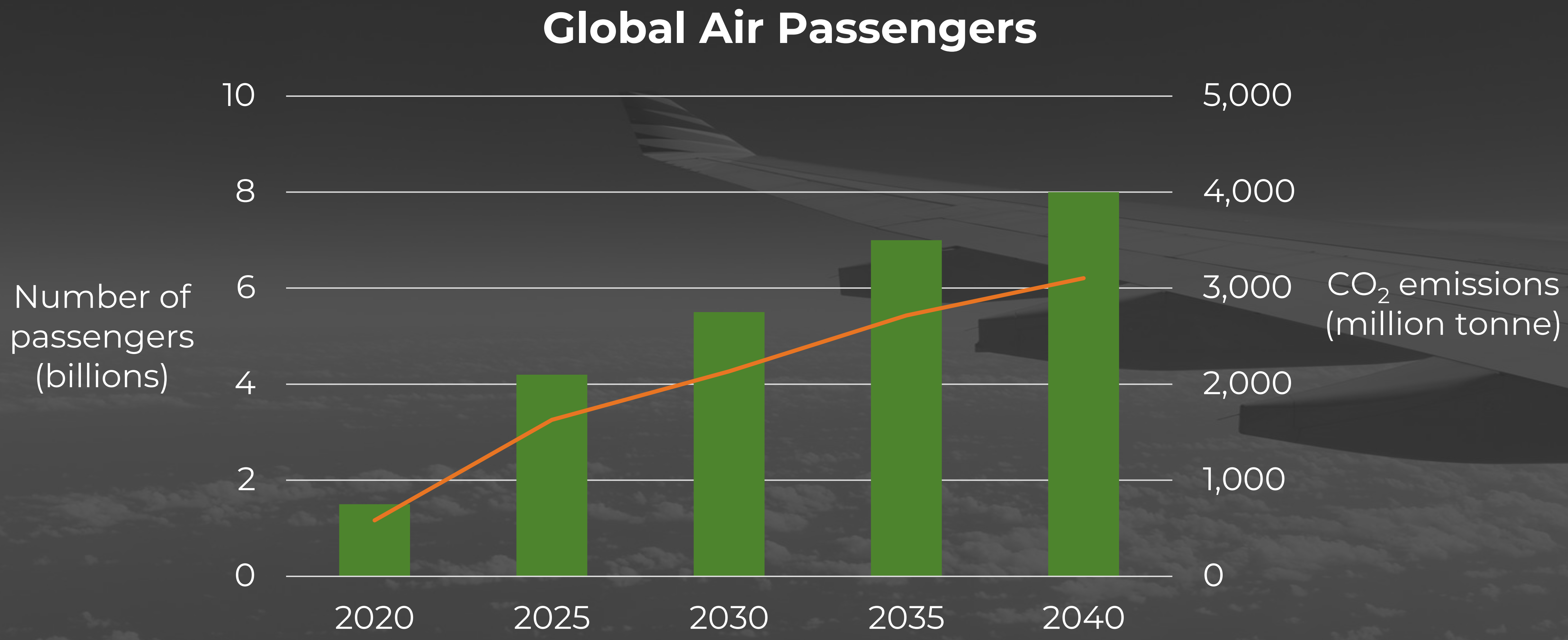
The Future of Aviation: Opportunities in SAFs, Hydrogen, and Electric Aviation

Runeel Daliah
Principal Analyst

Lux Research | The Deciding Factor

The aviation sector will grow to 8 billion passengers by 2040, leading to over 3 billion tonne of CO_2 emissions



Source: Global Outlook for Air Transport (June 2023) and International Energy Agency

The IATA approved Fly Net Zero by 2050 to combat emissions

IATA

The International Air Transport Association (IATA) is a trade association of 317 airlines from 120 countries.

At the 77th IATA Annual General Meeting, the IATA approved **Fly Net Zero by 2050** to achieve net-zero carbon emissions from its operations by 2050.

Each airline must deploy innovative aviation technology to achieve net-zero operations by 2050

DELTA

Emirates

KLM

Lufthansa

BRITISH AIRWAYS

UNITED

SINGAPORE AIRLINES

AIR CANADA

air mauritius

British Airways is the flag carrier of the U.K. and has one of the largest global networks

British Airways is the flag carrier of the U.K. and has one of the largest global networks

BRITISH AIRWAYS

London Heathrow

253 aircraft

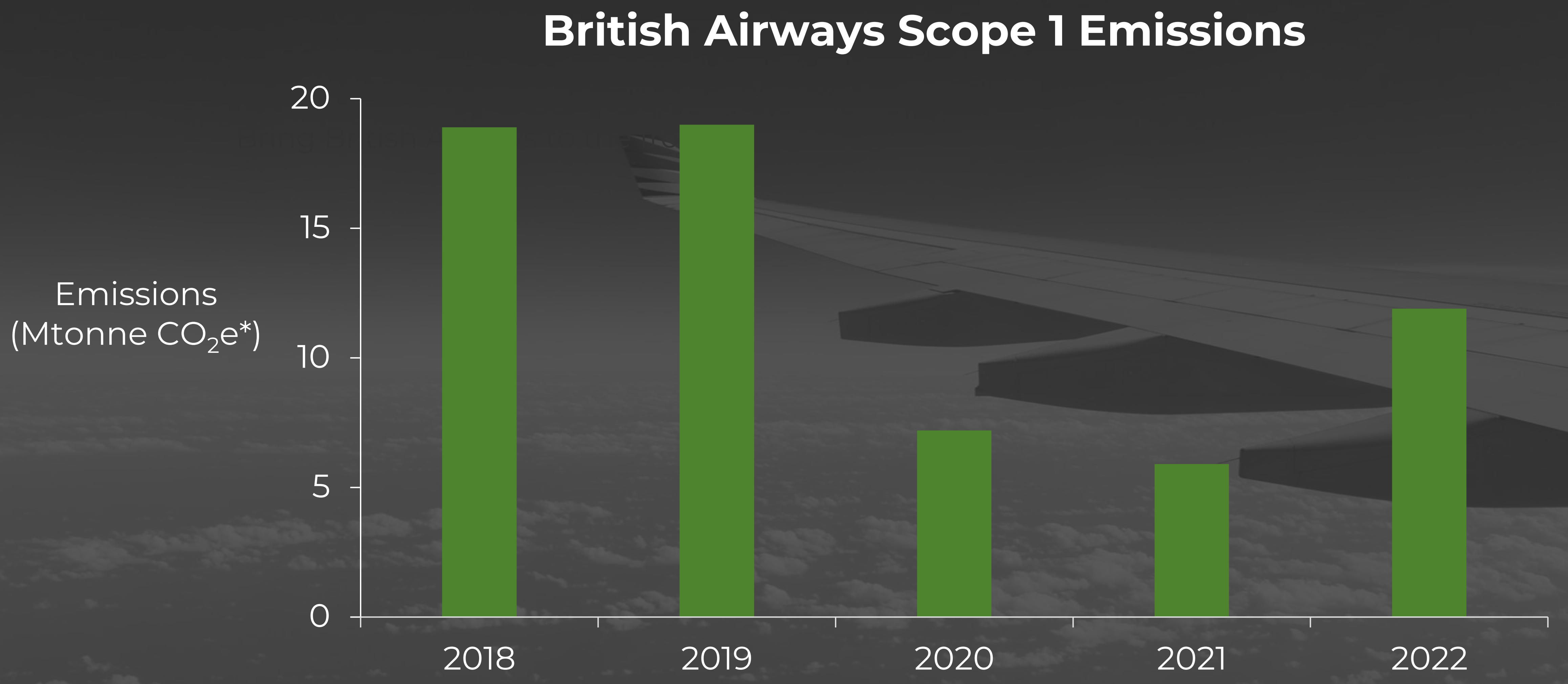
206 destinations

Source: British Airways

British Airways flies to over 70 countries

Source: British Airways

British Airways emits nearly 20 million tonne of CO_2e every year



*CO_2e, CO_2 equivalent. Source: Global Outlook for Air Transport (June 2023) and International Energy Agency

British Airways emits nearly 20 million tonne of CO_2e every year

How can British Airways reach net-zero emissions?

