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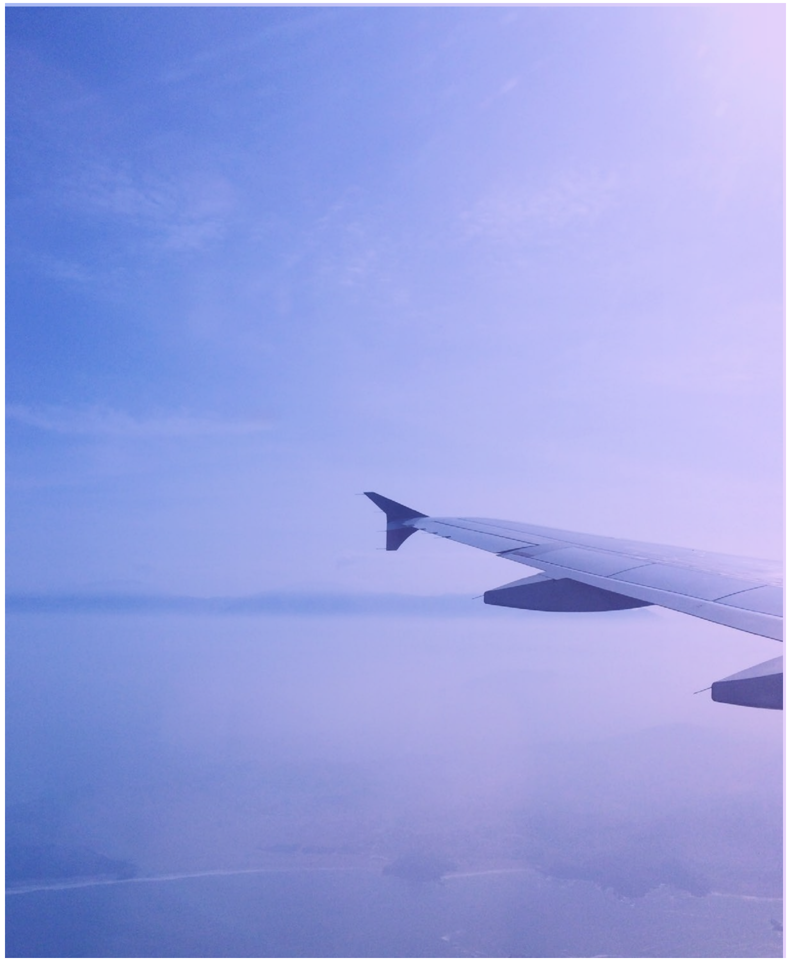
SAF Manufacturing in Ireland

A report commissioned by Aircraft Leasing Ireland

Aircraft Leasing Ireland
Ibec

March 2023



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Executive summary

Context

The aviation industry's goal is for net zero emissions by 2050, but as air travel returns to its long-term growth rate of 3.5-4%, incremental fuel efficiency gains which average 1.9% per year are insufficient. Amongst the many actions needed to decouple growth and emissions, Sustainable Aviation Fuels (SAF) is set to be by far the biggest contributor globally.

Emissions are growing

Aviation has achieved sustained growth from the early 1990s to 2019, but this growth has also seen a doubling of GHG emissions by the sector.

2.3%[1]

of GHG emissions globally are from the aviation industry

Net Zero 2050

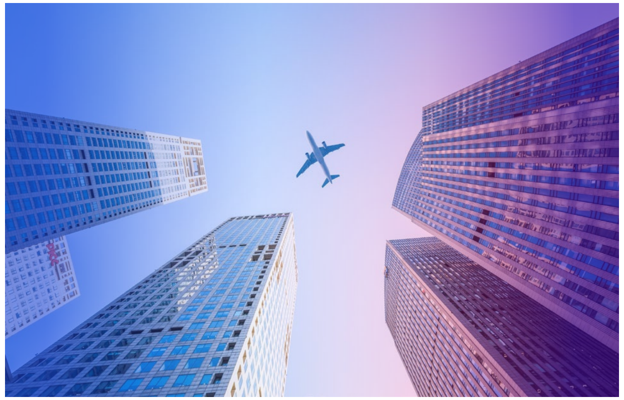
IATA industry target which assumes 65% of reduction will come from SAF

Up to 90% lifecycle

GHG emissions reduction possible through the use of SAF

Improved Efficiency

Fuel efficiency of international aviation improved by 1.9%[2] per year between 2010 and 2019.



