Decarbonising Irish Aviation: The Role of SAF, Bioenergy, and E-Fuels

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Abstract

This report explores the feasibility of meeting EU Sustainable Aviation Fuel (SAF) mandates from an Irish perspective, assessing the availability of indigenous bioresources, the scalability of e-fuels, and the strategic role of hydrogen and renewable integration.

1 Introduction and Problem Definition

- The aviation sector accounts for 2-3 % of global CO2 emissions [3] Not only that, but GHG emissions are also caused through NOx and Contrail formation.

- The aviation industry is expected to grow by 3-5 % per year [1]

- The EU has agreed to create a mandate that all fuel in EU airports will be 6 % SAF in 2030 and 20% in 2035. Ultimately, the plan is to get to 65 % SAF in the future.

- Even if we get the SAF to where it needs to be, that doesn't fully decarbonise aviation. To achieve this, we need to combine a number of different strategies: Achieving net-zero aviation requires a combination of strategies: 65% SAF, 13% new aircraft technologies, 3% operational efficiencies, and 19% offsets/carbon capture." (Jagtap et al., 2025)

- It is unclear if Ireland has enough indigenous biofuel resources to achieve the targets, and if efuels will be at the scale in time. Efuels will require advancements in renewable energy scale and a reduction of price, as well as scaling up DAC.

- Although according to a study by Shehab et al [9], the EU as a whole has enough sustainable feedstocks to meet the short-term SAF targets using current technologies

- There is a lack of research specific to Ireland on how the country will achieve its targets

- Aircraft fuel efficiency has increased by 70% since the 1960s, yet total aviation emissions continue to grow because the traffic growth outpaces the efficiency gains. Between 1970 and 2010, the aircraft fleet grew from 3700 to 21,000 and passenger kilometres increased 9-fold. [7]

2 Policy Landscape (EU, Ireland, Global)

The agreed upon SAF uplift at EU airports will be 2% by 25, 6% by 2030, 20% by 2035 and 70% by 2050. It is expected to see an exponential rate of growth.

- Most studies suggest that the only way to achieve targets is to introduce policy incentives such as quotas, subsidies, kerosene taxes [5]. These measures can help control demand for both fossil fuel-derived jet fuel and for SAF. Even optimistic scenarios require demand management to offset emissions growth fully [2]

- The policy landscape poses a difficult question as success requires the cooperation of many different countries. As hard as it is to create effective policy on a national scale, it can be even more difficult to produce international policy that countries all agree on. There is currently no international SAF certification standard for flights between jurisdictions. [9]

- Introducing SAF-friendly policy brings with it the risk of airlines working around the policy by buying cheap fuel outside the EU to avoid SAF costs, which is known as tankering.

- The role of ReFuel EU: ReFuel EU is an EU regulation that was written as part of the Fit for 55 with the aim of increasing the use of sustainable aviation fuel without distorting the competition. The regulation applies to fuel suppliers at EU airports, Aircraft operators flying to and from EU airports and Airport managing bodies. It sets and enforces the key SAF blending mandates of 2% in 2025 up to 20% in 2035 and 70% in 2050. ReFuel defines a set of rules that participating parties must follow to avoid penalties; Fuel suppliers must blend SAF at an airport level, Airlines and Airports must report fuel types and volumes, Airlines can't avoid SAF by carrying extra fossil fuel from non-EU airports, the regulation defines what SAF fuels are compliant with its sustainability criteria based on the GHG life cylcle savings, and how sustainable the feedstocks are. [8]

3 SAF Production Technologies

3.1 Bio-based SAF

- Bio-based SAF entails fuels that are made from biological materials, not fossil fuels

- They are currently the most widely adopted branch of SAF as they are the most technologically ready.

- There are different pathways that are produced from different feedstocks

- The carbon reductions we see from adopting Bio-based SAF range from 50% to 80 % [6]. Some pathways have been shown to lead to negative WTwa GHG emissions due to the carbon sequestration of growing the feedstocks

- Although the carbon emissions reductions are significant, there are other issues with the sustainability of biofuels. Availability of many of the viable feedstocks is limited, and competition with food crops creates sustainability concerns.

- Another problem with biofuels is the risk of importing feedstocks from asia/south america. If we do this, we risk causing excess deforestation, human rights violations, and increasing food competition, which is particularly bad in poorer countries.