Source: Global Outlook for Air Transport (June 2023), International Energy Agency

Electric Aviation

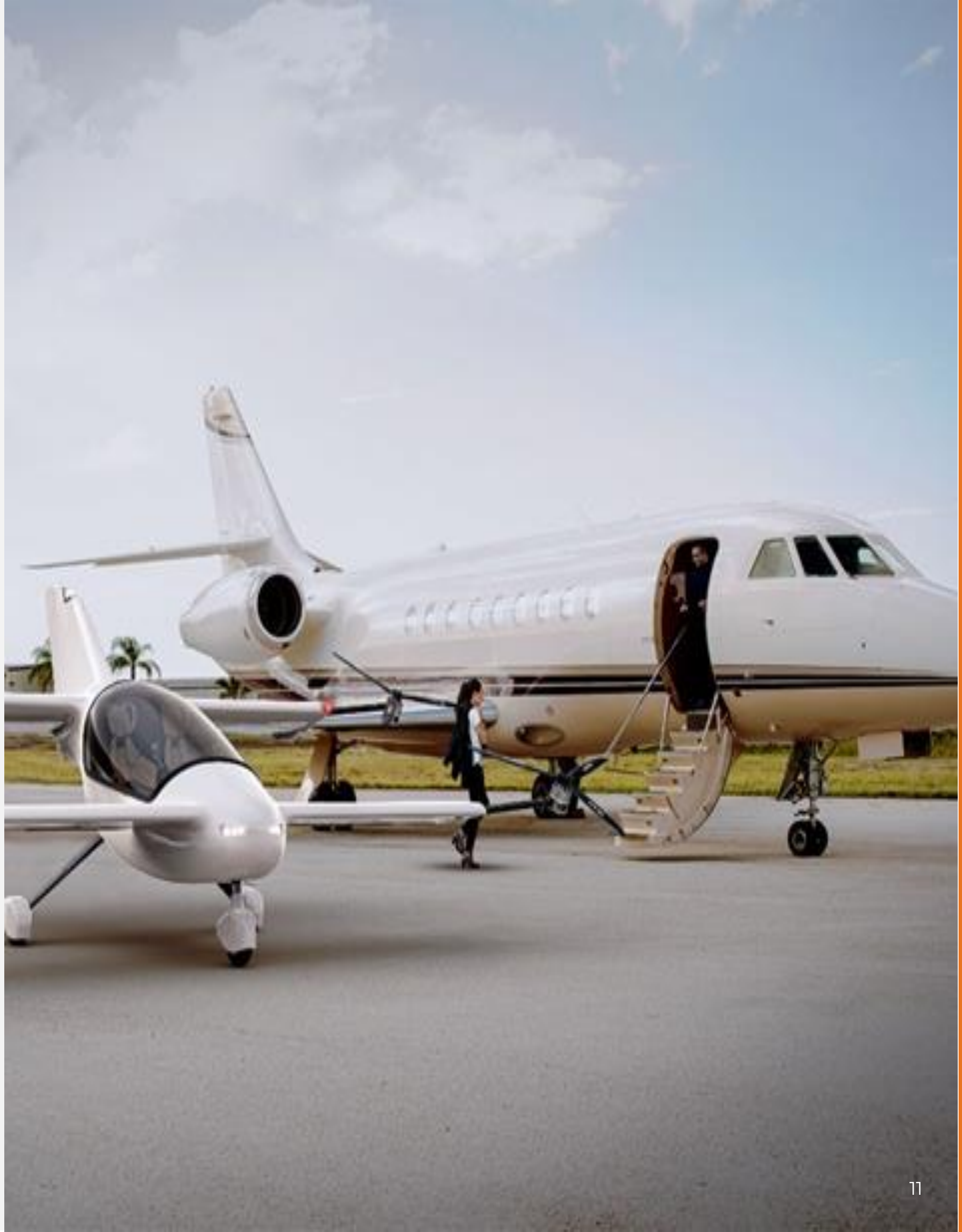
Hydrogen Aviation

SAF

Electric aviation

The electric aviation industry can be segmented into three target applications that each have a distinctly different use-case:

- **Air taxi and flying car** target intra-urban transit applications with the goal of reducing commuting times and ground transport congestion.
- **Small regional aircraft** are nine- to 20-passenger aircraft and small cargo planes. These planes are used for applications including island hopping, fjord hopping, and accessing rural locations.
- **Commercial aircraft** target long-distance international travel with seating of more than 100 passengers.



Electric aviation

The electric aviation industry can be segmented into three target applications that each have a distinctly different use-case:

- **Air taxi and flying car** target intra-urban transit applications with the goal of reducing commuting times and ground transport congestion.
- **Small regional aircraft** are nine- to 20-passenger aircraft and small cargo planes. These planes are used for applications including island hopping, fjord hopping, and accessing rural locations.
- **Commercial aircraft** target long-distance international travel with seating of more than 100 passengers.

Air taxis & flying cars

Propulsion
Electric motor powered by batteries

Range
200 km

- Developers pursue vertical take off & landing configurations that require no landing strips.
- Aircraft designed for short distances have rotor-based architectures.
- Aircraft for longer distances have hybrid architectures; they use rotors for takeoff and landing but switch to fixed-wing operations in horizontal flight.

Electric aviation

The electric aviation industry can be segmented into three target applications that each have a distinctly different use-case:

- **Air taxi and flying car** target intra-urban transit applications with the goal of reducing commuting times and ground transport congestion.
- **Small regional aircraft** are nine- to 20-passenger aircraft and small cargo planes. These planes are used for applications including island hopping, fjord hopping, and accessing rural locations.
- **Commercial aircraft** target long-distance international travel with seating of more than 100 passengers.

Small regional aircraft

Propulsion
Electric motor powered by batteries

Range
400 km

- Developers favor fixed-wing architectures due to increased efficiencies at cruising altitude and availability of landing strips.
- Electric power trains also enable more aerodynamic aircraft designs due to an absence of hot exhaust.
- Some companies are developing hybrid electric aircraft to reach the market quickly with higher range capabilities.

Electric aviation

The electric aviation industry can be segmented into three target applications that each have a distinctly different use-case:

- **Air taxi and flying car** target intra-urban transit applications with the goal of reducing commuting times and ground transport congestion.
- **Small regional aircraft** are nine- to 20-passenger aircraft and small cargo planes. These planes are used for applications including island hopping, fjord hopping, and accessing rural locations.
- **Commercial aircraft** target long-distance international travel with seating of more than 100 passengers.

Commercial aircraft

Propulsion
Electric motor in hybrid configuration

Range
~700 km

- All developers focus on fixed-wing configurations.
- Power train choices vary between hybrid electric and all-electric designs, although hybrid is the most likely.
- Very limited commercial activity; battery size and weight are the major technical hurdles.

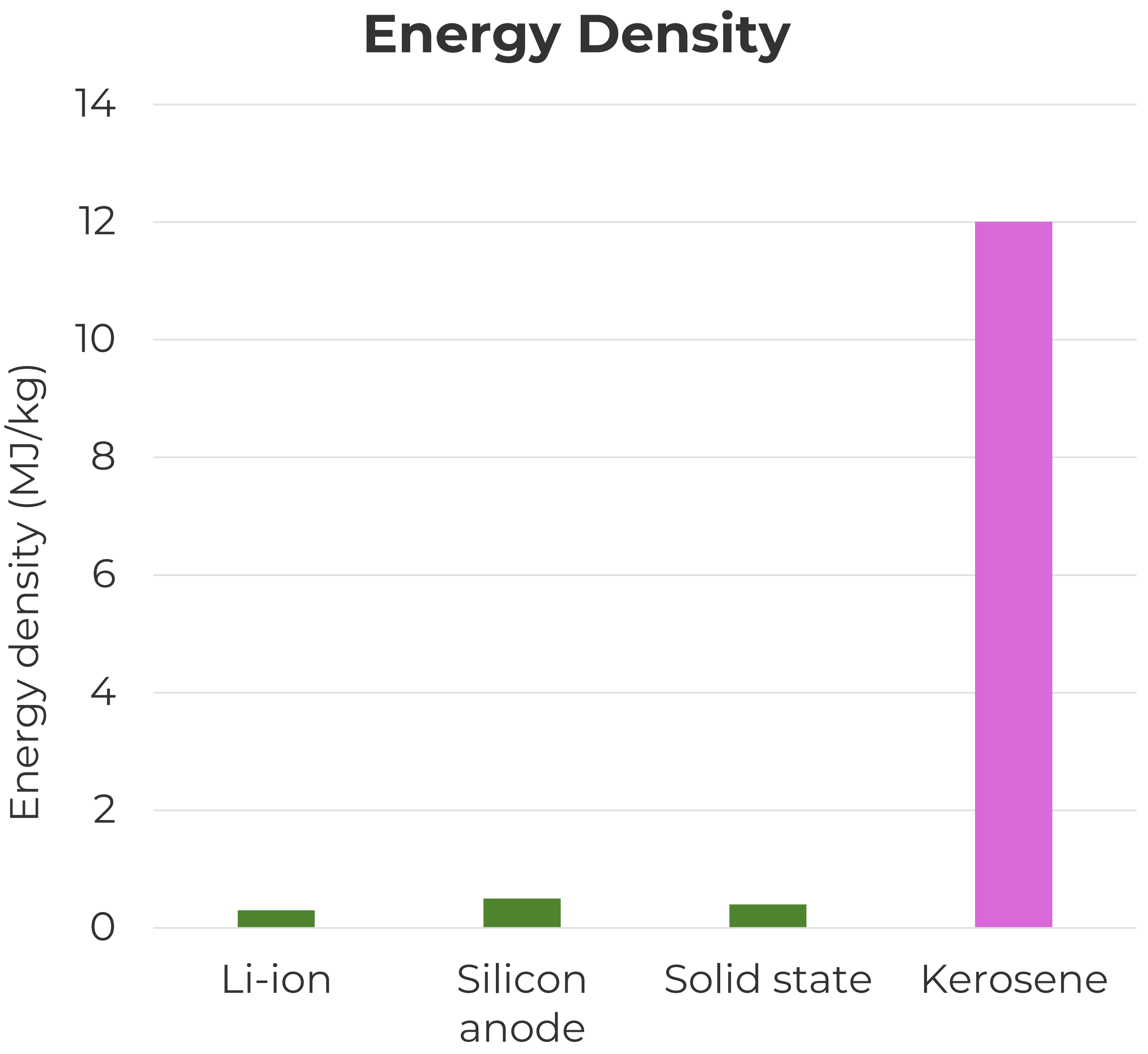
Wright Electric is testing an all-electric aircraft with a 2-MW motor.

