Dear Ministers:

The International Council on Clean Transportation (ICCT) welcomes the opportunity to comment on the UK’s sustainable aviation fuels mandate consultation. The ICCT is an environmental research organization that supports policymakers worldwide with technical evidence and analysis for the purpose of developing effective environmental standards for the transport sector. We commend the United Kingdom for its efforts to proactively address aviation emissions, which are responsible for about 7% of UK GHG emissions in 2018 and have increased by 88% above 1990 levels.\(^1\) As one of the world’s largest aviation markets, and a leader in establishing binding emission targets for both domestic and international aviation, UK policy holds global implications for aerospace manufacturers, airlines, investors, and consumers alike.

The following sections provide a number of technical observations in response to several questions raised in the Jet Zero SAF mandate consultation document, including on the carbon intensity standard scheme, sustainability criteria, overarching trajectory, interactions with domestic & international policy, and considerations for delivering SAF to the market.

**A Greenhouse Gas Emissions Scheme to Reduce the Carbon Intensity of Jet Fuel**

The Department for Transport (DfT’s) [consultation document](https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Aviation.pdf) on a SAF mandate lays out a set of key policy design principles for a forthcoming SAF mandate proposal. ICCT commends the DfT for putting forward this detailed, evidence-based approach for a greenhouse gas (GHG)

emissions reduction scheme for aviation fuels. JetZero correctly identifies SAFs as one component of an overall strategy to reduce aviation emissions, rather than the primary mode of emissions abatement. Decarbonizing aviation, particularly long-haul flights generating the bulk of aviation emissions, will necessitate scaling up the production and consumption of SAFs. However, the substantial cost gap—SAFs can cost from two to five times the cost of conventional jet fuel—all but ensures that airlines will not transition towards SAFs in the absence of policy intervention.\(^2\) A binding SAF mandate, particularly with a stable, long-term target would foster demand for SAFs and accelerate the deployment of the industry. The efficacy of such a mandate on mitigating the impacts of climate change, however, depends on which SAFs are used as well as the quantity of SAFs deployed (we discuss this in more detail in the subsequent section).

The proposal to implement a GHG intensity standard for aviation fuels rather than a volumetric SAF blending mandate has several advantages, including rewarding better-performing pathways proportionally to their GHG reduction, and incentivizing additional technology and performance improvements in eligible fuel pathways.\(^3\) However, the efficacy of such a GHG intensity standard strongly depends on the quality of the underlying life-cycle assessment (LCA) accounting of fuels in the scheme; methodological choices such as excluding indirect emissions for crop-based biofuels, for example, may overstate the emissions reductions for those fuels for the purposes of compliance and thereby reduce the \textit{de facto} emissions savings achieved through the policy. This is one reason why the UK’s proposal to entirely exclude food- and feed-based biofuels from the SAF mandate is an important safeguard. Further, we note that GHG intensity standards drive the blending of those fuels with the cheapest GHG reductions, but not necessarily those with the greatest long-term potential. For example, the cost per tonne of abated carbon for hydrotreated used cooking oil-derived jet fuel is one-third that of zero-carbon electrofuel.\(^4\) Sub-targets may still be necessary to drive the uptake of specific pathways, such as electrofuels, in order to ensure that they are cost-competitive in the near and medium-term (i.e., through 2035).\(^5\)

A separate, binding SAF mandate will likely provide a stronger signal for new SAF production than inclusion in the existing Renewable Transport Fuel Obligation (RTFO)—particularly if there is no binding obligation on aviation fuels in the RTFO. Including SAFs in the RTFO may also

constrain the eligibility of SAFs to the criteria already established within the RTFO, rather than providing the flexibility to set more rigorous criteria for SAFs in a new policy.

**Fuel eligibility and sustainability criteria**

ICCT commends the DfT for proposing a comprehensive set of sustainability criteria that would ensure that SAFs mandated in the UK would be made primarily from residues, wastes, and electrofuels with a greater certainty of achieving high GHG savings.

