested in novel landscape configuration to support environmental drivers such as improving soil fertility, increasing biodiversity, enhancing water retention, and sequestering carbon. Mixed cropping has potential (Annexe 4) – but will likely bring yield implications and other complexities that mean that it will probably not feature soon.

**Summary**

Diversifying the supply of SAF feedstocks to offset UCO risks and deliver mandate volumes before advanced and PtL SAF scales is critical. It is tempting to wait for evidence that the refreshed UCO verification standards are having the desired effect. But whether they work or not, we will likely face a supply issue for 1g SAF. To get ahead of the issue steps need to be taken now to enable feedstock diversification – it will take time to establish new intermediate crops and build the alcohol to jet capacity that will be needed.

Cover crops in the UK are unlikely to be a silver bullet, as they are typically oilseed crops grown outside of the main crop-cycle, with short day length which limits feedstock yield. That said, they should be included in the SAF feedstock mix. They can contribute to feedstock diversification.

UK Agriculture could support cultivation of further industrial crops with little or no impact of food production. Evidence from the 1990s, when oilseed production increased, led to an economic boost to the farming sector through investment in new equipment and improved management. The carbon intensity driver in the SAF mandate design could further incentivise investment in lower emissions agricultural practice.

Crop-based SAF can be grown sustainably in the UK if the production is verifiable, traceable, and doesn't reclaim land allocated for environmental stewardship.

The technology now exists to monitor crops automatically using remote sensing and blockchain, so policy decisions could be monitored in near-real time, looking for unintended consequences.

Farmers can switch between different crops so can react not only to urgent geopolitical shocks if more food is needed in the next growing season but also feedback from a monitoring programme.

Using these new technologies, there is nothing stopping us from implementing a trial allowing crop-based SAF in the UK now.

The use of domestic wheat ethanol to produce SAF could have the quadruple benefit of:

- helping mitigate the dependence on vegetable oils,
- offsetting the impact on domestic agriculture and manufacturing of the loss of ground fuels market,
- providing an incentive for continuous improvement in agricultural and process emissions, and
- enabling the early deployment of A to J technology - which also has a role in 2g SAF.

## Risk 2: Advanced SAF - too little, too late?

We have seen that advanced SAF has the potential to meet – and potentially go beyond – the 2040 targets above the HEFA cap. Sufficient feedstock supply is available. Incentives already built in to mandate design will push improvements in emissions reduction as well as cost performance, thereby increasing the probability of targets being fulfilled. The cost and emissions reduction potential of these technologies is compelling, with the potential not only to reduce long-term dependence on crop and UCO pathways but even to compete with or outperform PtL on cost and GHG grounds. The prospect of very efficient advanced SAF plants using green hydrogen and carbon capture is even more exciting – reducing UK SAF exposure to this technology as well. The fact that this could be a UK-driven, UK-led industry is a bonus.

Getting these technologies to scale is therefore imperative if we are to see this promising sector lift off.

The original DfT commissioned independent stakeholder review concluded that Government intervention should focus on enabling sensible market arrangements and ensuring sustainable access to feedstocks. However, it also noted that further support may be necessary for the first sites to be built, given the higher risk of First of a Kind (FOAK) projects. This was called the “Icebreaker”.

### Enabling market arrangements

Good progress has been made on enabling supportive markets. The overall mandate design is very strong, creates clear market spaces and incentivises progressive improvement in cost and emissions performance. The key outstanding matter pertaining to market design is the completion of the RCM.

We need to make sure that the RCM provides the revenue certainty that investors demand while supporting (and certainly not undermining) the creation of a vibrant, fungible, transparent market for advanced SAF. DfT are clearly taking this challenge very seriously. Decisions have been announced on design fundamentals; scheme type (Guaranteed Sales Price), who pays (industry – with suppliers bearing the levy, but any costs likely passed down the value chain) and who is the counterparty (the Low Carbon Contracts Company (LCCC), who also administer the scheme). A levy management mechanism has been proposed – although there are concerns around the requirement for in-year settlement. Overall, however, the scheme is off to a good start and the legislative process has been successfully kicked off.

The scope (proportion of the total mandate target that is potentially covered by RCM contracts), tenor (contract duration), governance and in particular the strike price and reference price discovery mechanisms appear to be subject to further discussion and announcement but are absolutely critical.

The scope trade off rests on a judgement of the probability that the advanced SAF mandate levels will be delivered. A bullish view would argue for limited coverage of the mandate requirement, focusing on higher risk but scalable technology platforms. The risk is that the technology failure rate is higher than expected and the mandate is not delivered. A more cautious approach would increase RCM coverage of mandate targets – with the risk that the market goes long and the least competitive non-RCM early mover plants are shuttered and a merchant volume spot market doesn't materialise. In all cases sufficient competitive tension is necessary to drive "best offers" from applicants – the RCM volume capacity should be set at a level lower than expected mandate demand. In any extent, scope decisions will also have to take potential variations in emissions performance into account.

Tenor is important. The probability is that early assets will have higher financing costs, higher build costs and higher feedstock costs than later builds – when confidence will be higher and learning curve benefits realised. The first wave of plants need to be supported throughout the initial investment payback period – typically 12-15 years.

The governance question centres on collaboration through the value chain. Trust will require high transparency, whether in the recording of scheme inflows and outflows or any additional administrative cost and risk premia that are applied, whether by the LCCC or the suppliers. How scheme surpluses, expected to be collected by the LCCC from the producers, and deficits, levied on the suppliers by the LCCC and then distributed to the producers are managed is important. The opportunity is to use this as a lever to reduce scheme risk, and therefore cost. The current proposal (as published in the recent DfT RCM funding consultation document), where LCCC estimates any scheme shortfall at the start of the year, applies a levy on suppliers to cover this and then applies a second levy at year end if required to cover unanticipated costs, adds to supplier risk (and end-user cost). If instead the scheme balances could be managed through a rolling float, with a safety buffer balance topped up as needed either by an additional levy or through the addition of any receipts from producers in short market conditions, supply chain risks would be reduced, volatility smoothed, and costs reduced.

The price discovery question is challenging – but fundamental to scheme success. The purest way to establish the strike price is through reverse auction – as deployed to great effect in successive rounds of the Offshore Wind CfD. This has the virtue of enabling a high level of price discovery, applying one price to all successful applicants, encouraging projects to examine their risk appetite and risk assessment closely and reducing the burden on the scheme authority. The alternative seems to be a series of bi-lateral negotiations, with each project potentially having its own, bespoke, strike price. This mechanism will clearly be preferable to most project developers and will be most effective in supporting the FOAK assets, but least effective in enabling a functioning market to be established (especially if mandate coverage is decided to be at the high end).

Market reference price discovery is also problematic. Until a trusted public price quote is available the challenge is clear. There are at least three possible options:

- Ask the SAF producers for the prices that they achieved in the market.
- Ask the airlines and/or fuel suppliers for the prices they were charged.

- See whether a viable certificate trading market emerges with published and fungible certificate pricing information.

The obvious issue with the first is that a producer with complete RCM coverage loses an incentive to seek the highest price for their product in a long market.

The issue with the second is complexity and resistance from participants (and, at least in the short term, uncertainty about the formation of the supplier premium over factory gate prices).

The issue with the third is that RTFO experience shows that such markets tend to be shallow – and therefore at risk of being gamed once linked to potentially material economic outcomes.

One thing is clear (and should be considered in contemplating scope): The development of a merchant market alongside the support for new assets is important. A market dominated by fixed (or input cost indexed) term offtakes and RCM will make it very difficult to identify a realistic market price.

**Enabling a winning advanced biofuels industry: clearing the path for feedstocks and beyond**
Progress on supporting advanced SAF feedstock access is patchy.