Decrease in Intensity

The average block fuel intensity of new aircraft decreased by 41% between 1970 and 2019.

41%

1. Source: ALI Our Future
2. Source: IEA

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Executive summary

SAF will change the way we fly and theoretically can be produced locally in any country, including Ireland, reducing the impact of shipping fuel and contributing to energy independence. However there are many challenges such as certification of sustainability, feedstock availability, investment, and competing needs for fuel such as for road transport.

It is critical for any country including Ireland to have Government engagement with a suitable policy framework and associated supports to facilitate and deliver SAF production. Manufacturing of SAF can dovetail with Irish and EU goals for independent, sustainable energy production.

Demand for SAF is growing exponentially and production is ramping up globally, especially in the USA with its comprehensive stimulus packages for SAF producers. The EU has set mandates for minimum SAF usage which ramps up over time, accelerating significantly from 2035 onwards.

Aircraft Leasing Ireland (ALI) is the Ibec group representing the aircraft leasing industry in Ireland. Comprising 40 members, its objective is to retain and develop Ireland's position as the leading global centre for aircraft leasing. ALI have commissioned this report on SAF manufacturing possibilities in Ireland.

With a long and innovative history in aviation, Ireland can help lead the way in the rollout of SAF in the EU and globally. ALI has a key influencing role to play and should in the first instance act as an advocate for the development of SAF in Ireland.

In the short-medium-term (1–5 years) ALI should play to its members strength to influence and educate, work with Government to help develop a framework for SAF production, partner with universities to fund research and development or support third-party investors (e.g. fuel suppliers embarking on their own refinery project). ALI could also support Ireland in creating the SAF certification/accreditation register.

Ireland has particular opportunities in the medium-long term from its huge offshore wind energy potential, which can be used not just for domestic energy use but also in development of green hydrogen and synfuel Power-to-Liquid ("PtL") development. There are opportunities to export if sufficient volume can be produced, and to play a leading role in associated technological research and development. However, this would require substantial support and upscaling to be achieved.

It is likely that biofuel SAF can meet the needs of the 2020's, and are predicted to make up 94% of SAF in 2030 as compared to 6% synfuels. PtL, however, is key to winning long term.

Baseline	Target
0.07 Mt In 2021, only 0.07 Mt (or 70 kt) of SAF was produced globally	**22 Mt** Over 22 Mt in SAF forward purchasing agreements have been made globally
0.1% SAF made up 0.1% of global jet fuel demand in 2021	**5.5%** Realistic projections estimate that SAF production will sit at 5.5% (or 3.4 Mt) of global jet fuel demand in 2030
15x – 5x IATA has historically reported SAF as 15x the price of conventional jet fuel in 2018 and 5x the price in 2021.	**2x – 6x** PtL prices in 2050 are predicted to be 1.04x to 2.84x greater than the current cost of jet fuel (2022). However, on average PtL is 2.3x to 6.4x greater than the historical price of jet fuel.
7 GW The Irish government's has set an offshore wind target of 7 GW production capacity by 2030	**85 GW** Ireland could *theoretically* produce 85 GW of offshore wind
1 Mt Jet A Ireland's jet fuel demand in 2019 was 1000 kt or 1Mt	**23 Mt PTL** Ireland could *theoretically* produce 23 Mt of PtL (over 20x 2019's jet fuel demand)

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02

What is SAF?

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Types of SAF

Sustainable biofuels' market readiness coupled with the projected advancement in synfuels over the next 30 years makes SAF an encouraging means to decarbonise the sector.

Examples of Sustainable Aviation Fuel Feedstock

Sustainable Biofuels

- Sugar and starch crops
- Lignocellulosic biomass[1]
- Vegetable oils, animal fats

Synfuels

- Hydrogen from water
- CO2 from point source of Direct Air Capture

1. Lignocellulosic biomass is a plant or plant-based material that is not used for food or feed and mainly includes agricultural residues, energy crops, forestry residues, and yard trimmings.