It aims to launch its flagship 186-seater Wright 1 aircraft with an 800-mile range by 2030.

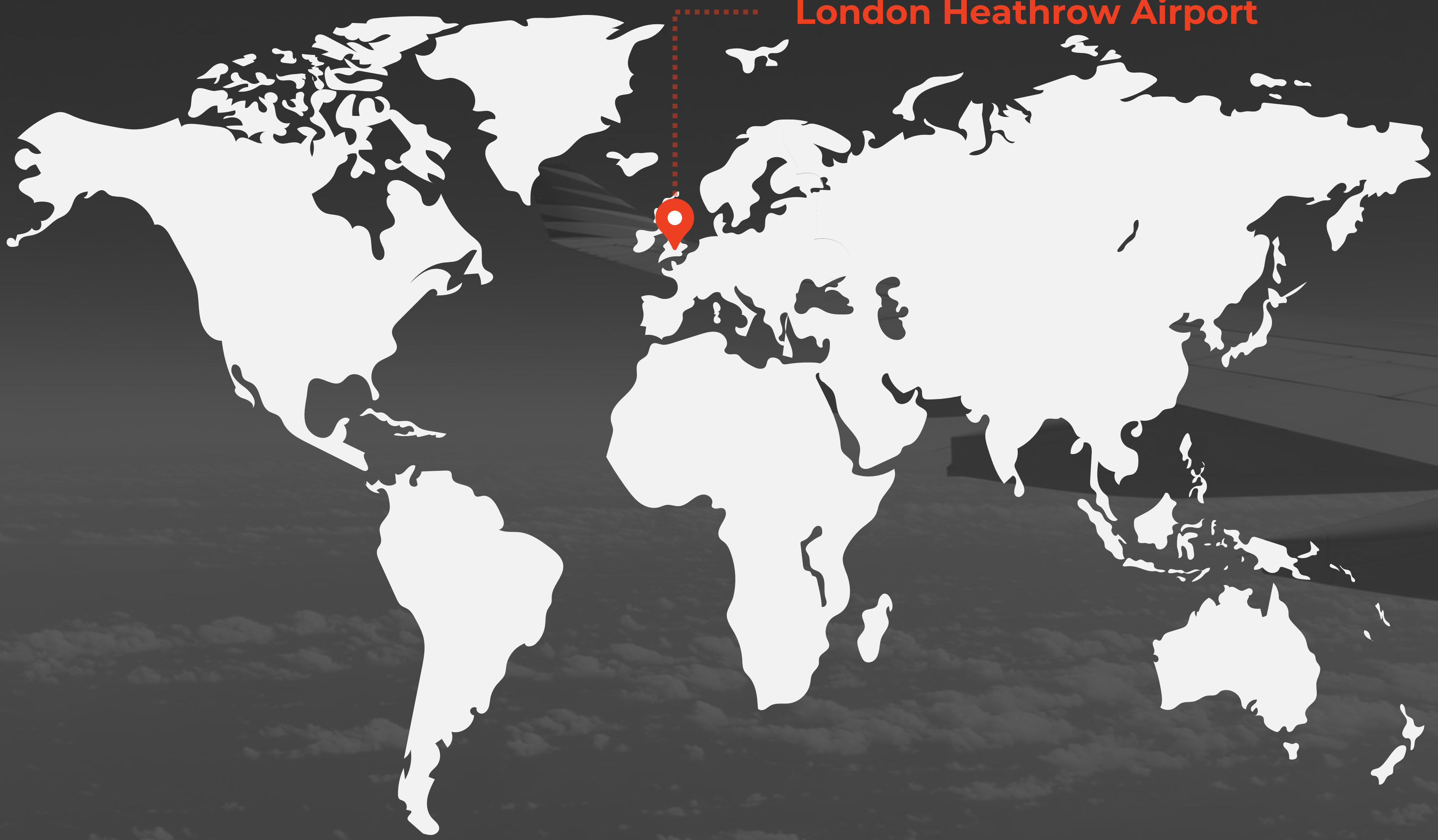
Wright

Image source: Wright Electric

The Li-ion battery isn't suitable for fully electric commercial aviation



How far can British Airways fly with an all-electric plane?



British Airways can use all-electric planes for intracontinental flights

Electric Aviation

Hydrogen Aviation

SAF

Hydrogen aviation

The hydrogen aviation industry can be split into two propulsion technologies that each have a distinctly different use-case:

- **Fuel cell** companies are developing unmanned aerial vehicles and small to medium-size airliners. The largest fuel cell-electric aircraft flown to date is a 40-seat regional airliner.
- **Combustion** developers mostly target commercial applications flying passengers on medium- to long-haul routes. Active companies are currently at the conceptual and testing stages.

Image source: Universal Hydrogen

Hydrogen aviation

The hydrogen aviation industry can be split into two propulsion technologies that each have a distinctly different use-case:

- **Fuel cell** companies are developing unmanned aerial vehicles and small to medium-size airliners. The largest fuel cell-electric aircraft flown to date is a 40-seat regional airliner.
- **Combustion** developers mostly target commercial applications flying passengers on medium- to long-haul routes. Active companies are currently at the conceptual and testing stages.

Fuel cell

Propulsion
Electric motor with fuel cells

Range
500 km

- Proton exchange membrane fuel cells are preferred as they operate at low temperatures and in dynamic mode.
- Often used in hybrid configuration with batteries or combustion engines
- Fuel cells will face challenges operating at high altitudes, due to low temperature, pressure, and oxygen concentrations.

ZeroAvia develops fuel cell-electric propulsion systems. It flew a six-seater aircraft in January 2023.

It aims to launch 19-seater planes flying 300 miles by 2025 and 200-seater planes flying 2,000 miles by 2030.

ZEROAVIA

Image source: ZeroAvia

Hydrogen aviation

The hydrogen aviation industry can be split into two propulsion technologies that each have a distinctly different use-case:

- **Fuel cell** companies are developing unmanned aerial vehicles and small to medium-size airliners. The largest fuel cell-electric aircraft flown to date is a 40-seat regional airliner.
- **Combustion** developers mostly target commercial applications flying passengers on medium- to long-haul routes. Active companies are currently at the conceptual and testing stages.

Hydrogen combustion

Propulsion
Turbofan engine

Range
3,700 km

- Planes will use liquid hydrogen. Modifications to the combustor are required, including a new cryogenic fuel delivery system.
- A major challenge is flame stability. Flame flashback, where the flame propagates back to the tank, can lead to explosions.
- Limited commercial activity; commercial deployment is decades away.