The decision to allow the use of Recycled Carbon Fuels (RCFs), with EfW as the counterfactual, is positive. It opens the prospect of hard to recycle plastics and similar feedstocks being sourced (9). The inclusion of Industrial Waste Processing Gases, on the same terms, is also supportive.

That said, there are still risks associated with securing access to feedstocks which need to be bid away from alternative, more mature, applications and where there is a real cost to the provider if offtake does not meet plan (a probability while the earliest, first-of-kind plants are starting up and shaking down).

The understandable risk aversion of local authorities combined with the preference of tier 1 waste companies to treat their in-house EfW assets makes MSW supply particularly challenging and expensive, especially for the first tranche of MSW SAF plants.

Two interventions would better align incentives through the supply chain, reduce risk, improve investibility and reduce the cost of capital (and likely provide better long-term outcomes for local authorities – competition for their waste will reduce the local authorities' costs). They are:

1) **Develop a time-limited performance guarantee mechanism so keeping a local authority "whole" if offtakes fall short of contract levels. There will need to be a pass-through mechanism of some kind with any MSW collector/aggregator.**

2) **Consider upgrading MSW and other wastes for application in the hardest to abate sectors as "recovery plus" in the waste hierarchy.**

Based on the report’s techno economic model, if the discount on gate fee for a FOAK asset could be reduced from 100% to 20%, the certificate cost would come down by around £0.50.

**Diversifying feedstocks for advanced SAF pathways should also be considered. Wood pellets, if sustainably sourced, would be an attractive option for both gasification and cellulosic fermentation pathways.**

As is widely recognised, UK electricity prices for industry are significantly higher than in many other European countries, let alone the US and many other potential competitors for SAF production. SAF plants will be energy intensive operations. That they are included in the British industry supercharger/British industrial competitiveness scheme is very welcome, especially given their high growth potential, presence in economically challenged regions and solutions to the hardest to abate sectors of the economy.

Access to RCFs, and in particular hard to recycle plastics, will likely be an attractive feedstock for SAF plants (particularly once ETS starts to impact EfW operations). The application of the EfW counterfactual is critical, but the longevity of the counterfactual is not certain. Rather than ask for a universal guarantee that the counterfactual will not be changed, regardless, **consideration should be given to offering a plant-specific RCF counter factual guarantee for at least 10, and ideally 15 years.**

MSW FT plants produce syngas that is hydrogen deficient. Conventionally this means that CO in the syngas is used in a water-gas-shift process to achieve the required H2 to CO ratio. If green hydrogen could be sourced instead, MSW productivity would be enhanced, emissions reduced, and any production based on the imported hydrogen could qualify as PtL. The challenge is that the rules for qualification of green hydrogen are even more demanding for SAF than they are in the national hydrogen production business model (NHPBM). This almost certainly means that SAF assets will not be able to secure supply of green hydrogen – so rendering any prospect of UK production contributing the PtL mandate even more challenging. This may be a consequence of an aversion to potential “double dipping” but why different standards apply for application in different parts of the economy is baffling. **Green hydrogen qualification standards should be aligned – ideally to the NHPBM standard.** This will have a significant positive impact on SAF economics – particularly if they don’t have access to CCS.

It is clear from the techno economic modelling that the combination of SAF production with CCS is compelling, both reducing the cost of certificate generation (despite the higher capital costs) and reducing the physical volumes required to meet targets and it is a strength of the mandate design that it rewards negative emissions. The challenge is that the development of UK CCS capacity is slow, and access arrangements appear potentially complex. **The development of a merchant market, with SAF plants able to bid for CCS capacity, would be very helpful.**

There are some promising signs of development in carbon removal (DACCS) technologies. The concern is that the potential of these technologies could be used as an excuse to delay or stop positive steps to emissions reduction in aviation – including the development of SAF – especially when attainment of net zero already places a significant burden on carbon removal and offsetting (CA pathway). However, there might be an application for DACCS carbon credits that aligns well with the development of the SAF sector. In theory the economics of capturing a concentrated stream of CO2 at source should be better than capturing atmospheric carbon, but for assets that do not have access to CCS, or where CCS availability does not meet SAF FID schedules the possibility of allowing SAF plants to acquire and "staple" DACCS credits to their own emissions. The price of carbon credits will be critical, but the possibility of de-risking access to sequestration, improving investment economics and further relieving pressure on physical volumes makes this worthy of further exploration.

It is worth stressing the point that much depends on the confidence of investors in the longevity of regulation. If there were any doubt that the Mandate treatment of negative emissions might change it would be much more difficult to encourage investment SAF plants accessing CCS and increase calls for a version of bilateral contractual arrangements (as seen with the RCM).

**Icebreaker: reducing the cost of capital through mitigating cost, schedule and performance risk.** Many of these technologies are very capital intensive, so steps to reduce the cost of capital by de-risking the pioneer plants are of great value. The continuation of the AFF and the creation of the SAF Clearing House are welcome, but the challenges are not just about getting projects to FID but also that they are built on time, to budget and perform to expectation. Only then, when track record starts to build, supply starts to scale and a market starts to form, will investor, supplier and customer confidence be such that the potential of these technologies will be fulfilled. FID on a FOAK asset does not mean that the technology is commercial and that all development is done. There is as much learning – and more risk – during construction and early operation as there is during the research and development phases.

A range of possible approaches was discussed in the second DfT Independent SAF Commercialisation Report, circulated in August 2023. Levers assessed included:

- **Funding support for technology risk insurance premia.**

- **A light touch variant of the debt-comfort package provided to investors in the Thames Tideway Project.**

- **Bespoke, project specific and granular KPI driven performance guarantees.**

The relevant section can be found in Annexe 2.

Although none of these are straightforward, it is not clear that any action has been taken on any of the options outlined.

Targeted interventions to underpin investment in the high-risk, early-mover technologies – for example leveraging investment from Great British Energy to crowd in commercial funds or extending competitive grants from the AFF to increase non-dilutive funding in the first commercial assets, would clearly be very supportive.

## Risk 3: Regulatory Misalignment

The SAF market (and renewable fuels more broadly) is a regulatory artefact. The UK market exists alongside a global spectrum of competing arrangements in both ground fuels and SAF. There are varying degrees of alignment between markets and the interaction between them is complex and risk enhancing, encouraging regulatory arbitrage and negative system effects.

The Government cannot rely on other countries working to harmonise regulation, but it can at least improve arrangements within the UK. The RTFO and the SAF mandate have many shared elements – particularly around feedstock definition. They differ significantly in a critical respect. The SAF mandate differentiates between qualifying products on the basis of carbon intensity – embedding an incentive to improve emissions performance. The RTFO uses the blunt instrument of double certification – strongly incentivising one set of products over the other, but with no differentiation between products in their respective categories and no incentive to improve environmental performance beyond the minimum qualifying requirement.

The RTFO also awards certificates based on the volume of renewable fuel supplied as opposed to the quantity of renewable energy supplied. For example, crop-based ethanol and crop based HVO both generate one RTFC, even though one litre of HVO delivers 56% more renewable energy than one litre of ethanol (by contrast, different SAF pathways all produce a product with a consistent energy value).