- **HEFA** - Most mature, proven feedstock pathway, made from waste oils and fats. Compatible with existing refineries and distribution systems. Certified under the ASTM for up to 50 % blending. For these reasons, it is likely to be the way forward short term.

  - Limited by feedstock availability and by geopolitics. Many vegatble oils are also used directly as food or in food preocessing, so diverteing more for SAF purposes also diverts it from food supply chains. The waste oils are sustainable but they don't come close to meeting demand.

  - Conclude that it is useful short term but not sustainable or scalable for full SAF roll-out

  Around 86% of the HEFA Bio-feedstock is imported from outside the EU [9]

- **Fischer-Tropsch based fuels** Also widespread, uses solid feedstocks such as municipal waste and forestry residues to create a syngas which is then upgraded to hydrocarbons. A lot of this biomass and waste can be sourced locally in Ireland and in the EU.

  - Uses the Fischer-Tropsch process, which has been used for coal gasification since 1923 and proves useful to this day, for synthesis of SAF.

  - According to Sheab et al, FT-SPK CO_2 intensity ranges from 7.7-12.2 gCO_2e/MJ, which makes it one of the most sustainable routes. It also burns with a very low aromatic content which means soot and contrails are reduced.

  - The FT process has a higher CapEx and has a lower technology readiness level than HEFA fuels. Scaling production will be slower than HEFA.

- **Alcohol-to-Jet** ATJ technology is emerging but technology readiness remains low. A high feedstock cost and conversion efficiency.

  - There is a wide range of feedstock options, this is a good sign as diversity of feedstock will contribute greatly to the sustainability of the fuel long-term. Some feedstocks can otherwise be used for food which triggers food vs fuel debates [9].

  - There is generally a lower yield from atj

  - ALthough there is serious promise in CO_2 reduction of some fuels

  - [[Miscanthus]] is the feedstock which provides lowest WTWa CO_2 equivalent emissions in both standalone and distributed ATJ production schemes. [[Paper One]]

  - There is serious promise found in the carbon reduction capability of miscanthus as an atj feedstock in particular as shown in jagtap et al. [4]

- **Sugar-To-Jet**

3.2 Power-to-Liquid (PtL)

- What is Power-To-Liquid Fuel: PtL, also described as efuel or synthetic aviation fuel is a category of SAF in which hydrogen and carbon, either CO or CO_2, are combined and upgraded to create a synthetic jet fuel.

-Different Technological Options: There are many potential pathways to produce efuel, the hydrogen can be sourced sustainably from ALkaline, PEM or SOEC electrolysis. The carbon can be sourced from Direct Air Capture, Point Source Carbon Capture or Anaerobic Digestion. on top of this there are two main pathways of production: methanol-based and Fischer-Tropsch-based [5]

- Benefits: PtL doesn't compete with food production. They are chemically similar to fossil-based kerosene, which allows them to be compatible with existing infrastructure. And they carry with them all the benefits of classic jet fuel, high volumetric and gravimetric energy density. They do release CO_2, just like fossil kerosene but it's the same CO_2 that was originally captured, making it sustainable with up to 90-100% GHG reduction. ReFuel EU encourage the use of PtL fuels, mandating that they meet a 1.2% share of the fuel supply by 2030. Ireland, as a country with massive renewable potential, could benefit from becoming a green fuel exporter.

Drawbacks- It can be 4-5 times more expensive to produce than fossil-based jet fuel. Eyberg et al found that the LCOP of PtL as a base case is 0.81€/kWh and found that the optimistic 2050 projection was 0.23€/kWh. Producing Efuel requires a large amount of electricity, between hydrogen electrolysis and Direct Air Capture. This means the success of Efuel depends on being able to produce cheap renewable energy.[3]

3.3 Hydrogen Production Routes

- **Alkaline Electrolysis**
- **PEM Electrolysis**
- **Solid-Oxide Electrolysis**

3.4 Production Routes

- **Methanol-To-Jet Production**
- **Fischer-Tropsch Production**

3.5 Carbon Capture Methods

- **Direct Air Capture**
- **Point Source Capture**

4 Feedstock Availability in Ireland

5 Infrastructure and Logistics

6 System Integration and Strategic Pathways

7 Barriers and Research Gaps

8 Conclusions and Recommendations

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