- **Sustainable Biofuels** are derived from biological sources that do not compete with food production
- **Synfuels** are derived from non-biological (NBO) sources
- Both are '**drop-in**' fuels – they do not require significant changes to current aircraft infrastructure
- Sustainable biofuel is market ready with 7 approved production pathways
- Synfuels are at an early stage of development with the potential to provide a long term solution to the decarbonisation of the aviation industry

370K SAF flights since 2016

100M litres or 0.1%

SAF produced in 2021 made up 0.1% of global jet fuel demand that year

45 Airlines

With SAF experience as of 2020

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Barriers to Production

The low production and use of SAF to date can be attributed to 3 key barriers:

01

High capital cost

- SAF typically has a price range of approximately 2 to 5 times greater than that of conventional aviation fuel.
- SAF production scales are currently not financially competitive nor profitable, regardless of the pathway, simply making SAF too expensive to capture a sizeable portion of the jet fuel market

02

Feedstock availability and cost

- Competition for feedstocks (such as forestry residue biomass) between the aviation and road transport sectors is expected to increase, which will put a strain on feedstock availability.
- Current and future restrictions on the use of food-based feedstocks will significantly affect both the availability and cost of such feedstocks.

03

The authentication processes

- The extensive authorisation process of SAF under the ASTM.
- Each production pathway is required to undergo years of stringent testing and certification.
- Consequently, the commercialisation of SAF takes several years to reach a small sliver of the aviation market with high investment costs.

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Production pathways

Under the ASTM, 7 sustainable biofuel production routes have been approved for blending with conventional jet fuel, with HEFA being the most mature pathway.

	FT – SPK[1]	HEFA[2]	HFS – SIP[3]	FT- SPK/A[4]	ATJ[5]	CHJ[6]	HC-HEFA[7]
Approval year	2009	2011	2014	2015	2016	2020	2020
Blend allowance	Up to 50%	Up to 50%	Up to 10%	Up to 50%	Up to 50%	Up to 50%	Up to 10%
Feedstock	Biomass (forestry, residues, grasses, municipal solid waste)	Vegetable oils and animal fats	Microbial conversion of sugars to hydrocarbon	Renewable biomass, agricultural waste and forestry residues, wood and energy crops	Agricultural waste products	Triglyceride-based feedstocks (plant oils, waste oils, algal oils etc.)	Biologically derived hydrocarbons such as algae
Producers using the pathway	Veloycs	Alt Air, SkyNRG, Neste, World Energy, TOTAL, SG Preston	Amyris	-	Gevo and LanzaTech	ARA and Euglena	IHI World

1. Fischer Tropsch Synthetic Paraffinic Kerosene 2. Hydroprocessed Esters and Fatty Acids 3. Hydroprocessing of Fermented Sugars – Synthetic Iso-Paraffinic Kerosene
4. Fischer Tropsch Synthetic Paraffinic Kerosene with Aromatics 5. Alcohol-to-jet 6. Catalytic Hydrothermolysis Jet 7. Hydroprocessed Hydrocarbons, Esters and Fatty Acids

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03

SAF Globally

Key Hubs

Although at present there is a greater uptake of SAF in the USA, several European countries have announced mandates which will drive up the production and use of SAF in the EU.

The map on the right shows the percentage of SAF required per country to be blended with conventional kerosene by a specified year.

United States

There is a greater uptake of SAF in the United States compared to Europe due to incentives;