A consequence is that SAF needs to bid product away from the ground fuels double certificate volume-based market – in effect it creates a price (or cost) floor, often at a higher level than would be necessary were a level playing field to apply. There is a strong argument to bring RTFO certification arrangements in line with the SAF approach with RTFC's awarded based on carbon reduction per unit of energy. This would:

- Reduce the risk of inefficient resource allocation,
- Support simplification, market transparency and effective market operation

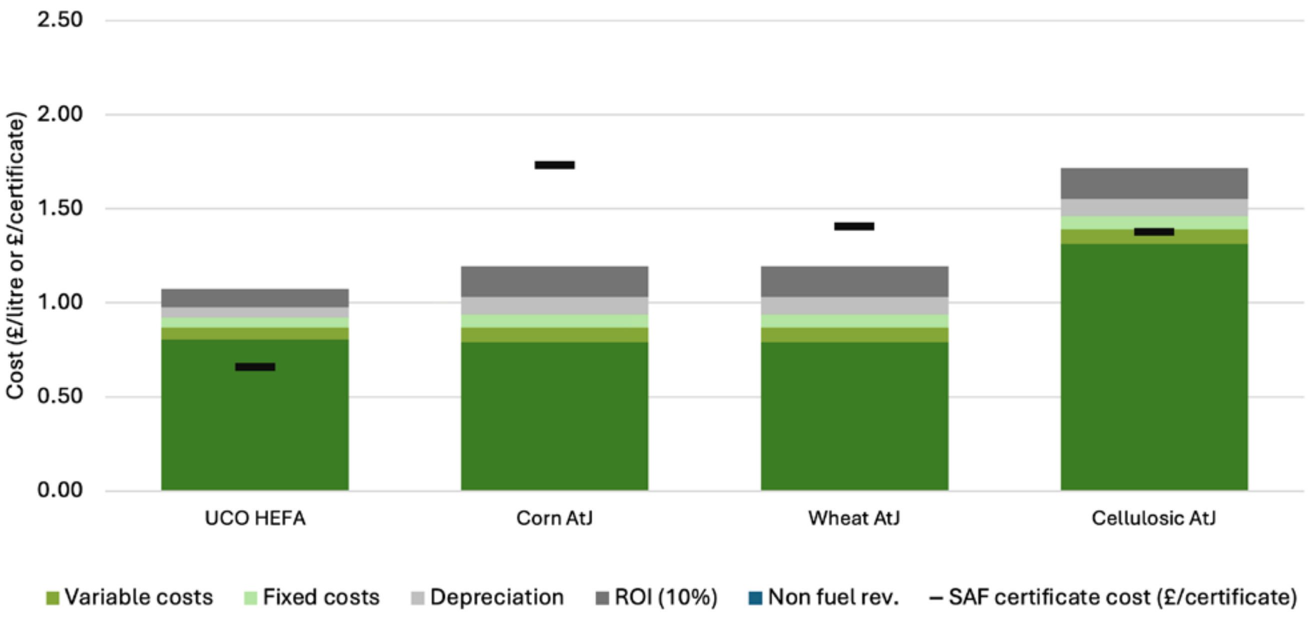
- Provide a greater incentive (by increasing the addressable market) for innovation and best practice in reducing emissions across the renewable transport fuels value chain.
- Reduce the cost of SAF in some cases (for example, a SAF ethanol to jet producer needs to bid ULDUR away from the double certificate market, whereas value would be defined by emissions performance in an aligned market).

Application of the existing default ILUC factors (as a consequence of dropping the crop ban for SAF) would minimise the risk of high-ILUC crops entering the ground fuels value chain. Direct emissions should be evidenced on a case-by-case basis – as already applied under the SAF mandate.

To illustrate this, our modelling indicates that, using actual 2024 RTFO statistics reported by DfT and applying the standard ILUC factors, were vegetable oil based HEFA SAF to be offered it would not meet the minimum emissions saving threshold, that corn-based ethanol to jet would marginally fail, but that the better emissions performance of UK ethanol would allow it to qualify for UK SAF.

For ground fuels, the difference in process emissions between HVO and HEFA is relatively minor – so palm oil would still fail to qualify. The alcohol-to-jet process has a greater emissions burden, so with this A to J step removed both US corn ethanol and UK wheat ethanol would qualify. Importantly, the premium certificate value of the UK wheat ethanol would allow for a premium to be paid over US corn ethanol – we calculate this to be worth up to £120/te (based on the CI data quoted in DfT's RTFO statistics).

**Figure 29: Cost build-up for HEFA and selected AtJ SAF technologies (10% ROI)(5). Full assumptions found in Annexe 1.**



**Instituting a consistent, feedstock neutral, energy and GHG denominated mandate system for both SAF and ground fuels** therefore has great appeal as a de-risking approach. Other adjusting mechanisms could still be applied on a market-specific basis if needed – for example maintaining different buy-out prices and retaining submarkets to incentivise investment in new technologies (such as the HEFA cap – or rather the “advanced SAF mandate”).

One nuance to this approach (as proposed by the RTFA) would be to **apply the default ILUC factors when assessing the qualifying status of products but not using it when assessing certificate value.** This would increase the certificates generated by each litre of crop based SAF or ground fuel, and so reduce the physical volumes required to comply with the mandate.

Another risk is the dependence that successful mandate implementation has on other parts of the economy and other Government departments. Failure to effectively coordinate activity across Government risks undermining much of the good work already done on market design. The EV transition was very effectively supported by the work of a joint DESNZ/DfT unit – OZEV. The creation of a UK SAF Production Team is welcome. **Any capacity that it can be given to engage with, influence and coordinate activity across Government is to be strongly encouraged.** Could “Mission Control” established by DESNZ to “turbocharge” the delivery of the clean power mission provide a model?

**A thought on contrails:**
The use of SAF could provide additional climate benefits compared with using current aviation fuels and it is important to maximise these in the design of UK production. The presence of trace elements such as sulphur and some aromatics in fuel enhances the formation of contrail-cirrus. These contribute about half the present-day climate impact of aviation, compared with a third for CO2 and a sixth for NOx emissions. If these trace compounds are not present in SAF, then the formation of contrail-cirrus could be greatly reduced and the overall climate impact of aviation could be reduced substantially. Ensuring this gain will require implementing results of research from on-going UK and international research programmes into the formulation of SAF and the design of its supply chain. This may require revision of the aviation fuel certification rules. The important point here is to keep the SAF discussion linked into the contrail-cirrus issue to ensure maximum joint benefit.

# Annexe 1

## Technoeconomic modelling assumptions(5)

**General modelling assumptions:**

- Technoeconomic models are on the basis that the first-of-a-kind, integration and scale-up learnings have already been implemented in plant designs
- Certain technologies (for example electrolysers in the PtL pathway) are anticipated to develop significantly over time and projected 2030 performance has been assumed
- Power grid carbon intensity assumes 50 g CO2e/MJ in line UK 2030 target
- Projects assumed to have 25-year lifespan
- Cost of product includes a 10% ROI with 15% ROI modelled as a sensitivity
- Where available carbon intensity based on RTFO average values (or RTFO average for ethanol used as ATJ feedstock) with adjustments for SAF conversion process emissions and fossil energy use
- Unless otherwise stated, projects are assumed to be located in the UK
- Costs have been adjusted to a consistent 2025 basis (using CEPCI factors) and construction costs are assumed 20% greater in the UK vs US (where the majority of reference plants are based) based on selected cities in a 2025 Arcadis report

**HEFA specific:**

- Model based on public domain information and disclosures combined with proprietary Featherstone Fuels models and analysis
- World scale facility at 1.4 million tonnes annual liquids production
- Process pathway consists of feedstock pretreatment, hydro-deoxygenation, hydrocracking and dewaxing
- Feedstock assumed to be used cooking oil (UCO), which is assumed to price with diesel plus $350/tonne

- 2% feedstock loss assumed for pretreatment
- Hydrogen based on theoretical requirement to deoxygenate feedstock and saturate product plus 10% surplus
- Biopropane and other process gases are assumed to be used alongside natural gas as feedstocks for process hydrogen requirements