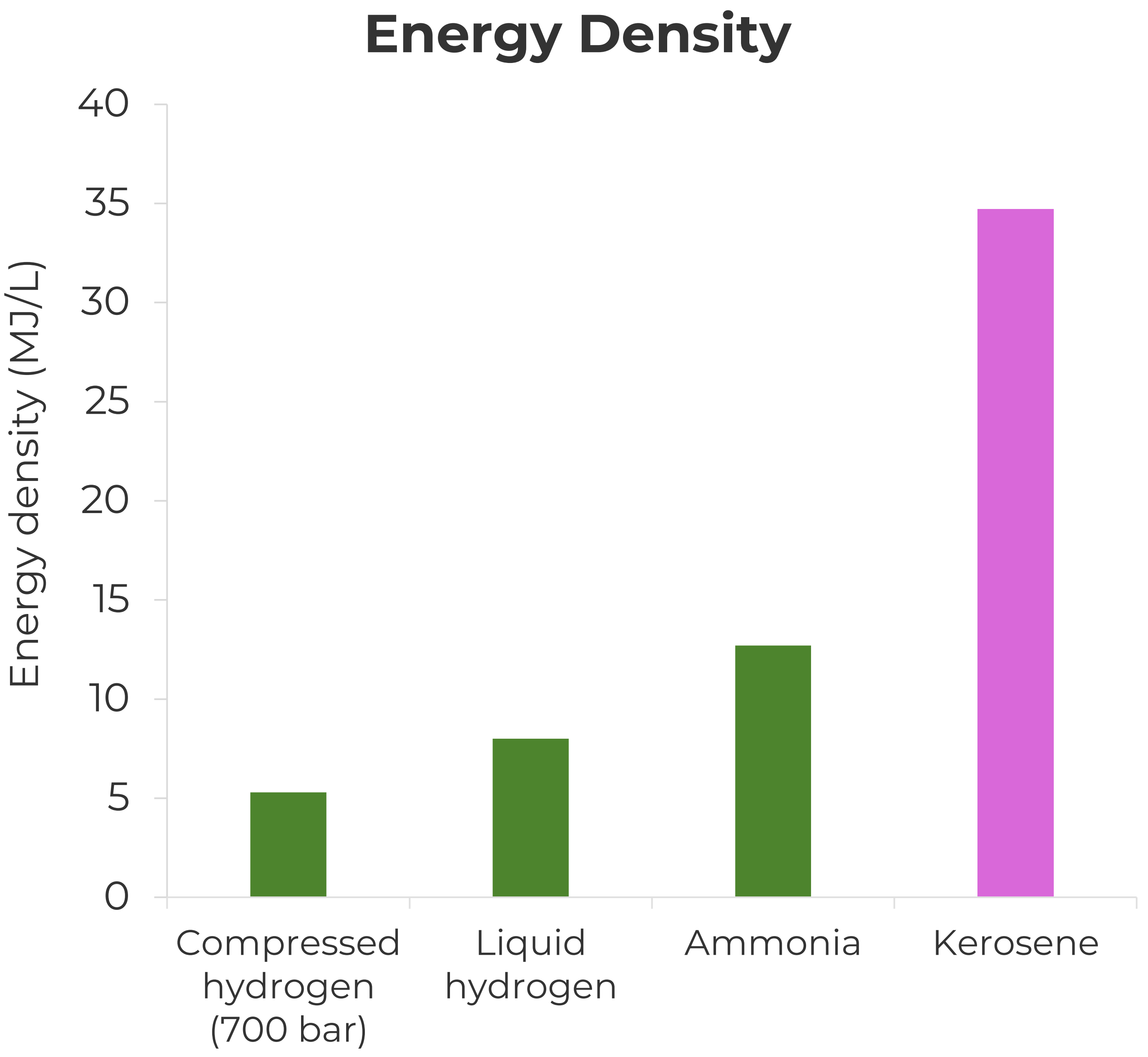
Airbus launched ZEROe in 2021 and unveiled three concepts for aircraft powered by hydrogen combustion.

The designs include blended-wing body and turbofan planes, including a 200-seater plane for a 2,000-mile flying range.

AIRBUS

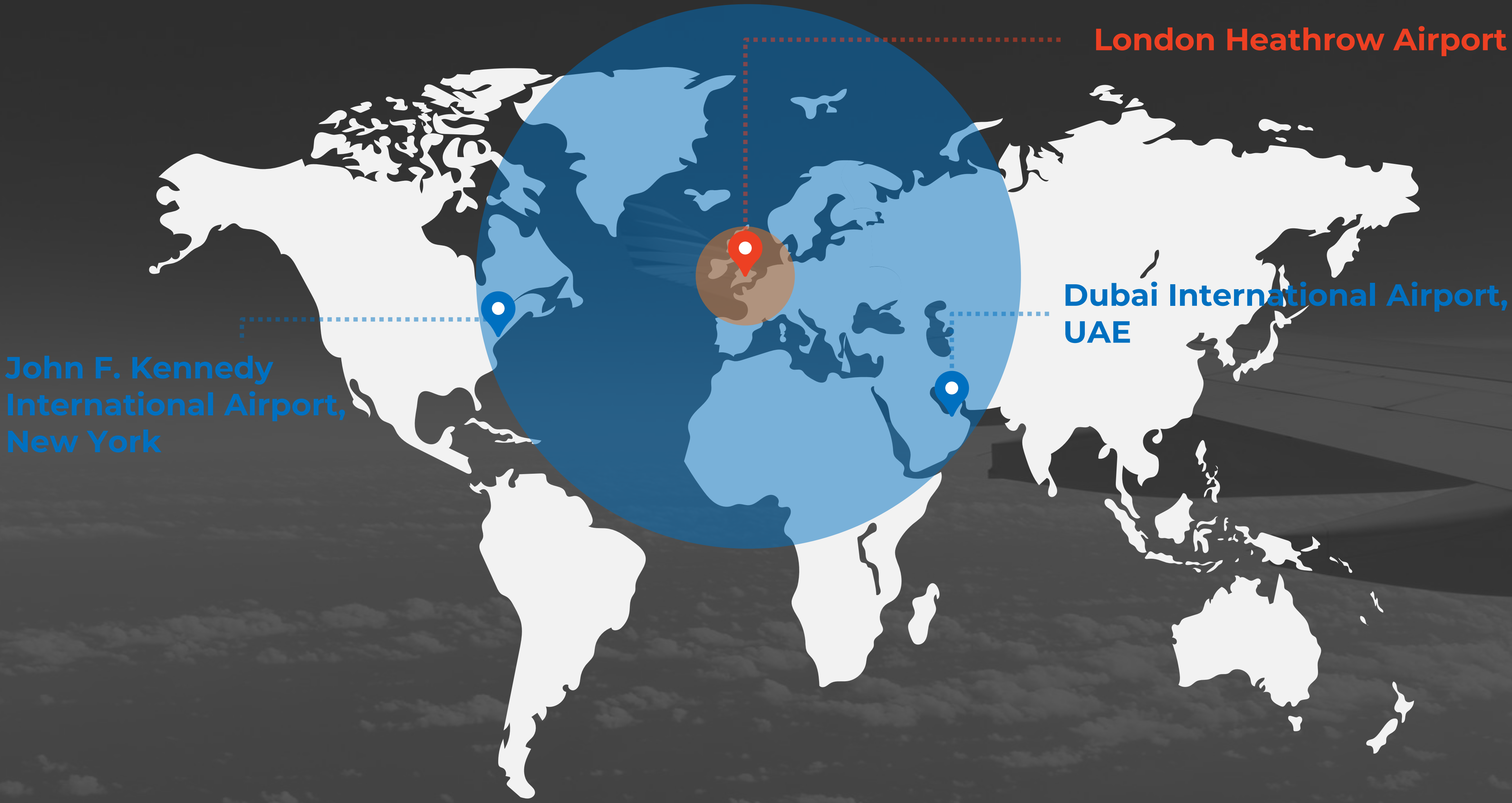
Image source: Airbus

The energy density of hydrogen cannot match that of jet fuel



How far can British Airways fly with hydrogen-fueled planes?

British Airways can use hydrogen planes for intercontinental flights



Electric Aviation

Hydrogen Aviation

SAF

SAF

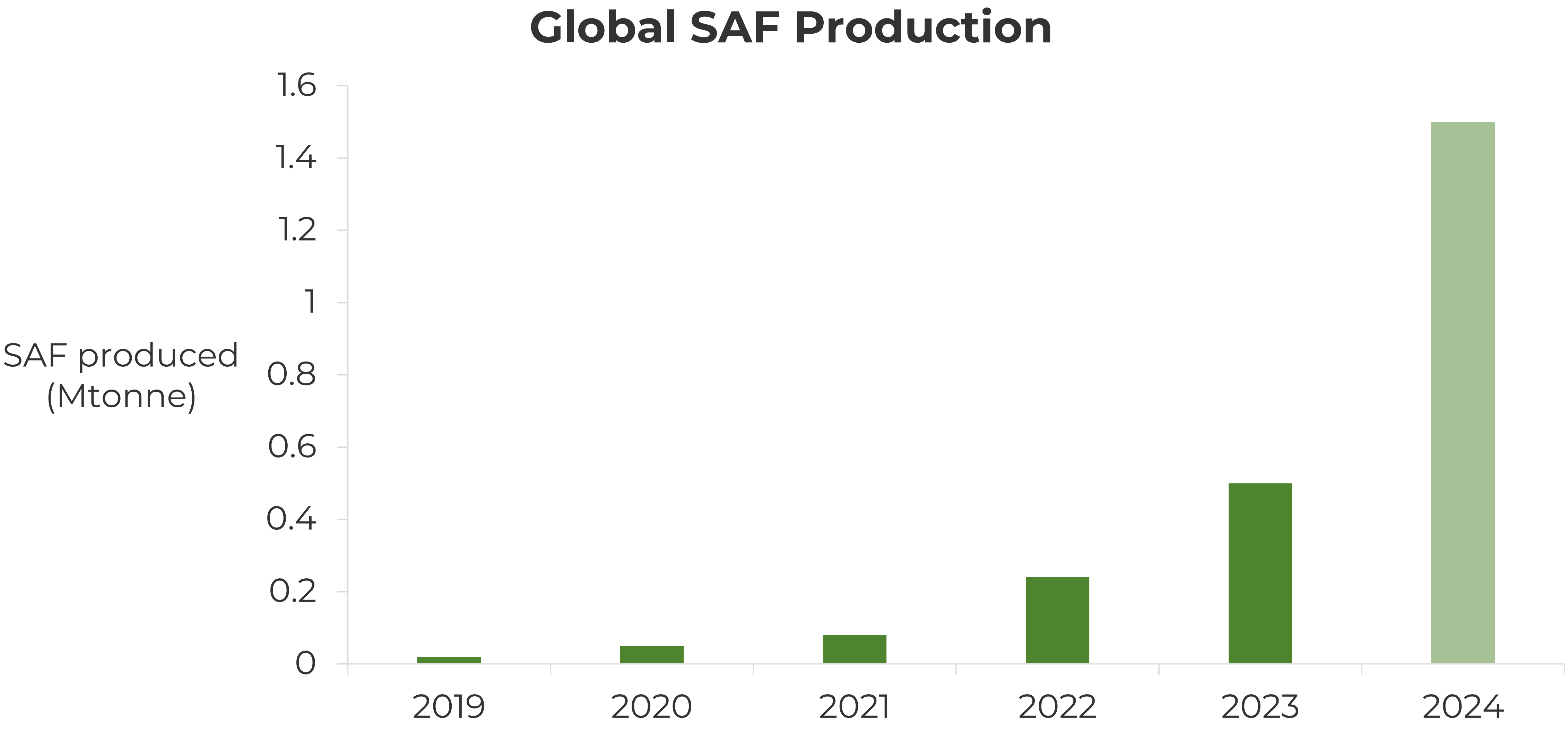
SAF is drop-in aviation fuel made from low-carbon feedstock. SAF can be blended into fossil jet fuel or used directly.