The life-cycle GHG emissions from SAFs depend significantly depending on their feedstock and conversion pathway; some SAF pathways are at or near zero-carbon, whereas others can meet or exceed the emissions from fossil fuels.\(^6\) In particular, those pathways using either feedstocks linked to deforestation (palm and soy oils) and those made from non-biogenic waste generally have higher emissions. Comprehensive life-cycle GHG accounting, taking account both the direct and indirect emissions from fuel production through to final use, is critical to assess the climate implications of SAF production. DfT’s proposal to exclude specific indirect land-use change (ILUC) criteria or to estimate ILUC emissions is acceptable because of the separate eligibility criteria that fully exclude the contribution of the food-based feedstocks with high or uncertain ILUC emissions. The proposed use of a 60% GHG reduction threshold, compared to the 10% GHG reduction threshold required by CORSIA, would further ensure that the proposed SAF mandate would support only the fuel pathways with the greatest GHG savings.

The inclusion of the waste hierarchy in the proposed sustainability criteria is an important consideration against diverting biomass feedstocks from non-energy existing uses. The diversion of feedstocks away from existing uses can in some cases generate substantial indirect emissions, wherein the displaced materials are replaced by other, substitute products through “displacement effects”.\(^7\) The demand for these substitutes can generate indirect emissions, particularly if those substitute materials are either fossil fuels or food crops. To ensure that the waste hierarchy is meaningfully implemented and that feedstocks with high indirect displacement emissions are not eligible under the policy, we recommend that the DfT include more specific language on how feedstocks’ diversion risk will be assessed. In order for a byproduct, residue or waste feedstock to be eligible, we recommend that DfT first assess the environmental and market impacts of diverting it to biofuel production, including the climate

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impact of these materials’ likely substitutes. Only after this assessment would feedstocks be eligible for inclusion in the SAF mandate. DfT can look for an example to the European Commission’s commissioned report assessing the environmental and market impacts as well as fraud risks of novel biofuel feedstocks that are being considered for addition to the Renewable Energy Directive’s advanced biofuel list.\(^8\)

Previous research on displacement effects suggests that some feedstocks’ indirect emissions could push them up and over the proposed 60% GHG reduction threshold. The DfT’s inclusion of processing residues as likely eligible feedstocks in the consultation is broad enough that several potentially risky feedstocks could be eligible under a SAF mandate. For example, the diversion of palm fatty acid distillates (PFADs) to biofuel production may divert them from existing uses in oleochemicals, soap industry and livestock feed and induce replacement by virgin palm oil, the cheapest substitute. Though PFAD-derived SAFs have direct production emissions of only 20.7 gCO\(_2\)e/MJ as assessed by ICAO, the indirect displacement emissions from palm substitution increase the total GHG impact of these fuels to beyond the fossil fuel baseline.\(^9\) The figure below illustrates the impacts of displacement effects on a per MJ-fuel basis for potential biomass by-product feedstocks that could be used in Europe estimated by Malins (2017), in three sets of scenarios: without ILUC for substitute materials, using the ILUC emission factors calculated for the RED II, and using ILUC factors from European Commission modeling using the GLOBIOM model.\(^10\) It is evident from a displacement analysis such as the one illustrated in Figure 1 that some residues, particularly those whose replacements include virgin vegetable oil or woody biomass, pose strong displacement risks that would dilute any emissions savings from their use in aviation. These are the kinds of environmental and market impacts that we recommend DfT assess before adding any new materials to the SAF eligibility list.


\(^9\) Ibid.

\(^10\) Ibid.
We note that the life-cycle impacts of RCFs made from refuse-derived fuel vary considerably depending on the share of non-biological materials such as plastics in the waste stream—the combustion of these fuels would emit CO2 in the atmosphere that would have otherwise been sequestered in a landfill.\textsuperscript{11} Based on the default value for municipal solid waste-derived SAF in ICAO’s LCA modeling, a refuse-derived fuel with 20% non-biological waste content or higher would fail to meet the GHG reduction threshold proposed in this consultation.\textsuperscript{12}