**ATJ specific:**

- Model based on public domain information combined with proprietary Featherstone Fuels models and analysis
- Facility assumed to have 94,000 tonnes annual liquids production, scaled up from reference facility
- Process pathway consists of ethanol dehydration, dimerization, oligomerization and hydrogenation
- Various ethanol feedstocks modelled, including:
- US corn ethanol – assumed to be the marginal price setter for UK single counting crop ethanol, and priced at US value plus freight and import duty
- UK wheat ethanol – assumed to price off US corn ethanol
- ULDUR ethanol – price calculated from corn ethanol with adjustment for non-crop double -counting status
- Flue gas ethanol – assumed to price at parity with ULDUR ethanol
- Cellulosic ethanol – assumed price as corn ethanol with appropriate premia for cellulosic US RINs and CA LCFS value
- Hydrogen based on theoretical requirement to saturate product plus 10% surplus
- CI based on relevant ethanol feedstock, adjusted for yield and fossil emissions associated with heat and power
- CCS variant assumes that 90% of ethanol fermentation CO2 is captured and sequestered

**Gasification/Fischer Tropsch specific (MSW):**

- Model based on public domain source combined with proprietary Featherstone Fuels models and analysis
- Facility assumed to have 63,000 tonnes annual liquids production, scaled down from reference
- Process pathway consists of waste processing facility, feedstock management, gasification, Fischer Tropsch and hydrocracking
- FT tail gas used for power generation, reducing imported power demand by 37%
- Mixed black bag MSW feedstock assumed to be delivered with a gate fee of £85/tonne less 25% discount, with zero gate fee modelled as a sensitivity
- MSW SAF facility includes waste sorting equipment, which separates metals for recycling and inerts and hazardous material for disposal (at the facilities expense) with the remainder dried and processed into gasifier feed
- MSW waste processing facility assumed to have capital cost of €242/annual tonne of incoming waste with power requirements of 90 kWh/tonne of incoming waste
- Surplus heat from SAF facility is used to dry feedstock
- Gasifier selection for MSW feedstock uses external natural gas heat source
- Carbon intensity based on an Energy from Waste counterfactual
- CCS variant assumes that 90% of feedstock carbon that is not converted into liquid products is captured as CO2 and that 90% of this is sequestered

**Gasification/Fischer Tropsch specific (waste wood):**

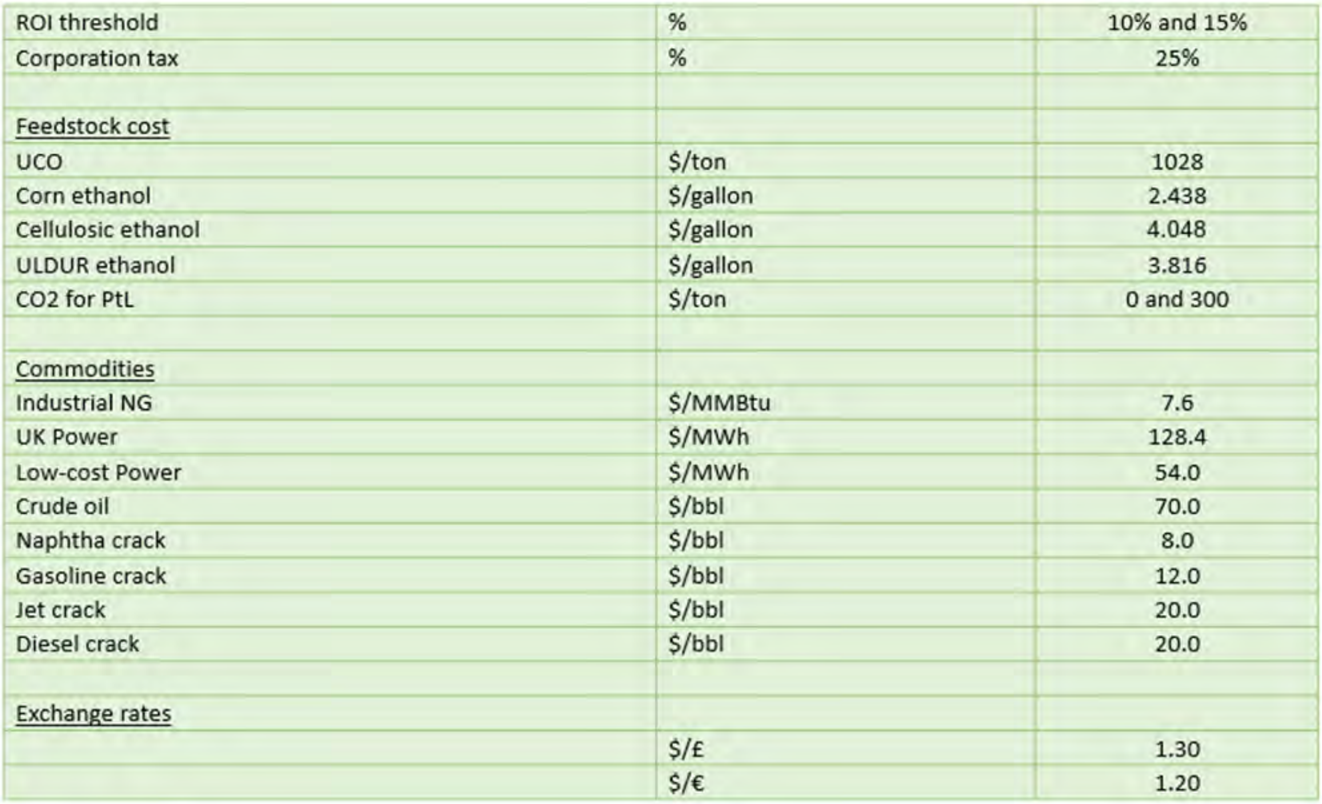
- Model based on public domain source combined with proprietary Featherstone Fuels models and analysis
- Facility assumed to have 63,000 tonnes annual liquids production, scaled down from reference
- Process pathway consists of feedstock management, gasification, Fischer Tropsch and hydrocracking

- FT tailgas used for power generation, reducing imported power demand by 37%
- Chipped waste wood is assumed delivered at a cost of £40/tonne, with an assumed 20% loss
- Waste processing facility is assumed not required for waste wood gasification process
- Surplus heat from SAF facility is used to dry feedstock
- Gasifier selection for waste wood feedstock uses heat from feedstock oxidation within the gasifier, at a cost of lower yield
- Carbon intensity based on an Energy from Waste counterfactual
- CCS variant assumes that 90% of feedstock carbon that is not converted into liquid products is captured as CO2 and that 90% of this is sequestered

**PtL specific:**

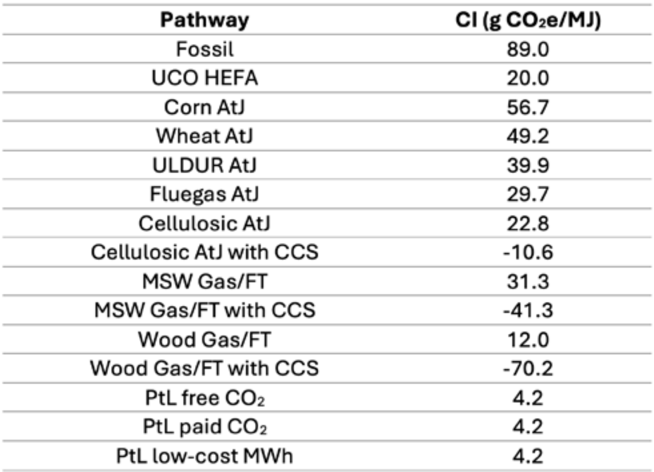
- Based on proprietary modelling conducted by Tranby Technology Limited under contract from Featherston
- e Fuels Limited, with assumptions updated based on Project SkyPower (October 2024)
- PtL process based on electrolysis, reverse water gas shift, Fischer Tropsch and hydrocracking pathway
- Facility assumed to have 55,000 tonnes annual liquids production, based on SkyPower reference
- Electrolyser efficiency assumed as 50 MWh/tonne of hydrogen, based on SkyPower 2030 assumption
- Electrolyser cost assumed as 1856 €/kW, based on SkyPower 2030 assumption
- Baseline renewable power cost for UK assumed to be £99/MWh, based on SkyPower 2030 projection
- Power sensitivity cost of £42/MWh used to simulate product produced in a region with access to low-cost renewable power
- CO2 cost of zero, simulating the best case with CO2 sourced from concentrated local sources, (such as a neighbouring ethanol or gasification facility) plus a $300/tonne CO2 cost alternative case