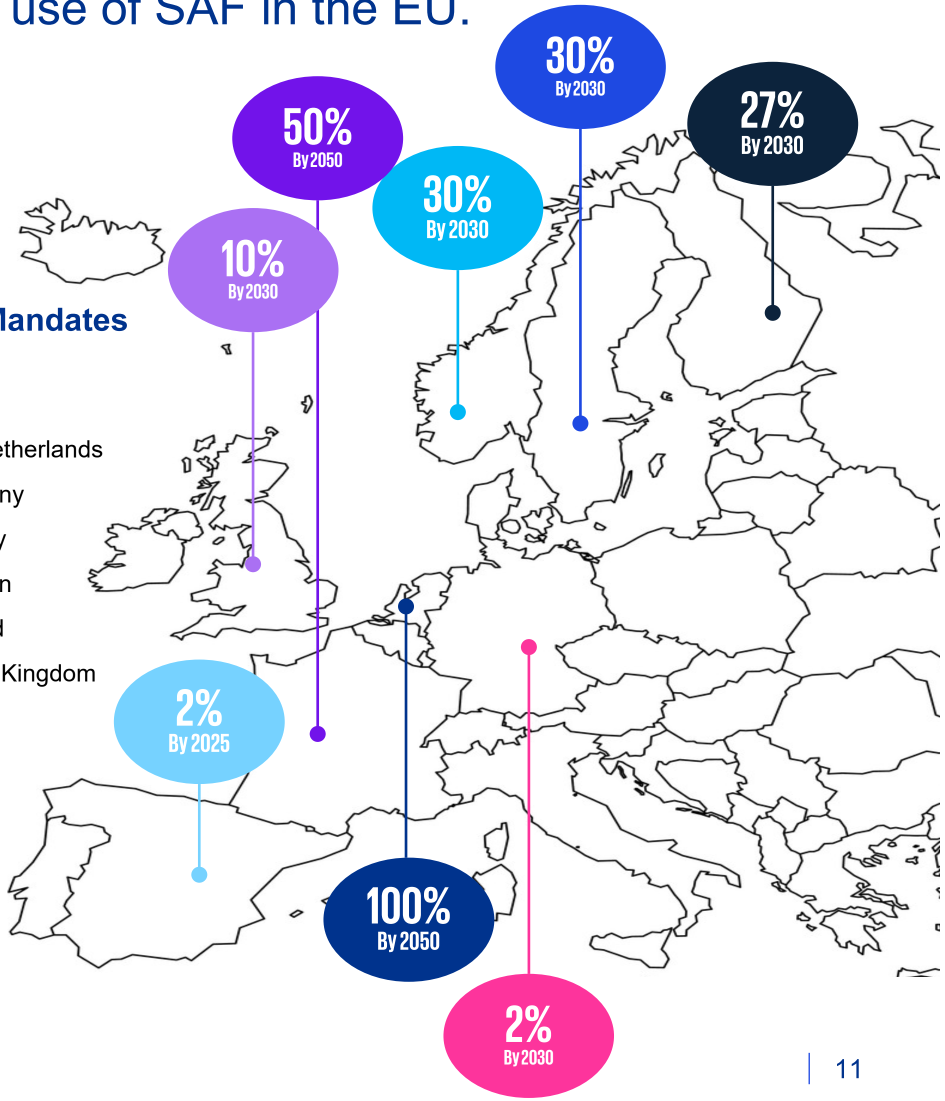
- The Department of Energy, Agriculture, EPA, Transport and FAA collaborated to develop the "SAF Grand Challenge" roadmap to increase production to at least 3 billion gallons SAF per year by 2030 and enough to cover 100% of fuel demand by 2050.
- The Inflation Reduction Act provides for SAF producer credits of up to $1.75 per gallon on top of other incentives, plus multi-billion dollar funds for research and to help finance start-up of new production facilities.

Europe

SAF production is ramping up in Europe but is not as far advanced as in the US, with a majority of SAF currently used tanked or imported from third countries. The EU is focussing on minimum SAF use mandates and requirements, with some individual European countries setting their own more ambitious mandates. Some individual members/airports are considering incentives for SAF as well. The EU has also launched the Renewable Energy Directive which sets requirements for use of advanced biofuels, renewable energy, sustainable hydrogen and cross-border projects.

EU SAF Mandates

- Spain
- France
- The Netherlands
- Germany
- Norway
- Sweden
- Finland
- United Kingdom



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Production Capacities

Coupled with the European SAF mandates, production is also expected to increase in the coming years, with both fuel producers and purchasers making forward purchase agreements.