For the purposes of an LCA comparison, an assumption of 89gCO\textsubscript{2}e/MJ consistent with ICAO’s global average for fossil-derived jet fuel, is an appropriate fossil fuel comparator for SAFs at the outset of the SAF mandate. However, we note that our understanding of the climate impacts of aviation may change over time, taking into account recent research on the full, non-CO\textsubscript{2} effects of aviation emissions. A recent analysis by Lee et al. (2021)\textsuperscript{13} estimates that in 2018, the overall climate impact of flying was about three times that of CO\textsubscript{2} alone, with contrails/cirrus responsible for more than half (57%). This implies that, on a CO\textsubscript{2}-equivalent basis, UK aviation may have been responsible for about 100 Mt of CO\textsubscript{2}e prior to the COVID downturn. These climate-forcing impacts can vary depending on factors such as altitude, flight route, and time-of-day. Further, the exact difference climate impact between the contribution of conventional


Figure 1: Comparison of indirect displacement emissions results for various biofuel feedstocks using different ILUC factors for substitute materials

![Graph showing indirect displacement emissions results](image-url)
fuels and alternative fuels to non-CO\textsubscript{2} effects remains uncertain and requires further analysis; as analytical methods improve, we expect regulators to account for these differences in the comparative LCA of aviation fuels. To ensure that there is not over-crediting of emissions reductions from SAFs, we recommend that changes to the proposed fossil baseline should only be implemented once there is a consistent approach for estimating the non-CO\textsubscript{2} effects of SAFs.

Regarding e-kerosene produced from renewable electricity, the consultation document mentions a need to ensure that the electricity used to produce SAF is additional. This is an important issue that greatly affects the environmental performance of e-kerosene. Due to the significant energy losses in the conversion of electricity to e-fuels, any GHG emissions from fossil-based electricity are essentially magnified in the final fuel.\textsuperscript{14} Even using 100\% renewable electricity for e-fuels production can result in significant indirect GHG emissions if the renewable electricity is diverted from other uses. This is why it is so important that the renewable electricity used for e-kerosene be additional to what would otherwise have been produced. Guarantees of Origin (GOs) are not an adequate solution to this problem because the demand for GOs is much lower than the supply; this oversupply leads to a very low price for traded GOs and thus the value of GOs is insufficient to incentivize significant amounts of new renewable electricity production. The most robust mechanism that could be implemented using today’s tools are power purchase agreements (PPAs) with an added requirement that the renewable electricity used does not receive any financial policy support other than the value of the SAF produced.\textsuperscript{15} This measure would make it much more likely that the renewable electricity used for e-kerosene production would not have been produced in the absence of the UK’s SAF mandate and is thus additional. In addition, the use of PPAs instead of GOs increases the likelihood of temporal correlation - that the renewable electricity produced will be used in real time, rather than worsening the grid balancing problems that come with increased use of variable renewable electricity sources on the electric grid.

**Overarching Trajectory**

The deployment of SAFs is likely to be constrained in the first decade of policy due to the time lag associated with designing, constructing and ramping up production from facilities using novel and emerging fuel conversion technologies.\textsuperscript{16} In the short-term (i.e., by 2025), the primary source of SAF will likely be hydrotreated waste fats, oils and greases (FOGs) that can be produced using existing, commercialized technology used in the road sector with few


technological changes. Second-generation pathways using more abundant lignocellulosic feedstocks and electrofuels made from renewable electricity have more short-term barriers with respect to cost and facility construction, but have substantially higher potential feedstock availability in the long-term. Therefore, it is appropriate to assume more modest linear growth towards 2035 and faster, exponential growth from 2035 to 2050.

Of the scenarios illustrated in the consultation, a combination of Scenario B—“High Ambition” and Scenario D—"Late SAF breakthrough", achieves the most realistic balance between ambition and deliverability. In the first 10-15 years of the policy, we estimate that SAF production will be constrained not only by cost, but by the time necessary to build and scale up SAF production facilities. Based on ICCT’s assessment of UK feedstock availability for SAF production in the attached appendix, we only expect the non-electrofuels share to amount to 7.5% by 2030 when we factor in the long timeline of constructing and ramping up new cellulose biofuel facilities. With strong incentives for electrofuels, we estimate an additional 2.7% of 2030 demand could be met. Thus, from 2025 to 2035, we anticipate that achieving 10% of SAF uptake will be extremely challenging even with high incentives and if the contribution of waste oil-derived SAFs is capped (see below).