### Key model input cost assumptions:



| | | |
|---|---|---|
| ROI threshold | % | 10% and 15% |
| Corporation tax | % | 25% |
| | | |
| Feedstock cost | | |
| UCO | $/ton | 1028 |
| Corn ethanol | $/gallon | 2.438 |
| Cellulosic ethanol | $/gallon | 4.048 |
| ULDUR ethanol | $/gallon | 3.816 |
| CO2 for PtL | $/ton | 0 and 300 |
| | | |
| Commodities | | |
| Industrial NG | $/MMBtu | 7.6 |
| UK Power | $/MWh | 128.4 |
| Low-cost Power | $/MWh | 54.0 |
| Crude oil | $/bbl | 70.0 |
| Naphtha crack | $/bbl | 8.0 |
| Gasoline crack | $/bbl | 12.0 |
| Jet crack | $/bbl | 20.0 |
| Diesel crack | $/bbl | 20.0 |
| | | |
| Exchange rates | | |
| | $/£ | 1.30 |
| | $/€ | 1.20 |

### Modelled SAF pathway CIs:



| Pathway | CI (g $CO_2e$/MJ) |
|---|---|
| Fossil | 89.0 |
| UCO HEFA | 20.0 |
| Corn AtJ | 56.7 |
| Wheat AtJ | 49.2 |
| ULDUR AtJ | 39.9 |
| Fluegas AtJ | 29.7 |
| Cellulosic AtJ | 22.8 |
| Cellulosic AtJ with CCS | -10.6 |
| MSW Gas/FT | 31.3 |
| MSW Gas/FT with CCS | -41.3 |
| Wood Gas/FT | 12.0 |
| Wood Gas/FT with CCS | -70.2 |
| PtL free $CO_2$ | 4.2 |
| PtL paid $CO_2$ | 4.2 |
| PtL low-cost MWh | 4.2 |

# Annexe 2

## ICEBREAKER

### Context

The Icebreaker programme is intended to enable the first sites to be built, technologies tested at scale and finance, EPC, supply chain and market familiarity built.

2g SAF plants will cost hundreds of millions of pounds to build. The earliest of them will carry particularly acute cost, schedule and performance risks, typical for first-of-a-kind projects. Companies with strong balance sheets and experienced and expert internal project management, engineering and procurement capabilities may feel comfortable with assuming these risks, but bank lenders (and equity funds) seek a higher level of certainty. In the original report it was stated that equity owners should manage this – with Government intervention focused on enabling sensible market arrangements and ensuring sustainable access to feedstocks at the scale necessary to meet UK production needs.

However, the report also noted that Government support may be necessary for the first sites to be built, given the greater risks and uncertainties of first-of-a-kind project, and the risk of promising projects being trapped in the “valley of death”. The idea behind the Icebreaker was to provide support to fast-track projects to construction, restricted to a small, selected set of projects (2-5 depending on the diversity of technologies involved) and of 4-7 years duration (covering construction and the early years of operation). Project selection should be competitive and possibly leverage AFF learning.

The option posited featured the provision of very specific guarantees against discrete performance metrics (so not a blanket investment guarantee), making good any shortfall against critical project KPIs. It also offered the prospect of leveraging the UK Infrastructure Bank as a cornerstone investor – “crowding in” other lenders.

This section will provide a little more detail on the possible levers to build investor confidence. It should be noted that the definition of Icebreaker used here is that applied in the original report – specific interventions to mitigate FOAK technology and related risks. It does not look at broader options such as Government capital grant funding.

### Counterparty identification

The Icebreaker is a risk-sharing mechanism. It is difficult to see an incentive for direct industry involvement – why would a commercial airline step in to accept risk that commercial banks and experienced construction companies shun?

UKIB could be willing to act as a cornerstone investor, possibly taking on higher-risk exposure (e.g. mezzanine debt/first loss lender/equity), but only against “bankable” projects. UKIB involvement can be of substantial benefit to a project but does not remove the need for other forms of support if a project is to be bankable.

**The conclusion is that the most likely viable counterparty is Government**

A concern is that any government-backed guarantee is seen as a no-cost benefit. As described below, assuming risk always comes at a cost (the challenge is how best to price the risk). An ability to articulate the cost of the risk assumed by Government is important of itself but is also helpful in demonstrating the sharing of programme risk to industry.

A successful scheme would not only enable debt to be raised for FOAK projects. it should also reduce the borrowing costs for the projects and potentially reduce overall EPC costs. The division of these subsequent benefits between project and guarantor would need to be agreed.

**Risks**

This is not concerned with market or feedstock risk.

The risks in question are:

- Construction cost risk – for example general inflation, supply-chain disruptions and contractor under-performance.
- Construction schedule risk – supply chain disruption, planning and permitting issues, unforeseen remediation requirements etc.
- Technology integration risk – most individual modules in the proposed projects involve relatively mature technologies – but they typically haven’t been integrated together, at scale, before.
- Technology performance risk – AFF should help mitigate this – but variations in feedstock, handling complexity, and lack of hands-on experience makes it difficult to be absolutely confident that the kit will perform – on volumes, operating and maintenance costs, quality and emissions – as predicted.
- Operating risk – once commissioned, the time taken to get to nameplate capacity and then sustaining it.

The focus is on managing these risks during construction and the first 2-3 years of operation. It is worth noting that in a recent survey of potential SAF investors, technology risk was most frequently cited as being of greatest concern and risk reduction measures such as loan guarantees were the joint most frequently cited desired priorities from Government policy(1).

**Possible Levers**

Typically, technology licenses come with a range of warranties and guarantees. They will be conditional, specific to the individual technology component and vary in nature. Design engineers should offer warranties, but again with limitations and caveats.

Developers have the choice of procuring EPC contractors on a cost-plus or fixed-cost basis. The former comes at a lower price, but the developer carries much of the cost and schedule risk. The latter – sometimes called an “EPC wrap”- has the EPC contractor guaranteeing the delivery of a range of outcomes for a given cost. The EPC contractor assumes much more of the risk but charges a premium to do so. Invariably projects with a large debt component opt for the latter, if available.

The challenge for first-of-a-kind projects – amplified given the high capital cost and difficulty to modularise – is that the scope of the “wrap” EPC contractors are able and willing to provide is likely to be constrained to some of the more vanilla procurement and construction elements (the stretched state of UK EPC capacity does not help). The developer may be able to access insurance products to cover some of the residual construction and schedule risk.

The original Icebreaker concept – bespoke, project specific, granular KPI performance guarantees with narrowly defined “make good” provisions, remains valid, but challenging for Government to implement. It would likely require the selection and appointment of a qualified consultancy to assess and then negotiate with project developers the performance parameters and payment triggers. Pricing the risk – to enable the liability to be understood by Government - would be a further requirement.

An alternative could be the application of technology risk insurance. This has been tried in the US – Fulcrum’s FOAK Sierra Nevada plant had coverage provided by New Energy Risk – who claim to have developed a process that enables the evaluation and actuarial analysis of at least technology integration and performance risks. However, when Fulcrum went under the policy was not deemed to cover the specific reasons for failure.

A third alternative is a variant of the Government Support Package used on the Thames Gateway project.

RAF/MOD offtake arrangements would be helpful in improving general project confidence, as mentioned in the Revenue Mechanism section – but offtakes support revenue confidence rather than mitigate cost and performance risk, and anyway, absent a longer term fixed or index price with a take or pay arrangement, this would only reinforce the demand signal already established in the mandate itself.