Top 10 SAF Fuel Producers	**Total Offtake Volume (Mt)**
Gevo	6.44
Fulcrum	4.76
Alder Fuels	4.02
Neste	1.62
Shell	1.59
DG Fuels	1.03
Aemetis	0.90
OMV	0.85
Dimensional Energy	0.80
Velocys	0.78

Top 10 SAF Fuel Purchaser	**Total Offtake Volume (Mt)**
United Airlines	7.45
Delta	2.71
One World	2.68
Lufthansa	2.30
AirBP	1.55
American Airlines	1.51
Air France	1.42
Cathay Pacific	1.00
KLM	0.66
Southwest Airlines	0.59

Total SAF offtake volumes to date equate to approximately 26.66 Mt spread across both Europe and the USA. However, it is clear from the second table that greater commitment has been made by US airlines, as compared to European airlines, with regards to SAF utilisation

Source: ICAO SAF Offtake Agreement Tracker

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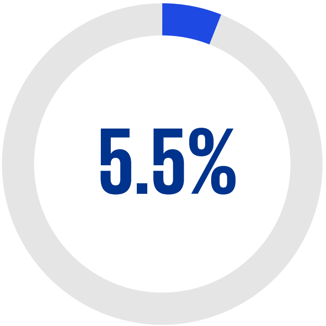
SAF in Europe

Feedstock Availability – EU Context

Existing and planned SAF projects alone cannot decarbonise the sector; a more ambitious SAF rollout needs to be incentivized and achieved, on top of other measures and technological advancements, to achieve the net zero by 2050 goal.

12.2 Mt

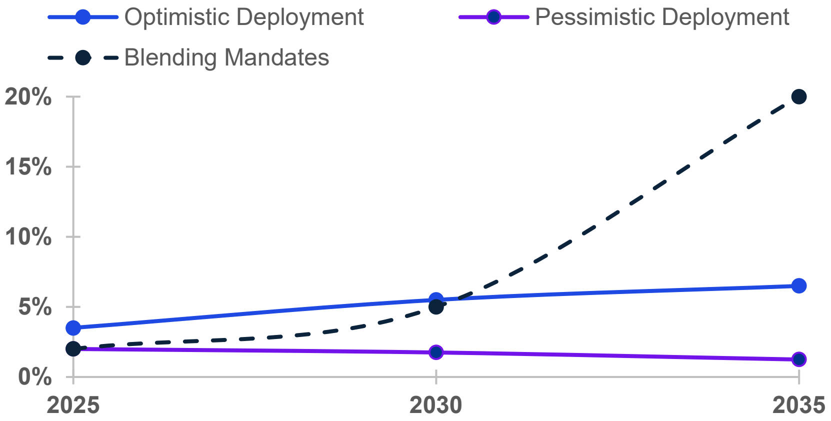
According to the International Council on Clean Transportation[1] the EU has a theoretical maximum production of 12.2 Mt SAF per year



Realistic production volumes of SAF in the EU in 2030 sit at approximately 3.4 Mt or 5.5% of 2030 jet fuel demand.

EU SAF Volumes

The optimistic and pessimistic SAF volumes as a percentage of total jet fuel demand compared to EU SAF blending mandates



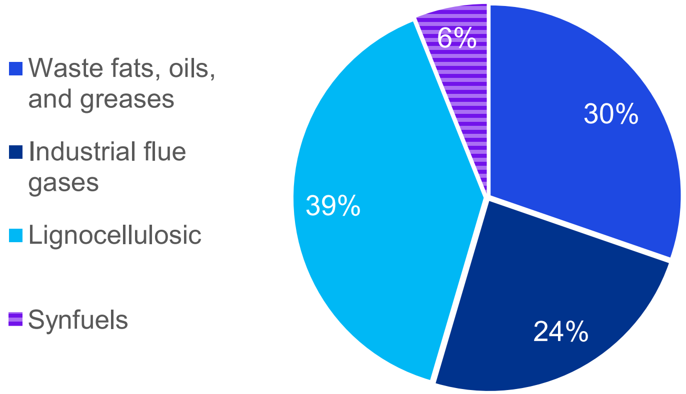
1.9%

In the pessimistic case the maximum SAF deployment sits at 1.9% of projected 2030 EU jet fuel demand. Coupled with the limited resource base for producing SAF, this suggest that for deeper decarbonisation to 2050 accelerated progress in design, operational efficiency of aircraft, carbon pricing and demand reduction, may be necessary.

2030

By 2030 the largest share of total available feedstock in the EU stems from agricultural residues. However, the bulk of deployment of fuels from these feedstock will only happen after 2030 due to time-lags in the ramp-up of commercial scale production facilities.