SAF can be segmented by feedstock:

- **Biobased SAF** is made from bioresources like biomass or sugars. The feedstock can be thermochemically or biologically converted to fuel.
- **Synthetic SAF** is made from CO_2 and hydrogen gas. The gases are thermochemically converted to fuel.

Image source: Universal Hydrogen

Over 500,000 tonne of SAF were produced in 2023, but projected increase to 1.5 Mtonne in 2024 is unlikely



Source: [IATA]

Corporations dominate HEFA, while startup activity is concentrated within FT and ATJ

FISCHER-TROPSCH (FT)

ASTM status: Approved

JM		Axens SOLUTIONS	sasol	Arcadia eFuels
Fulcrum BIOENERGY	DG FUELS	RAVEN	Dimensional Energy	VELOCYS
WASTEFUEL	IDUNN H2	RED ROCK BIOFUELS	twelve	norsk e-fuel
INERATEC	INFINIUM			

ALCOHOL-TO-JET (ATJ)

ASTM status: Approved

Axens SOLUTIONS	TotalEnergies	Exxon	Honeywell UOP	TOPSOE
LanzaJet	gevo	Vertimass	BYOGY RENEWABLES	Swedish Biofuels
GLOBAL BIOENERGIES				

HYDROTREATED FATTY ACIDS AND ESTERS (HEFA)

ASTM status: Approved

NESTE	TotalEnergies	SKYNRG	world energy	bp
PHILLIPS 66	Honeywell UOP	preem	TOPSOE	eni
Axens SOLUTIONS		Exxon	AEMETIS	CEPSA

CATALYTIC HYDRO-THERMOLYSIS (CH)

ASTM status: Approved

ARA			

HYDRO-DEOXYGENATION (HDO)

ASTM status: Under review

VIRENT			

SYNTHESIZED ISOPARAFFINS (SIP)

ASTM status: Approved

amyris			

HYDROPROCESSED HYDROCARBONS (HHC)

ASTM status: Approved

IHI			

INTEGRATED HYDROPYROLYSIS & HYDROCONVERSION (IH2)

ASTM status: Under review

Only 3 SAF technologies are relevant for commercial aviation

FISCHER-TROPSCH (FT)

ASTM status: Approved

JM, Shell, Axens Solutions, Sasol, Arcadia eFuels, Fulcrum Bioenergy, DG Fuels, Raven, Dimensional Energy, Velocys, Wastefuel, IDUNN H2, Red Rock Biofuels, twelve, norsk e-fuel, Ineratec, Infinium

ALCOHOL-TO-JET (ATJ)

ASTM status: Approved

Axens Solutions, TotalEnergies, Exxon, Honeywell UOP, Topsoe, LanzaJet, gevo, Vertimass, Byogy Renewables, Swedish Biofuels, Global Bioenergies

HYDROTREATED FATTY ACIDS AND ESTERS (HEFA)

ASTM status: Approved

Neste, TotalEnergies, SkyNRG, World Energy, bp, Phillips 66, Honeywell UOP, preem, Topsoe, eni, Axens Solutions, Shell, Exxon, Aemetis, Cepsa

CATALYTIC HYDRO-THERMOLYSIS (CH)

ASTM status: Approved

ARA

HYDRO-DEOXYGENATION (HDO)

ASTM status: Under review

Virent

SYNTHESIZED ISOPARAFFINS (SIP)

ASTM status: Approved

amyris

HYDROPROCESSED HYDROCARBONS (HHC)

ASTM status: Approved

IHI

INTEGRATED HYDROPYROLYSIS & HYDROCONVERSION (IH2)

ASTM status: Under review

Shell

HEFA

Technology overview

- The catalytic hydrotreatment of oil-based feedstock in the presence of hydrogen removes oxygen, followed by hydrocracking into renewable diesel, naphtha, and SAF.
- It uses vegetable oil or waste fat, oil, and grease feedstock; waste feedstock requires pretreatment to remove impurities.
- The typical jet fuel fraction in a HEFA facility is 15%; it can be adjusted to up to 80% for maximum jet output.

ASTM status
Approved (2011)

Feedstock
Vegetable and waste oils

Commercial outlook

- HEFA is at commercial scale, with multiple facilities producing it.
- Due to the commercial maturity of HEFA, there is little room for technology innovation.
- The key focus area is feedstock supply chain management and pretreatment, as feedstock is the largest expense for a HEFA facility.

Neste develops NEXBTL for the hydrotreatment of bio-oil to renewable fuels.

It is at scale, with two biorefineries in Netherlands and Singapore with a combined capacity of 3 million tonne/y of renewable fuels.

NESTE

Image source: Neste

Fischer-Tropsch

Technology overview

- Synthetic gas (syngas — hydrogen and carbon monoxide) is catalytically converted into synthetic crude, which is then refined into diesel, jet fuel, naphtha, and waxes.
- The syngas can be produced from gasification of biomass or municipal solid waste (MSW) or from hydrogen and CO_2 through the reverse water-gas shift (RWGS) reaction.
- The typical jet fuel fraction in an FT facility is 10%–15%; early estimates indicate it can be tuned up to 50%–60%.

ASTM status
Approved (2009)

Feedstock
Syngas

Commercial outlook

- FT for SAF is currently at the introduction scale, with the first demo facility using MSW feedstock launched in 2021.
- The main challenges is the high capital expenditure of the gasification and FT units, downsizing the FT units to match the scale of feedstock supply, and integration of distinct units.

Fulcrum Bioenergy launched the first demo facility for SAF from MSW. The facility has a capacity of 10 million gallons per year.

The company uses Johnson Matthey's FT technology.

Image source: Fulcrum Bioenergy

Alcohol-to-Jet

Technology overview

- ATJ is a three-step catalytic conversion of alcohol to jet fuel. The alcohol is first dehydrated into its alkene, which is then oligomerized into long-chain hydrocarbons before hydrogenation into jet fuel.
- It can use methanol, ethanol, or isobutanol, although only ethanol and isobutanol are ASTM approved.
- Oligomerization is the heart of the ATJ process and core differentiator.

ASTM status
Approved (2016)

Feedstock
Ethanol, isobutanol

Commercial outlook

- ATJ is not yet commercial but has exhibited high momentum in recent years. The first demo facility converting ethanol to SAF was launched in 2024.
- ATJ uses inexpensive, recyclable, and stable catalysts that exhibit high selectivity toward paraffinic compounds — essential for competitiveness.