### Technology Risk Insurance

These insurance products focus on providing long-term performance cover for new build assets, indemnifying debt funders against shortfalls in plant performance (quality and quantity) for up to 10 years. It is limited in scope to technology risk – so plant configuration, component performance, integration and scale up. It does not cover contract or policy risk (including many elements of construction cost and schedule risk). Typically, it will cover debtor risk – so making good losses due to technology performance beyond an agreed threshold level (equity therefore taking on the initial risk) as well as funding efforts to correct the underperformance.

The insurance pricing process reflects aspects of the original Icebreaker concept – it is based on the development of a set of quite detailed parameters rooted in an engineering analysis of the design. Finite underwriting capacity and syndication thresholds typically limits the amount covered per project ($100m is most often quoted). It is claimed that it can be designed in parallel with the normal financial close timeline (so months, not years). The benefits – aside from potentially unlocking debt finance in the first place – include lower cost of debt and the provision of an external “quality stamp”, increasing stakeholder confidence and broader investibility.

The intent is that the cost of the premiums be no greater than the saving in cost of debt – a ballpark of approx. 10% of underwritten value has been suggested. Premiums are typically paid up front.

From an “Icebreaker” perspective the opportunity could be for Government to offer to fund or co-fund the premium on selected FOAK projects. This also outsources to the insurer the risk and administration of due diligence so reducing Government burden while offering transparency around the cost and value of Government support. Happily, 2g processes appear to be familiar to the insurers. Based on the $100m insured per project/10% premium estimate the support of Icebreaker Insurance to, say, 5 projects would require between £20m and £40m of public funding, depending on whether co-funded or not.

In the event that projects outperform the agreed metrics there are options where overperformance revenue is clawed back by the insurer – this option could reduce premiums or provide Government with a potential future revenue stream.

**At face value these insurance products look like they cover the key exposures envisaged in the original Icebreaker notion but delivered by the private sector through commercial contracts. Familiarity and comfort with these products are mixed. In the Fulcrum case, the insurance policy did not help. The Fulcrum experience suggests that these policies also need to cover start up risk if they are to appeal to investors. This may have an impact on expected premiums. If this is seen as a viable option a focused study involving developers, commercial senior debt providers, UKIB and the insurers is advised.**

### Government Support Package

This was suggested by UKIB – the notion of a “light” variant of the comprehensive debt-comfort provided by HMG to investors in the Thames Tideway project. It includes Government acting as insurer of last resort, the provision of contingent equity support in the event of cost overruns and some specific market support capacity. The obvious concern with the creation of a like scheme for the first few pioneering SAF plants is the likely cost and time involved in designing, negotiating and implementing such a scheme, and the question of whether the Government wishes to hold equity in SAF plants. Ideally a more limited set of guarantees – perhaps delivered through a technology risk insurance package – will suffice.

### Other notes

The Icebreaker concept focuses on technology risk. Feedstock risk likely requires a very different approach – options were laid out in the original report and absent insight into the development of the Government’s feedstock strategy it is difficult to be more precise at this stage – although it is notable that awareness of, and concern about, feedstock risk among stakeholders has grown markedly since the original report was drafted.

### Conclusion

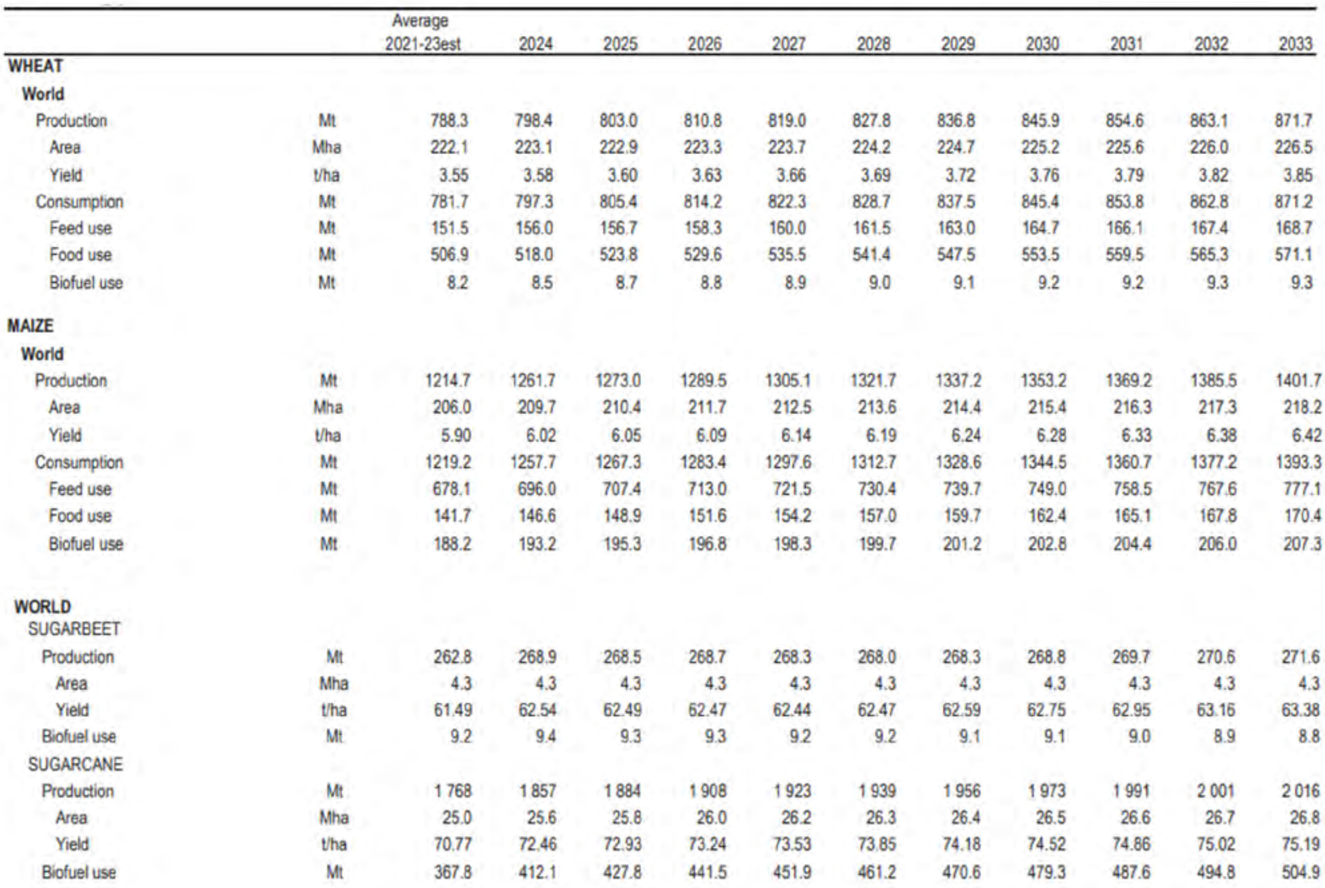
Technology risk is a key concern for funders. The case for Government intervention rests on the opportunity to accelerate the deployment of SAF manufacturing assets in the UK, developing supply chains, contractual models, market familiarity and mandate compliance – in effect de-risking sector scale-up. Any support beyond that should be limited to the first few assets where risk (and leverage) will be greatest. It should build on the AFF learnings and provide insight into those technologies that are most likely to emerge as winners.

The original Icebreaker approach will be challenging for Government to implement. A broader Government Support Package approach feels better suited for an infrastructure mega project rather than kick-starting the deployment of entrepreneurially driven manufacturing assets.

Insurance policies sourced from the market, and better defined, may still have appeal, Fulcrum notwithstanding.