Globally, most existing SAF production to date has primarily come from hydrotreated ester and fatty acid (HEFA) fuels, which can be produced at existing hydrotreated vegetable oil (HVO) biorefineries. approximately 5.7% of 2030 demand could be met through the diversion of existing waste fats, oils and greases (FOGs) from the road sector and existing levels of imported waste FOGs already used for biofuel production. However, the short-term diversion of these feedstocks from the road sector towards aviation has a limited net impact on the climate, simply diverting emissions reductions from one sector to another. Further, diverting existing waste oil-derived fatty acid methyl ester (FAME) biodiesel production towards HEFA production can result in less carbon abatement on net, after taking into account changes in efficiency and the yield of end-products from HEFA production. Optimizing for a greater share of jet fuel production at existing HVO biorefineries requires additional hydrogen and energy and may decrease the overall liquid fuel yield of the fuel conversion process. Further, increasing waste oil imports to meet SAF targets poses risks of fraud from imported waste oils, which has been documented in several European countries with high incentives for used cooking oil-based biofuels.

A cap on the contribution of waste FOGs towards the SAF mandate would not only protect against fraud and diversion from the road sector, but may also create more opportunity for other pathways with greater potential resource availability & greater GHG savings to attract investment. To avoid driving the demand for additional waste oil imports, the cap on waste FOGs in the policy could be set at 0.8% of 2030 UK jet fuel demand (or 0.1 Million tonnes of fuel), equivalent to the UK’s domestic waste FOG availability as calculated in the Appendix below.

Electrofuels may be substantially more expensive than even some advanced biofuels in the near and mid-term, due to the cost of electrolyzers and of supplying additional renewable electricity and captured carbon. At a projected cost of 2 Euros per liter or higher, they may face even greater economic barriers than other SAFs, despite their long-term potential. Therefore, a separate incentive within the mandate, such as a multiplier or sub-target for the contribution of electrofuels may be necessary in the near and mid-term (i.e., through 2035) to support their development and ensure that quantities reach the market. We note that due to the constraints on domestic biomass, achieving the SAF blend targets in nearly all of the modeled scenarios in the consultation (Scenarios B through E), will require substantial quantities of electrofuels by 2050. High levels of electrofuel production may necessitate substantial investment and changes to the electricity grid; to illustrate, achieving a 30% blend from e-fuels (3.6 Mt) would necessitate over 20 commercial-scale e-fuel production facilities, compared to zero today in the UK. Assuming a 60% conversion yield for the electrofuel production process, these targets would necessitate an additional 73 terawatt-hours (TWh) of renewable electricity production, representing a 24% increase over current total UK electricity production (~300 TWh).

**Interactions with Other Domestic and International Policy**

Double-counting or double-claiming emissions reductions may undermine the efficacy of some climate policies. If the UK implements a GHG intensity reduction scheme for aviation fuels, it

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23 Note that this calculation does not take into account the further split of middle distillates between diesel fuel and jet fuel.
would create a carbon market for GHG reductions achieved via SAF blending. Allowing emissions reductions to count across multiple schemes would dilute the efficacy of each policy and likely result in overstating of emissions reductions from those separate programs. The proposal to introduce a SAF mandate separately from the existing RTFO, rather than as an opt-in method of generating compliance, avoids this problem—maintaining the integrity of both the RTFO and the SAF mandate. With regards to SAFs in the ICAO Carbon Offsetting and GHG Reduction Scheme for International Aviation (CORSIA), that policy likely provides only a very weak signal for SAF deployment as it is primarily an offsetting scheme.\textsuperscript{24} The cost of GHG reductions from SAF blending may be at least 20-100 times higher than that of purchasing a carbon offset, particularly cheaper offsets from the Clean Development Mechanism (CDM).\textsuperscript{25} By its design, CORSIA does little to stimulate SAF production, and primarily credits the use of SAFs induced through national-level incentives and policies. Therefore, it is unlikely that SAFs used in the UK to comply with a SAF mandate would have been induced by, or attributable to CORSIA and thus pose little risk of double-counting.