Percentage contribution of feedstock type to SAF production in 2030



1. O'Malley, Pavlenko & Searle: Estimating sustainable aviation fuel feedstock availability to meet growing European Union demand

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Drivers For Demand

The aviation industry and EU governments alike need to collaborate to support the delivery of air travel's decarbonisation and associated regulatory drivers.

Key Percentage Requirements

2%

Every litre of jet fuel supplied to all airports must be blended with at least 2% of SAF from 2030 to 2035.

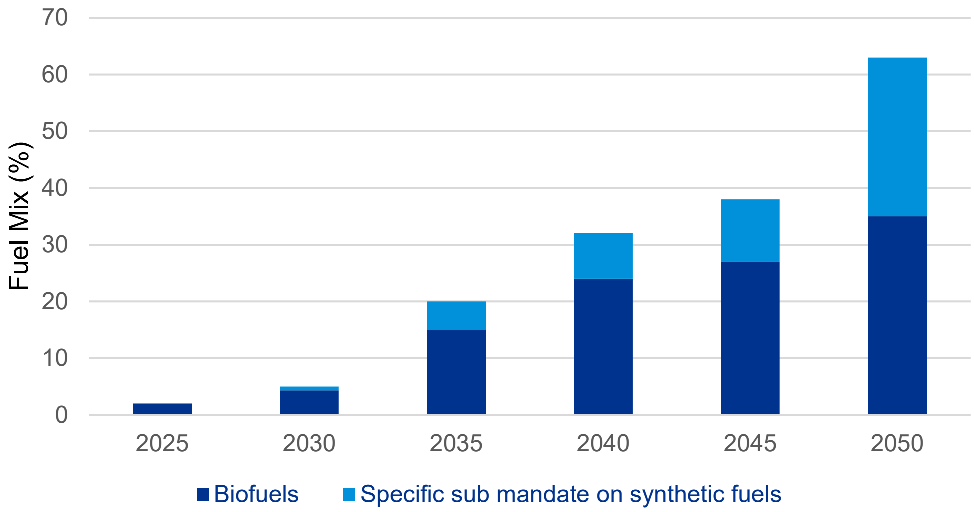
0.7%

Fuel suppliers are required to supply an overall 0.7% of renewable liquid and gaseous fuels of non-biological origin (RFNBOs) from 2030.

90%

A draft regulation establishes the obligation for aircraft operators to ensure that the yearly quantity of aviation fuel uplifted at a given EU airport is at least 90% of the yearly aviation fuel required to avoid tankering.

SAF Blending Requirements under REFuelEU



Societal pressure will drive regulatory and voluntary demand for climate action. For aviation that poses a significant challenge, passenger demand growth is largely in line with global GDP growth over the same time horizon which means increased emissions unless significant intervention across the sector is realised.

REDII

A principle component of EU 'Fit for 55' is a blending mandate for SAF via the REDII initiative

Incentives

- Airlines do not have to surrender any emissions allowances when SAF is used instead of fossil jet fuel
- Member States can count SAF towards the achievement of their national renewable energy targets

Fuel suppliers are required to meet the ramp up SAF targets of

5% In 2030

20% In 2035

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SAF supply potential in Ireland

Ireland has opportunities to explore both sustainable biofuel and synfuel SAF development. Stakeholders including ALI and Government can and should support both, with sustainable biofuels the short-term focus and PtL long-term. Actions for both need to start now to stimulate development, research and infrastructure including expansion of renewable electricity production. A comprehensive policy framework needs to be developed to support any and all paths for SAF in Ireland.

	Opportunity	Challenges
Imported Used Cooking Oil (UCO)	• Currently represents 50% of all renewable fuel on the Irish market • Only approx. 13% is made domestically	• Although technology pathway (HEFA) is mature there is competition with the road sector • Ireland cannot rely solely on SAF from HEFA in medium to long term
Forestry	• Largest biomass resource potential in Ireland by 2035 at current market prices	• SAF production pathway (ATJ/FT) not expected on a commercial scale until 2030 due to low technological maturity
Domestic Energy Crops	• Although growth is currently small in Ireland, could potentially account for 57% of total estimated bioenergy in Ireland in 2035	• Requires a minimum of double the current market price to become financially viable • Impacts food security

Other Options?