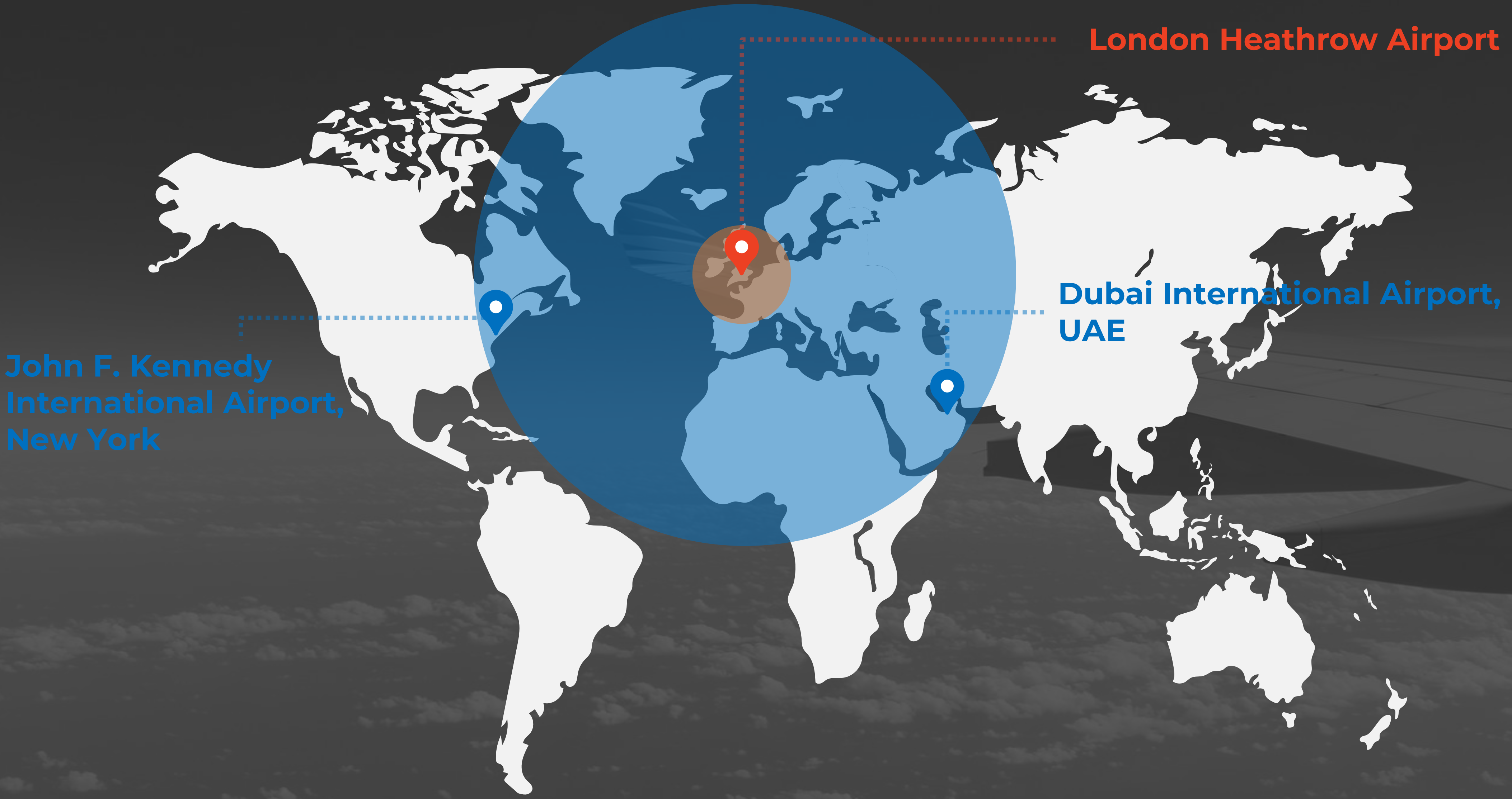
LanzaJet launched the first demo facility for SAF from ethanol in January 2024. The facility's capacity is 10 million gallons per year.

The company uses first-generation ethanol.