The interaction between a SAF policy and an emissions-trading scheme raises some issues of double-counting. California utilizes a parallel fuel carbon intensity obligation for transportation and an economy-wide emissions trading scheme; due to the nature of these two markets and the difficulty of achieving carbon reductions in the former, California’s Low-Carbon Fuel Standard (LCFS) has a carbon price nearly ten times that of the cap & trade program.\textsuperscript{26} These markets are separate, and fuel carbon intensity reductions achieved in transport are not allowed to generate emissions or offsets within the cap & trade program. To maintain the integrity of the UK ETS, we therefore recommend that life-cycle emissions reductions from SAFs are excluded as an emission reduction measure. In California, the transport portion of the cap & trade program is strictly based on the quantities of fossil fuels consumed and refined in the state. The primary risk for double-counting is therefore cases where an alternative fuel’s upstream production may involve stages that could generate an offset, such as carbon capture or avoided methane reductions. It is critical that for the certification for each pathway approved under a UK SAF mandate, that sustainability certifiers evaluate the different stages of fuel production to verify that offsets are not being claimed for upstream stages of SAF production.

To protect against tankering fuels from other markets and avoiding obligation with UK SAF policy, it may be necessary to introduce uplift requirements for fuel purchase at airports. The European Commission’s proposed ReFuel EU SAF policy obligates airlines as well as fuel

\textsuperscript{24} IATA. “Countering Misinformation on Sustainable Aviation Fuels,” 2018. \url{https://www.airlines.iata.org/blog/2019/09/countering-misinformation-on-sustainable-aviation-fuels}.
suppliers to comply with the policy\textsuperscript{27}. The proposed Regulation establishes the obligation for aircraft operators to ensure that the yearly quantity of aviation fuel uplifted at a given Union airport is of at least 90\% of the yearly aviation fuel required; they may be penalized for tankering excess fuel. Introducing a similar protection in the UK would mitigate the risk of tankering and also help to reduce the impact of tankering across Europe.\textsuperscript{28}

\textit{Delivering SAF to Market}

A SAF mandate alone may be insufficient to bring the advanced SAFs using second-generation conversion technologies into the market, particularly in the early years of the program. Complementary policies can help new producers mitigate investment risk and perceptions of uncertainty and bring initial fuel volumes onto the market. Given the slow uptake to date, along with the larger structural disparities for SAF deployment, the imposition of taxes on petroleum jet fuel would help promote SAFs. Duties on diesel and petrol used in the road sector are £0.58 per liter, whereas petroleum kerosene in aviation is untaxed.\textsuperscript{29} Introducing a jet fuel duty equal to road transport could have several beneficial effects. First, it could help close the cost gap between SAFs and conventional fuels. Second, it could level the playing field for alternative fuel producers of road and aviation fuels. Third, it could raise funds for targeted investments in SAF projects. The European Commission recently proposed a minimum €10.74/GJ duty on petroleum jet fuel in its revisions to the European Energy Tax Directive. Since advanced SAFs would be assessed only a €0.9/GJ tax; this approach would narrow the cost gap by approximately €0.34 (or £0.30) per liter of fuel.\textsuperscript{30}

Though a mandate can create a strong demand signal for SAFs, complementary policies are likely necessary to ensure that new suppliers enter the market and scale up production. We recommend direct, targeted policy support for novel and emerging SAF pathways that face technical and economic hurdles to ensure that there is sufficient fuel in the early stages of a mandate. Direct financial support should be provided only for projects using novel or emerging technologies, and which use high-performing and abundant feedstocks, including waste and residue gasification, and electrofuels. Direct grant funding can reduce the upfront costs of producing new facilities, whereas a central auctioning mechanism (similar to Contracts for

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Difference in the electricity sector) can reduce offtake risk by guaranteeing new producers a fair price for their finished fuel.\textsuperscript{31}

Thank you for the opportunity to comment on this important policy. If you have any questions, please reach out to me at stephanie@theicct.org or to Nik Pavlenko at n.pavlenko@theicct.org.

Best regards,

Stephanie Searle, Ph.D.