Feasibility studies are ongoing and likely more will be needed to investigate realistic options for Ireland, having regard to available feedstock. Lead times for HEFA/ATJ/FT production facilities could be up to 7-10 years, longer for large-scale PtL, but the work begins now for any and all options

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05

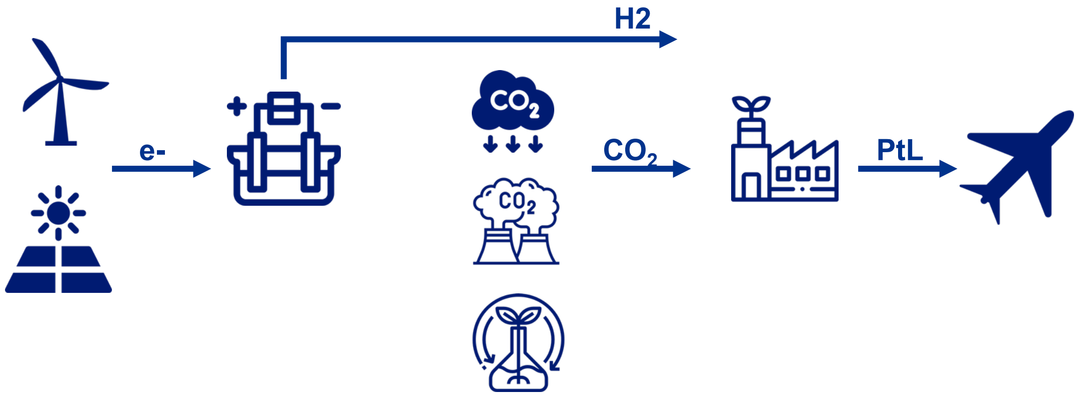
PtL – Long Term Future of SAF

Power to Liquids (PtL) Snapshot

Despite the novel nature of the technology and high associated costs, PtL presents a unique and low GHG SAF production option.

PtL is defined as the process of converting renewable electricity into synthetic fuels

Electricity Generation → Hydrogen Production → CO_2 Supply → Synthesis → PtL Jet Fuel



*** CO_2 can be sourced via 3 routes: directly from the atmosphere, from industrial waste gases or from the processing of bioenergy fuels**

The First PtL Plant

100 M litres annually

Norsk e-Fuel has developed the first PtL demo plant which will produce 100M litres of PtL fuel annually by 2026

The process utilises CO_2 from Direct Air Capture (DAC) from the Swiss company Climeworks which is then combined with hydrogen from Sunfire's electrolysis technology. One plant is predicted to service 50% of flight routes in Norway. The modular approach of the technology will provide a quick and flexible replication across Europe.

Germany's PtL Roadmap

€1bn

In 2021 Germany released its PtL roadmap which is supported by a €1bn investment by the federal government.

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PtL's cost is 2.3 – 6.4x that of fossil fuels

The increasing scale and shrinking cost of renewable electricity will support the transition from biological feedstocks to the adoption of PtL fuels.

The table below summarises the **minimum viable price of PtL jet fuel** according to different sources. **DAC incurs increased costs** compared to using CO_2 from existing industrial applications, due to the technological maturity and efficiency of the process. Overall price estimates for **PtL fuels range 1.04 to 2.84 times greater** than the price of fossil jet fuel today. Factoring in a **CO_2 abatement cost**, by assuming carbon savings of 85% and a jet fuel price of €0.39 per litre, results in a **PtL fuel price range of €245/t to €980/t** which, although **less than the price of jet fuel in 2022**, is at the top of the range of historical jet fuel prices.

	Feedstock	€/t	Compared with Jet A1 (historical) 0.39 €/l	Compared with Jet A1 (2022) at 1,101€/t[1]	Source
PtL FT	Renewable electricity & DAC	1,675	3.4	1.52	German Environment Agency (2016)
PtL FT	Renewable electricity and CO2 point sources	1,144	2.3	1.04	German Environment Agency (2016)
PtL FT	Renewable electricity and CO2 point sources	3125	6.4	2.84	Pavlenko, Searle & Christensen (2019)
PtL FT (2030)	Renewable electricity & DAC	2,338	4.8	2.12	McKinsey & Co. (2020)
PtL FT (2050)	Renewable electricity & DAC	1,530	3.1	1.39	McKinsey & Co. (2020)

Source: Royal Netherlands Aerospace Centre

1. Source: IATA Fuel Price Monitor

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PtL Feedstock Availability

The EU and UK are a prime location for PtL production facilities due to the abundance and quality of offshore wind resources.