# Annexe 3

## World crop yield projections(19)



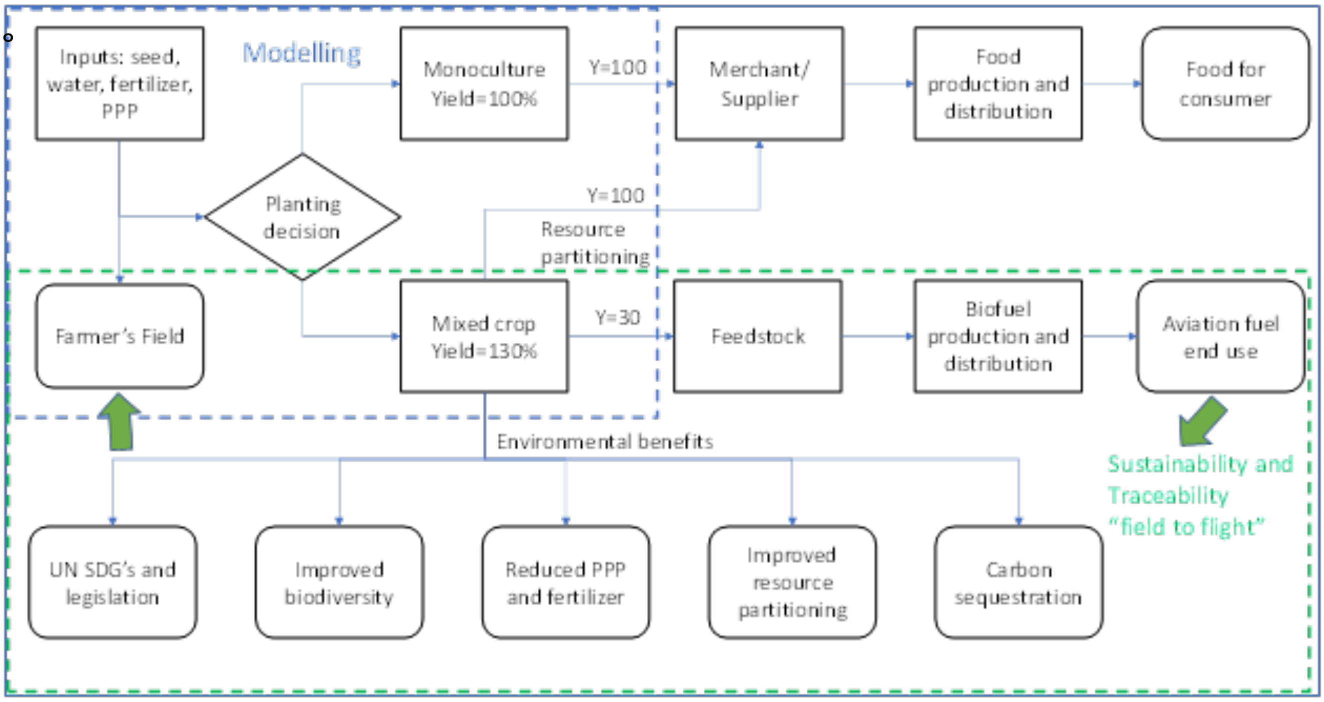
| | | Average 2021-23est | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WHEAT** | | | | | | | | | | | | |
| **World** | | | | | | | | | | | | |
| Production | Mt | 788.3 | 798.4 | 803.0 | 810.8 | 819.0 | 827.8 | 836.8 | 845.9 | 854.6 | 863.1 | 871.7 |
| Area | Mha | 222.1 | 223.1 | 222.9 | 223.3 | 223.7 | 224.2 | 224.7 | 225.2 | 225.6 | 226.0 | 226.5 |
| Yield | t/ha | 3.55 | 3.58 | 3.60 | 3.63 | 3.66 | 3.69 | 3.72 | 3.76 | 3.79 | 3.82 | 3.85 |
| Consumption | Mt | 781.7 | 797.3 | 805.4 | 814.2 | 822.3 | 828.7 | 837.5 | 845.4 | 853.8 | 862.8 | 871.2 |
| Feed use | Mt | 151.5 | 156.0 | 156.7 | 158.3 | 160.0 | 161.5 | 163.0 | 164.7 | 166.1 | 167.4 | 168.7 |
| Food use | Mt | 506.9 | 518.0 | 523.8 | 529.6 | 535.5 | 541.4 | 547.5 | 553.5 | 559.5 | 565.3 | 571.1 |
| Biofuel use | Mt | 8.2 | 8.5 | 8.7 | 8.8 | 8.9 | 9.0 | 9.1 | 9.2 | 9.2 | 9.3 | 9.3 |
| **MAIZE** | | | | | | | | | | | | |
| **World** | | | | | | | | | | | | |
| Production | Mt | 1214.7 | 1261.7 | 1273.0 | 1289.5 | 1305.1 | 1321.7 | 1337.2 | 1353.2 | 1369.2 | 1385.5 | 1401.7 |
| Area | Mha | 206.0 | 209.7 | 210.4 | 211.7 | 212.5 | 213.6 | 214.4 | 215.4 | 216.3 | 217.3 | 218.2 |
| Yield | t/ha | 5.90 | 6.02 | 6.05 | 6.09 | 6.14 | 6.19 | 6.24 | 6.28 | 6.33 | 6.38 | 6.42 |
| Consumption | Mt | 1219.2 | 1257.7 | 1267.3 | 1283.4 | 1297.6 | 1312.7 | 1328.6 | 1344.5 | 1360.7 | 1377.2 | 1393.3 |
| Feed use | Mt | 678.1 | 696.0 | 707.4 | 713.0 | 721.5 | 730.4 | 739.7 | 749.0 | 758.5 | 767.6 | 777.1 |
| Food use | Mt | 141.7 | 146.6 | 148.9 | 151.6 | 154.2 | 157.0 | 159.7 | 162.4 | 165.1 | 167.8 | 170.4 |
| Biofuel use | Mt | 188.2 | 193.2 | 195.3 | 196.8 | 198.3 | 199.7 | 201.2 | 202.8 | 204.4 | 206.0 | 207.3 |
| **WORLD** | | | | | | | | | | | | |
| SUGARBEET | | | | | | | | | | | | |
| Production | Mt | 262.8 | 268.9 | 268.5 | 268.7 | 268.3 | 268.0 | 268.3 | 268.8 | 269.7 | 270.6 | 271.6 |
| Area | Mha | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 |
| Yield | t/ha | 61.49 | 62.54 | 62.49 | 62.47 | 62.44 | 62.47 | 62.59 | 62.75 | 62.95 | 63.16 | 63.38 |
| Biofuel use | Mt | 9.2 | 9.4 | 9.3 | 9.3 | 9.2 | 9.2 | 9.1 | 9.1 | 9.0 | 8.9 | 8.8 |
| SUGARCANE | | | | | | | | | | | | |
| Production | Mt | 1 768 | 1 857 | 1 884 | 1 908 | 1 923 | 1 939 | 1 956 | 1 973 | 1 991 | 2 001 | 2 016 |
| Area | Mha | 25.0 | 25.6 | 25.8 | 26.0 | 26.2 | 26.3 | 26.4 | 26.5 | 26.6 | 26.7 | 26.8 |
| Yield | t/ha | 70.77 | 72.46 | 72.93 | 73.24 | 73.53 | 73.85 | 74.18 | 74.52 | 74.86 | 75.02 | 75.19 |
| Biofuel use | Mt | 367.8 | 412.1 | 427.8 | 441.5 | 451.9 | 461.2 | 470.6 | 479.3 | 487.6 | 494.8 | 504.9 |

# Annexe 4

## The crop ban

Cropping methods that grow multiple crops together in a field, either through mixed cropping or inter-cropping, improve yield and diversity through two mechanisms; (i) Resource partitioning (or niche partitioning) is where a mixture of crops has a greater utilization of available resources, e.g. rooting depth, phenology canopy architecture. The classic example is the “Three Sisters” of maize-beans-squash. Maize provides support for climbing beans, beans fix nitrogen in the soil, and squash leaves provide weed suppression and water retention. (ii) Facilitation is the process by which crops provide complementary resource or environmental conditions. For SAF a suitable crop mix might include wheat and a legume to fix nitrogen, disrupting the spread of disease, biodiversity gains for improved nutrient cycling and carbon sequestration compared with monoculture.