Fuels Program Director, International Council on Clean Transportation
Appendix: UK Feedstock Availability Assessment

Estimated 2030 Jet Fuel Demand
We estimate 2030 jet fuel demand from emissions data published by the UK Department for Transport. Business-as-usual aviation emissions are projected to be 40.1 million tonnes (Mt) CO₂ in 2030, equivalent to roughly 12.7 Mt of jet fuel. Previous passenger growth estimates used by ICCT were based on five-year average trends in EU-27 jet fuel demand.

Availability Assessment
We assess the availability of sustainable aviation fuel (SAF) feedstocks including waste fats, oils & greases (FOGs), biomass residues, electrofuels, and industrial flue gas upgraded via the Lanzatech process. We report data for both domestic and imported fuel volumes in 2030 as a percentage of UK jet fuel demand.

In summary, we find that SAF feedstocks could provide approximately 10.2% of 2030 UK jet fuel demand (Table 1). The majority of this fuel would come from imported waste oil feedstocks, with a smaller share from electrofuels, domestic biomass residues, and recycled carbon fuels.

Table 1. Estimated UK SAF production potential by feedstock

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Mt SAF</th>
<th>%2030 jet fuel demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste FOGs (imported)</td>
<td>0.63</td>
<td>4.9%</td>
</tr>
<tr>
<td>Electrofuels</td>
<td>0.26</td>
<td>2.7%</td>
</tr>
<tr>
<td>Waste FOGs (domestic)</td>
<td>0.10</td>
<td>0.8%</td>
</tr>
<tr>
<td>Agricultural residues</td>
<td>0.10</td>
<td>0.6%</td>
</tr>
<tr>
<td>MSW</td>
<td>0.03</td>
<td>0.6%</td>
</tr>
<tr>
<td>Industrial flue gases</td>
<td>0.07</td>
<td>0.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.19</strong></td>
<td><strong>10.2%</strong></td>
</tr>
</tbody>
</table>

Fats, Oils & Greases
Fats, oils, and greases (FOGs) can be upgraded to SAF via hydroprocessing, a technologically mature conversion pathway. We assume used cooking oil (UCO) and inedible tallow will comprise the largest share of upgraded feedstocks, known as hydroprocessed esters and fatty acids (HEFA), although sewage FOGs, inedible vegetable oil pressings, and industrial food waste can also be used. Virgin vegetable oils are not designated as eligible feedstock under the UK Department for Transport’s (DfT) recent SAF consultation, therefore we exclude them from our analysis.

We estimate the total quantity of waste FOG supply in the UK based on existing use (as tracked by the DfT) and estimated potential for additional domestic collection. Today, approximately 1.3 Mt of waste FOGs are used in the road sector; in our analysis, here we assume the entirety of these volumes could be diverted from on-road fuel applications and used for jet-optimized SAF production via the HEFA pathway in 2030. We also assume that 15,000 tonnes of additional
UCO from commercial sources and 37,000 tonnes from household sources could be collected with improved commercial collection practices.\textsuperscript{iv}

We estimate the quantity of HEFA produced from waste FOGs by applying yield conversion factors from the Greenhouse gases, Regulated Emissions, and Energy Use in Technologies (GREET) model. We also assume that roughly 60\% of the refinery product yield is jet fuel in a jet-optimized slate. Taking into account existing waste FOG usage and increased collection, we estimate approximately 0.7 Mt of waste oil SAF could be supplied to the UK in 2030, or 5.7\% of annual jet fuel demand. These volumes are highly import dependent, with waste oils imported from outside the UK accounting for 89\% of total volumes.

**Biomass Gasification (Ag Residues, MSW)**

Biomass feedstocks could also provide a substantial share of SAF in 2030. These feedstocks can be converted to jet fuel via gasification to produce Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK). We include agricultural residues, forestry residues, and the biogenic portion of municipal and industrial solid waste as qualifying SAF feedstocks.