01

PtL is dependent on large volumes of cheap renewable electricity. PtL is therefore more attractive in locations with the ability to develop large scale renewable generation portfolios which are in excess of the demand of the power system.

02

Solar generation and offshore wind are considered the most suitable candidates for delivering the renewable electricity required for PtL production at scale.

03

PtL production focused on solar generation will be located outside the EU in location such as Morocco, Saudi Arabia and Chile

04

There is an opportunity for PtL production focused on offshore wind generation within the EU and UK owing to the abundance and quality of wind resource in the north Atlantic

05

PtL also requires large volumes of concentrated CO_2 which places constraints on the location of plants. Securing affordable and reliable and sustainable source of CO_2 may become a differentiating aspect of PtL production locations and projects

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Ireland's PtL Potential

Ireland's top ranked offshore wind resources, if fully tapped, is theoretically sufficient to produce 23 Mt of PtL SAF per year – over 20 times Ireland's actual (2019) jet fuel consumption. In practice offshore wind energy will also be needed for domestic electricity usage, fuels for road transport and green hydrogen production, but even within this there is a long-term opportunity for Ireland to produce enough SAF to cover its jet fuel needs and to be able to sell excess supply abroad.

PtL from current volumes of curtailed renewable electricity

In 2020, 12.1% of wind energy in Ireland was lost to dispatch down. This energy was lost as wind turbines were not generating as much electricity as they could have, due to; a lack of customers, lack of large scale electricity storage capacity and the inability of the grid to transport the power.

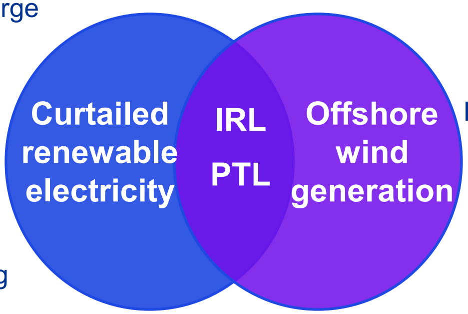
Had the surplus electricity been converted to PtL it could have supplied 4% (or 40 kt) of Ireland's aviation fuel demand.

The Challenge

Dispatch down renewable generation is 'deep and narrow', meaning that there is a very large surplus of generation for short periods of time.

Curtailed renewable energy could in theory power several hundred MW of electrolyser capacity but only for a few number of days.

The production facility would still have to pay grid use charges, as the surplus electricity would be sourced from across the grid, posing substantial costs. In this scenario the capacity factor of a PtL facility would not be practical.



PtL from large scale offshore wind generation

The Republic of Ireland's target to achieve 80% renewable electricity by 2030 includes a target to deliver 7 GW of offshore wind capacity over the same period.

If all of this offshore wind generation was used for PtL production it could produce 1/4 of Ireland's current aviation fuel demand (~233 Kt).

The Challenge

Producing enough PtL to cover 100% of Ireland's 2019 aviation fuel demand (1000kt) would require 30 GWh of energy – equivalent to the total energy consumption in Ireland in 2019. This presents a major challenge for the grid to provide enough renewable energy for this and achieve all other national electricity targets.

This would also require 1.7 Mt of CO_2 per year which proves challenging due to relatively small scale heavy industry in Ireland. **However, the SEAI predicts that Ireland's biomass resources could supply up to 3Mt of CO_2 annually.**

Ireland's substantial untapped potential in offshore wind

The GWEC ranked Ireland as the number 1 market for offshore wind generation due to its potential 85 GW of capacity.

If 85 GW capacity is developed and was entirely used for PtL production, it could theoretically be used to produce 23 Mt of PtL per annum, over 20 times Ireland's current annual jet fuel demand and 69 times the current electricity demand.

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