**Figure 30: Proposed SAF-food mixed cropping. Traditional farming monoculture (top line) vs mixed crop system (middle line), assuming 30% uplift from improved resource partitioning through mixed cropping systems, with environmental co-benefits (bottom line).**



Work at Cranfield University has considered how mixed cropping could be used to better partition resources and grow SAF alongside other food crops. Here the standard monoculture approach (100% yield) is considered alongside the mixed cropping approach (assuming 30% increase in yield). To achieve this yield uplift, the companion crops grown together will have complementary benefits. Nitrogen-fixing clover in a pasture mixed with Italian rye grass is a widely used example. The proposed design would model different landscape and crop configurations in silico (blue box) then experimentally with near real-time monitoring to quantify the environmental benefits. The sustainability and traceability of SAF from mixed crops is considered (green box) ‘field to flight’ and could contribute to the certification schemes (CI).

Novel crop systems could significantly enhance the production of biofuels by improving both the efficiency and sustainability of feedstock cultivation. Future systems could increase biomass yields through the development of high-yield, fast-growing crops that are resilient to environmental stresses such as drought, pests, and poor soil conditions. Additionally, crops can be genetically modified to have higher energy content, making them more efficient for biofuel conversion.

# List of Abbreviations

| | |
|---|---|
| **AFF** | Advanced fuels fund |
| **AHDB** | Agricultural and Horticultural Development Board |
| **AtJ** | Alcohol to Jet |
| **ASTM** | American Society for Testing and Materials |
| **AVTUR** | Aviation turbine fuel |
| **BECCS** | Bioenergy with carbon capture and storage |
| **BOLR** | Buyer of last resort |
| **CCC** | Climate Change Committee |
| **CCS** | Carbon capture and storage |
| **CI** | Carbon intensity |
| **CORSIA** | Carbon offsetting and reduction scheme for international aviation |
| **CPO** | Crude palm oil |
| **CTO** | Crude tall oil |
| **DACCS** | Direct air carbon capture and storage |
| **DCO** | Distillers corn oil |
| **DESNZ** | Department for Energy Security and Net Zero |
| **DfT** | Department for Transport |
| **EfW** | Energy from waste |
| **EPA** | Environment Protection Agency |
| **ETS** | Emissions trading scheme |
| **EUDR** | European Union deforestation regulation |
| **EV** | Electric vehicle |
| **FAME** | Fatty acid methyl ester |
| **FAO-OECD** | Food and Agriculture Organisation- Organisation for Economic Co-operation and Development |
| **FID** | Final investment decision |
| **Gas/FT** | Gasification Fischer Tropsch |
| **GHG** | Greenhouse gas |
| **GREET** | Greenhouse gases, regulated emissions, and energy use in technologies |
| **GSP** | Guaranteed strike price |
| **HEFA** | Hydroprocessed esters and fatty acids |
| **HVO** | Hydrotreated vegetable oil |

| | |
|---|---|
| **ILUC** | Indirect land use change |
| **ISCC** | International sustainability and certification system |
| **KPI** | Key performance indicator |
| **LCFS** | Low carbon fuel standards |
| **MSW** | Municipal solid waste |
| **NAFTA** | North American Free Trade Agreement |
| **NHPBM** | National hydrogen production business model |
| **OSR** | Oil seed rape |
| **OZEV** | Office for zero emission vehicles |
| **PFAD** | Palm fatty acid distillate |
| **POME** | Palm oil mill effluent |
| **PPA** | Power purchase agreement |
| **PTC** | Producer tax credit |
| **PtL** | Power to liquid |
| **RCM** | Revenue certainty mechanism |
| **RED** | Renewable energy directive |
| **RFNBOs** | Renewable fuels of non-biological origin |
| **RFS** | Renewable fuel standard |
| **RINs** | Renewable identification numbers |
| **ROCs** | Renewable obligation certificates |
| **ROI** | Return on investment |
| **RoW** | Rest of world |
| **RTFO** | Renewable transport fuel obligation |
| **RVO** | Renewable volume obligation |
| **SAF** | Sustainable aviation fuel |
| **SOC** | Soil organic carbon |
| **TRL** | Technology readiness level |
| **UCO** | Used cooking oil |
| **ULDUR** | Unrefined liquid dextrose ultrafiltration retentate |
| **1g** | First generation |
| **2g** | Second generation |
| **3g** | Third generation |

# References

1 **CCC.** The Seventh Carbon Budget. [Online] 2025. https://www.theccc.org.uk/publication/the-seventh-carbon-budget/.

2. **Sustainable Aviation.** Net Zero Carbon Road-Map. [Online] 2023. https://www.sustainableaviation.co.uk/wp-content/uploads/2023/04/SA9572_2023CO2RoadMap_Brochure_v4.pdf.

3. **DfT.** [Online] 2024. https://www.gov.uk/government/collections/sustainable-aviation-fuel-saf-mandate.

4. **Royal Society.** 2023. Net zero aviation fuels – resource requirements and environmental impacts policy briefing.

5. **Featherstone Fuels Ltd. 2025.** Independent Analysis- SAF Pathway Technoeconomics and US Renewable Diesel.

6. **The Boeing Cascade Climate Impact Model (V2.2).** [Online] 2025. https://cascade.boeing.com/.

7. **ICF.** Roadmap for the development of the UK SAF industry. [Online] 2023. https://www.sustainableaviation.co.uk/wp-content/uploads/2023/04/Sustainable-Aviation-SAF-Roadmap-Final.pdf.

8. **SkyNRG and ICF.** 2025. SAF Market Outlook.

9. **Ceres Environmental Management Consultancy.** 2025. UK Waste Market Analysis.

10. **Glenauk Economics.** 2025. Waste Oil Market Analysis.

11. **Timothy Searchinger.** 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change. [Online] https://www.science.org/doi/10.1126/science.1151861.

12. **DEFRA.** [Online] 2024. Balancing UK Agricultural Production and Environmental Objectives. https://post.parliament.uk/balancing-uk-agricultural-production-and-environmental-objectives/.

13. **RTFA.** 2025. Operational and planned biodiesel, bioethanol and SAF plants in the UK.

14. **European Parliament and the Council of the European Union.** [Online] 2023. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R2405.

15. **Philip New.** [Online] 2023. https://assets.publishing.service.gov.uk/media/64afb9edc033c1000d80621c/developing-uk-sustainable-aviation-fuel-industry-independent.pdf.

16. **UK Government.** [Online] 2024. Fourth Provisional RTFO Tables. 2024-fourth-provisional-rf-01-rtfo-tables-accessible - GOV.UK.

17. **4Air.** 4Air PolicyWatch. [Online] 2025. https://www.4air.aero/policywatch.

18. **RAC Foundation.** [Online] 2025. https://www.racfoundation.org/data/volume-petrol-diesel-consumed-uk-over-time-by-year.

19. **FAO/OECD.** [Online] 2024. Statistical annexe of the 2024-2033 agricultural outlook. https://www.oecd.org/content/dam/oecd/en/topics/policy-issues/agricultural-trade-and-markets/OECD-FAO%20Agricultural%20Outlook%202024-2033%20-%20Statistical%20Annex.pdf.

To know more please visit:
www.prysm-global.com

PRYSM
GLOBAL