To assess the share of biomass wastes and residues suitable for SAF production, we use an existing analysis of European waste and residue availability,\textsuperscript{v} separating out the UK portion of sustainably available feedstocks. That analysis assumes that feedstocks consumed in non-biofuel sectors today are unavailable for SAF conversion. This includes biomass burned for heat and power under National Renewable Energy Action Plans (NREAP) and crop and residues left in-situ to promote soil health. Total biomass availability also decreases through 2030. This is in part due to shrinking landfilled MSW volumes as a result of statutory targets. These include a maximum 10\% MSW landfill rate in 2035 under the Landfill Directive.\textsuperscript{vi}

We source data on hypothetical future facility sizes to determine the maximum number of FT-SPK plants built in the UK by 2030. Unlike HEFA facilities, gasification-FT biorefineries are still in the early stages of commercialization so we apply an additional ramp-up constraint to this fuel pathway to factor in the time delay to scale-up of the industry. With a design and scale-up timeline of approximately five years, we assume one demonstration scale facility will become fully operational before 2030, and one commercial-scale facility (with approximately 0.2 Mt production capacity) will begin ramping up production at half capacity by 2030.\textsuperscript{vii} Applying these constraints, we find there is insufficient availability of forestry residues to build a dedicated FT-SPK plant but that there is sufficient capacity to convert 11\% and 62\% of agricultural residues and MSW to fuel in 2030, respectively. In total, approximately 155,000 tonnes of SAF could be produced from this pathway, or 1.2\% of 2030 jet fuel demand. This estimate assumes that the product slate will be optimized for jet production in a 50\% jet optimized product slate.

**Renewable Fuels of Non-Biological Origin (RFNBOs) and Recycled Carbon Fuels (RCFs)**

RFNBOs are defined as fuels produced from renewable, non-biomass feedstocks. These include green hydrogen, ammonia and e-kerosene. Another potential SAF pathway involves upgrading ethanol intermediates produced from the fermentation of carbon-rich industrial flue gas.\textsuperscript{viii} This
RCF pathway is practiced by LanzaTech and is being demonstrated at steel mills. The UK aims to operate zero-carbon short-haul flights powered by hydrogen and all-electric aircraft; however, a realistic entry-into-service data is unlikely by 2035.\textsuperscript{i} Thus, we assume the only commercially ready pathways for SAF production in 2030 are alcohol-to-jet (ATJ) produced via the Lanzatech process and e-kerosene.

To calculate the volumes of SAF produced from alcohol-to-jet upgrading, we source steel production data from annual reports published by the World Steel Association.\textsuperscript{ii} We assume domestic production remains steady from 2019 levels, or 7.2 Mt. For the purposes of this analysis, we assume a 70\% capture rate across all steel mills and a conversion yield factor for synthesized ethanol reported by Bazzanella and Ausfelder.\textsuperscript{iii} A more complete description of this calculation is given in a 2021 ICCT report on EU SAF availability.\textsuperscript{iv} Although the Lanzatech process is not widely used today, it could be scaled up through subsidies or a SAF volume mandate. We assume a linear deployment for alcohol-to-jet upgrading through 2030 for a total of 0.7 Mt of SAF. We assume that 75\% of the fuel produced from this process would go towards aviation, based on the product slate.\textsuperscript{v}

In principle, there is an unlimited supply of renewable energy that could be used to generate electrofuels, but high electricity prices, conversion losses, and the limited commercial penetration of electrofuels will constrain deployment in the short term. It is also important that this electricity is additional, or sourced from new generation capacity, rather than diverted from existing plants serving the power sector. Further, if grid-average electricity is used, electrofuels may have greater climate impacts than conventional petroleum jet fuel.\textsuperscript{vi} In the absence of detailed modeling for UK’s complementary incentives and specific fuel deployment targets, we draw upon existing economic modeling for the EU-27 to estimate a potential share of electrofuels in aviation. The European Commission proposed a 2.6\% RFNBO mandate as part of its “Fit for 55” package to update the Renewable Energy Directive (RED II), along with a simultaneous 0.7\% electrofuels blending target for aviation and a 13\% GHG intensity reduction for transportation by 2030. Modeling the cost and availability of compliance pathways, we estimate that the EU-27 would achieve compliance for its fuels policies with 2.7\% electrofuels deployment as a share of aviation demand.\textsuperscript{vii} However, we note that this is likely an upper limit for electrofuel supply, as it relies on a combination of complementary policies and high carbon prices.

\begin{itemize}
\item \textsuperscript{i} UK Department for Transport, “Jet Zero Consultation: Evidence and Analysis,” July 2021.
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