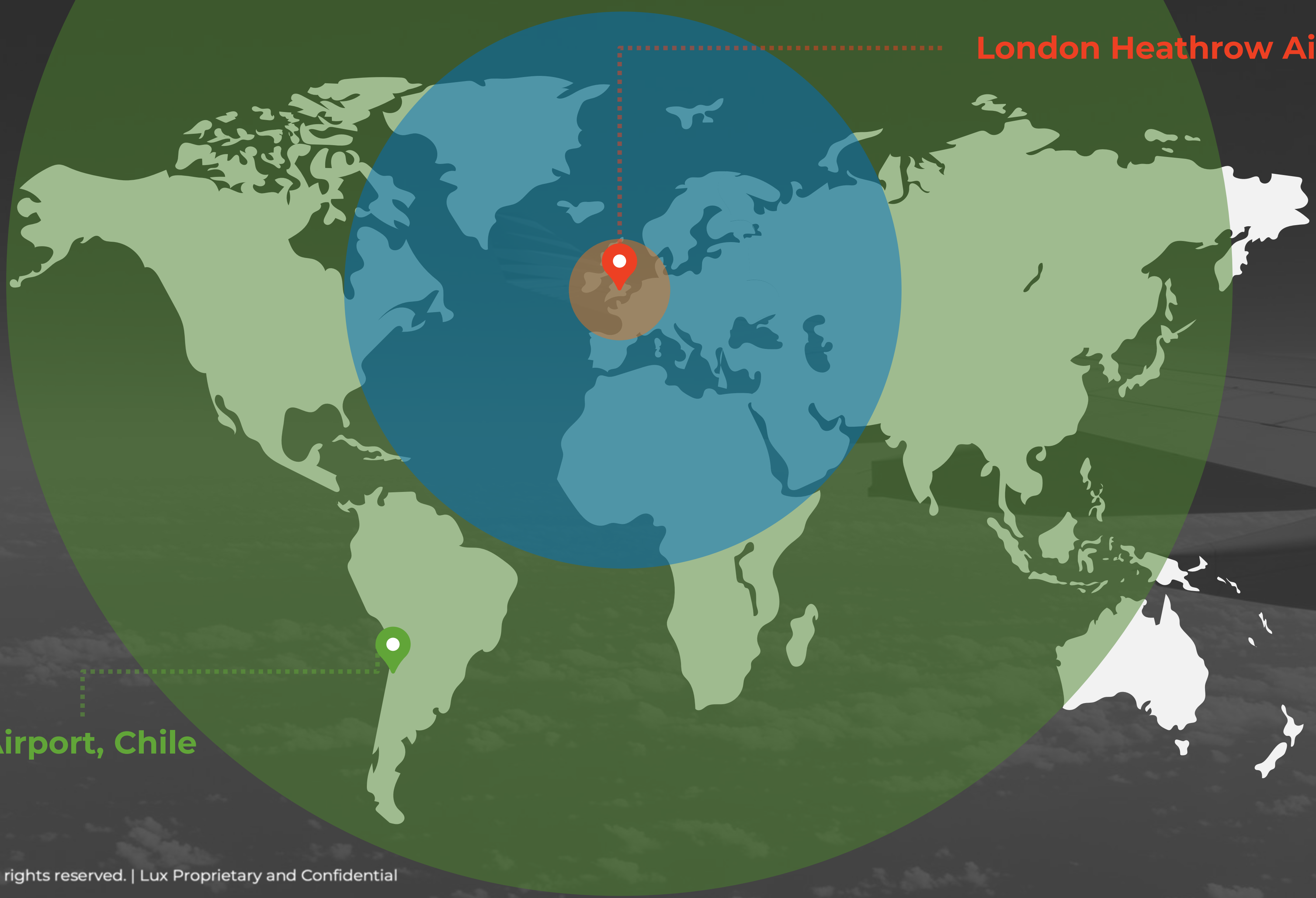
LanzaJet

Image source: LanzaJet

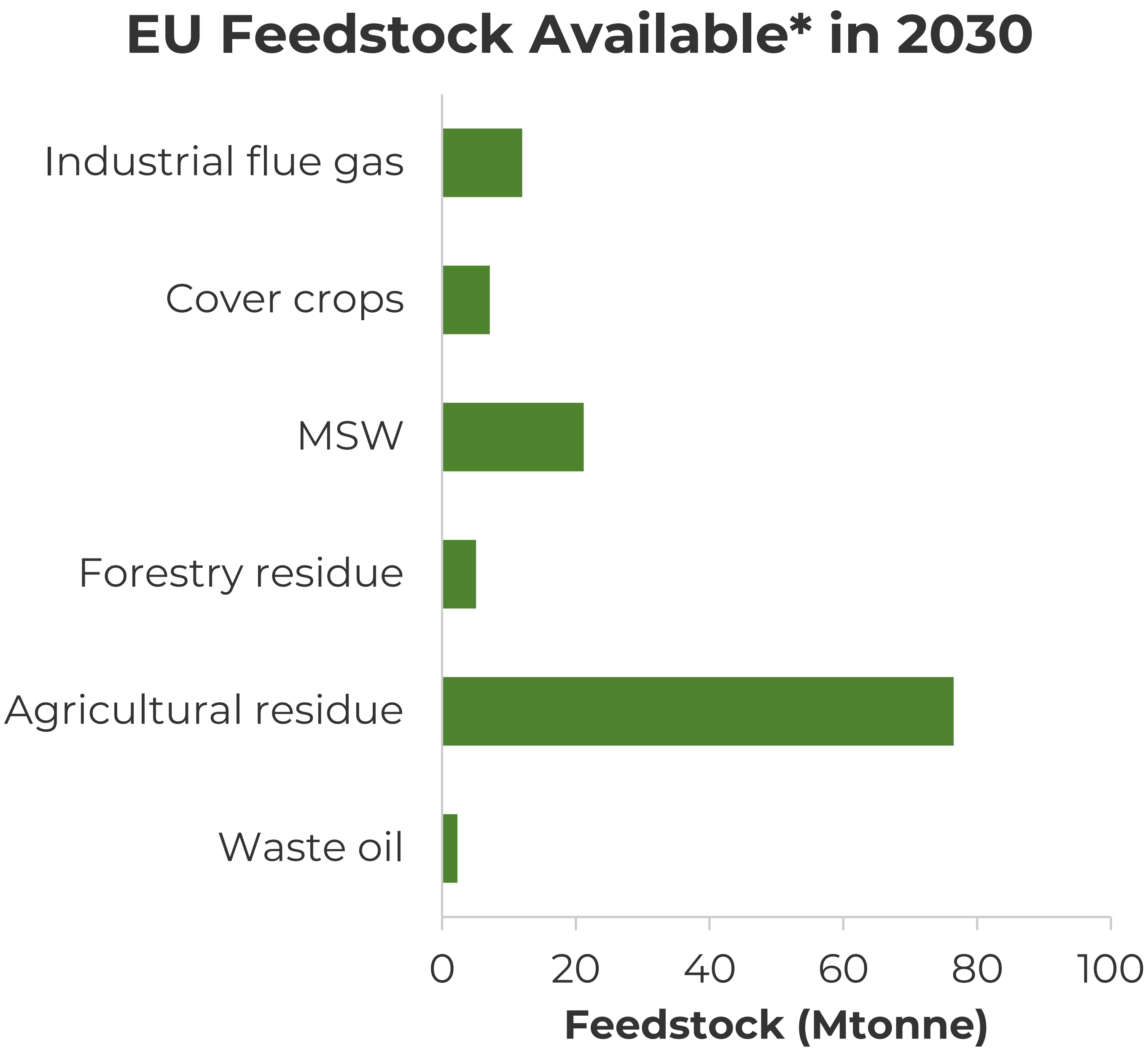
How far can British Airways fly with SAF-fueled planes?



British Airways can cover its entire network with SAF-fueled planes



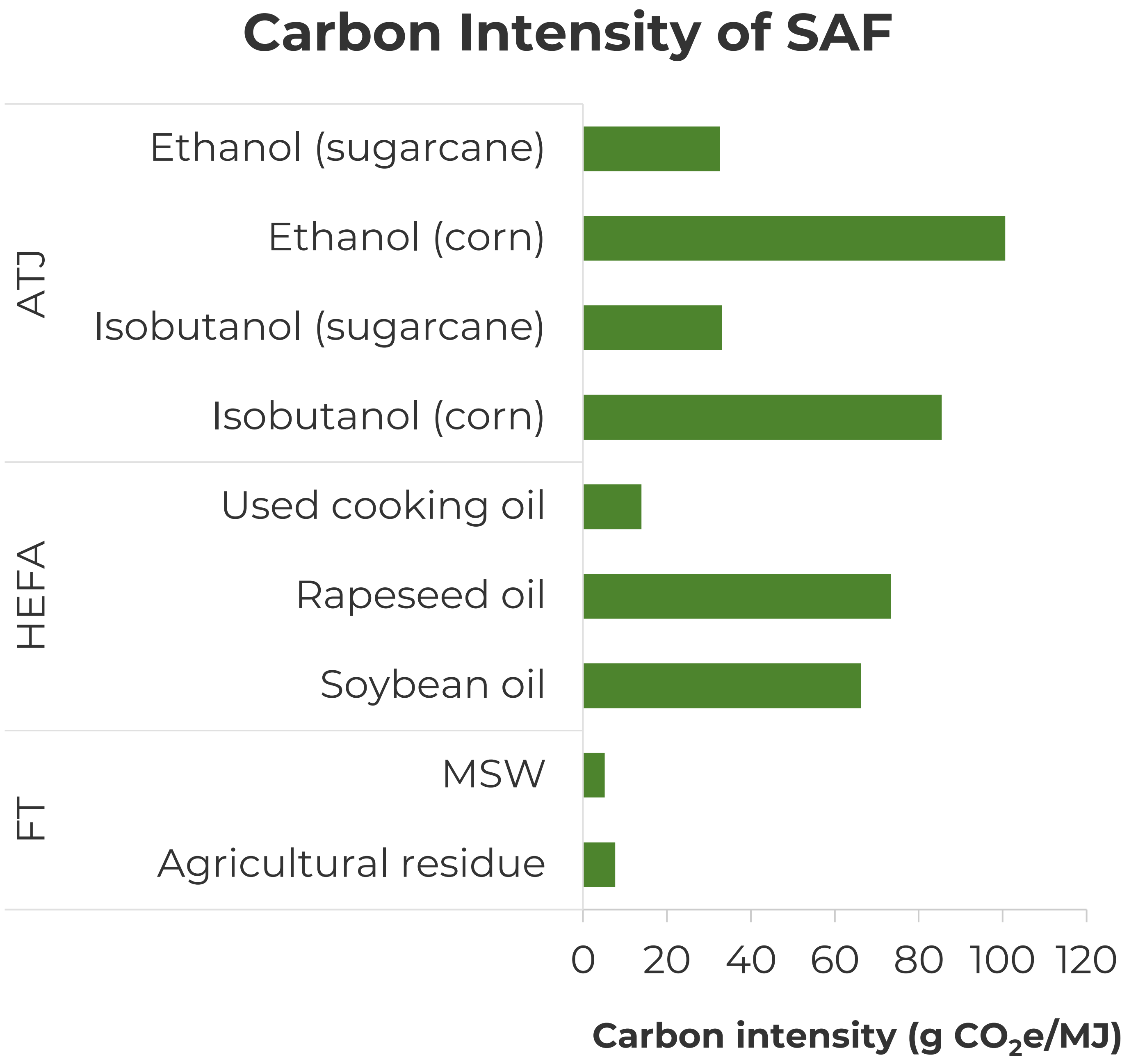
Feedstock availability is the greatest barrier to scaling up the SAF industry



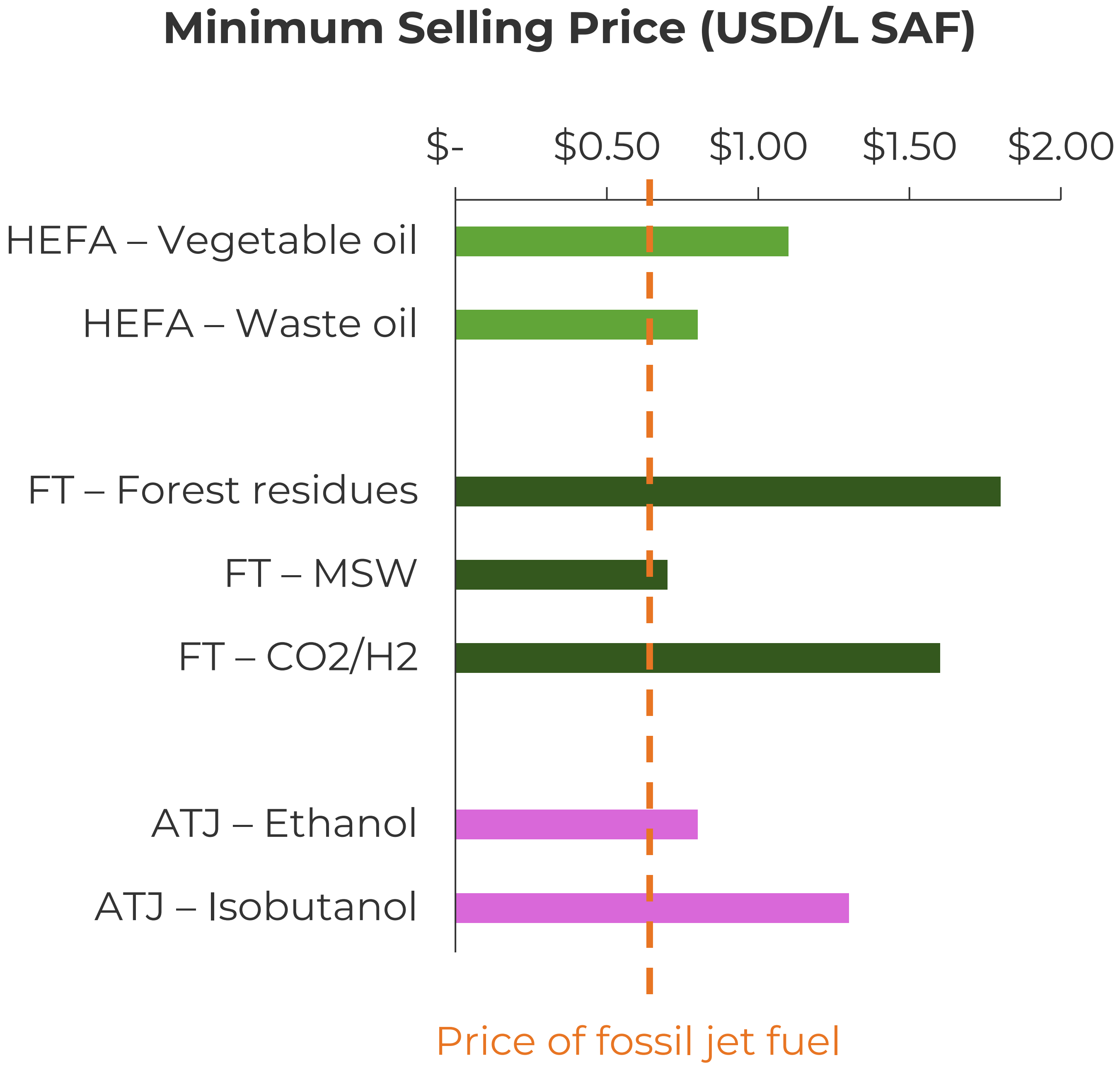
*Feedstock availability for all uses, including non-SAF applications.

Source: ICCT

Feedstock type is the greatest determinant of the carbon intensity of SAF



Cost parity with fossil jet fuel isn’t attainable without heavy subsidies



There is no perfect technology for SAF

HEFA	FT	ATJ
Feedstock: Vegetable oil, waste oil	**Feedstock:** MSW, biomass, CO_2/H_2	**Feedstock:** Ethanol, isobutanol
+ Commercial	+ Sustainable	+ Abundant feedstock
+ Low cost	+ Abundant feedstock	+ Low cost
+ Robust developers	+ Robust developers	
– Unsustainable	– Complex integration	– Unsustainable
– Lack of feedstock	– Expensive	– Lack of developers

+ Scalable technology

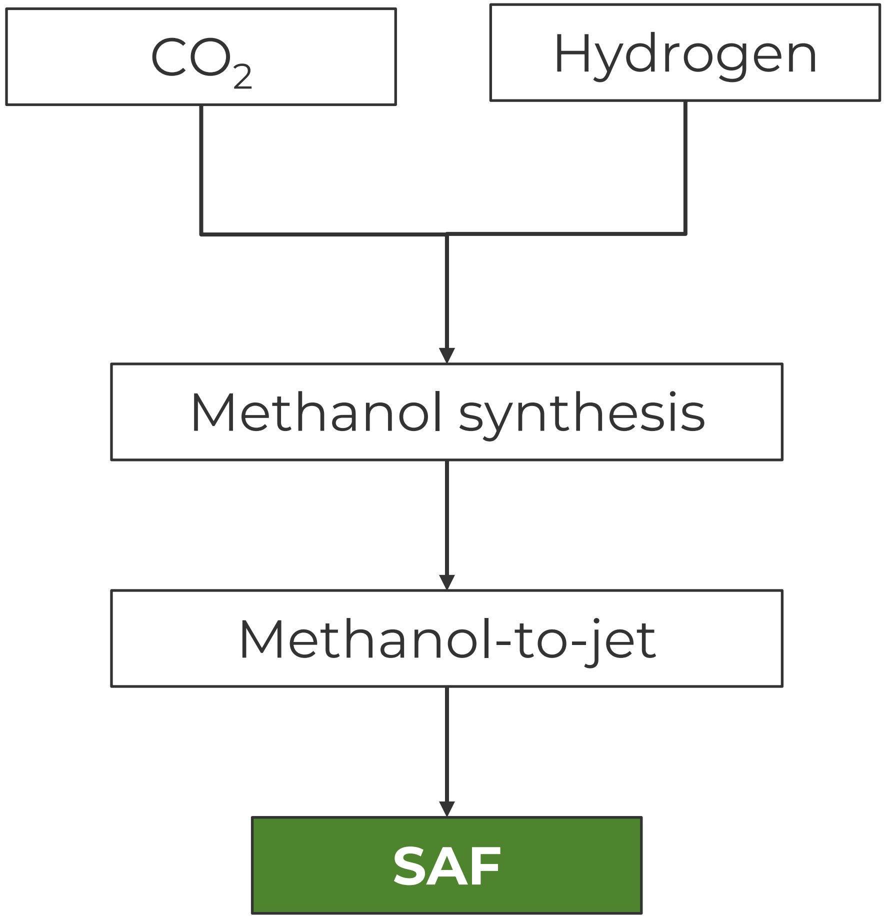
+ Abundant feedstock

+ Sustainable feedstock

+ Low cost

+ Robust developers

METHANOL-TO-JET



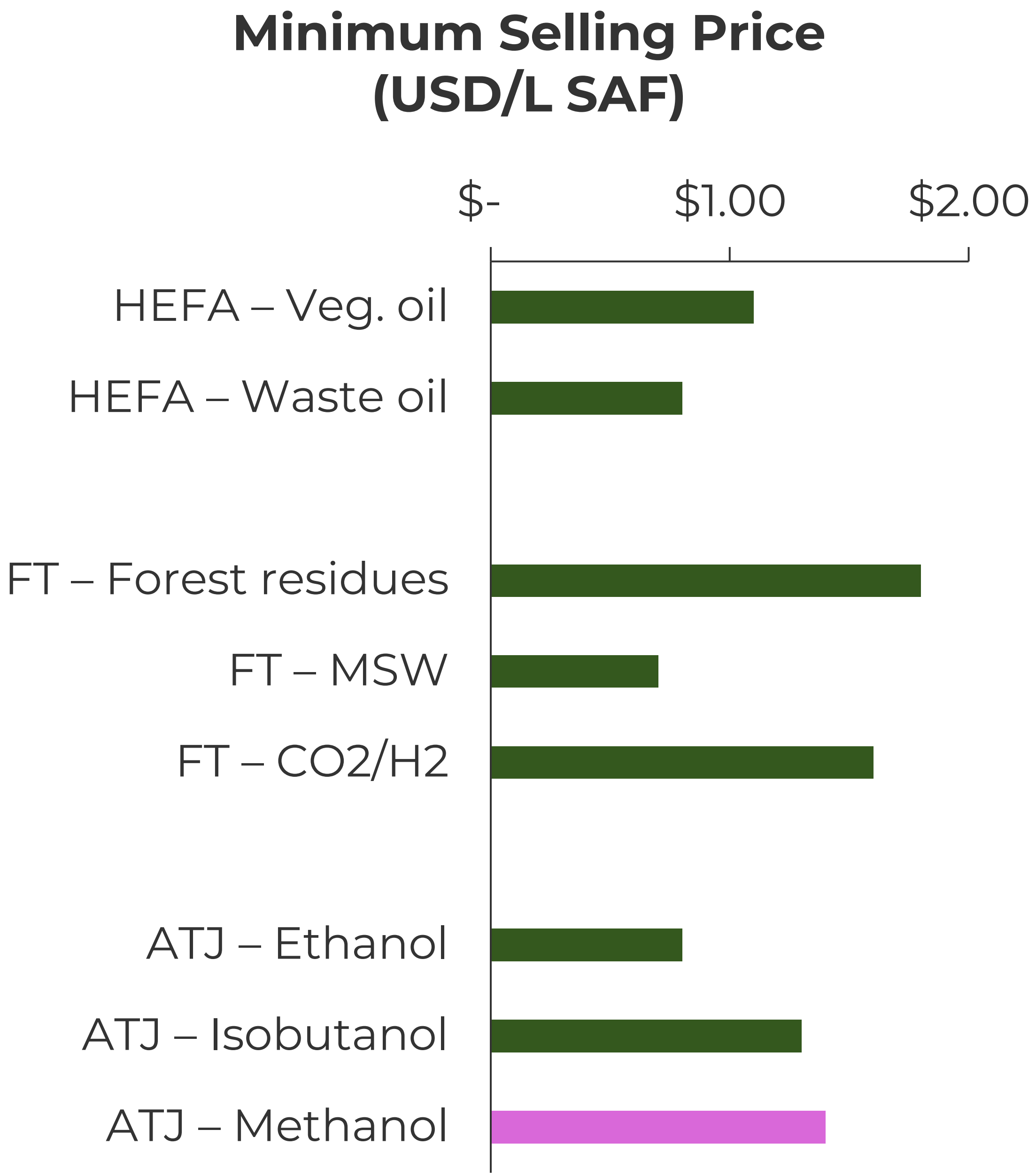
+ Scalable technology

+ Abundant feedstock

+ Sustainable feedstock

+ "Low cost"

+ Robust developers



+ Scalable technology

+ Abundant feedstock

+ Sustainable feedstock

+ "Low cost"

+ Robust developers

ExxonMobil

TOPSOE

uop A Honeywell Company

TotalEnergies

Axens SOLUTIONS

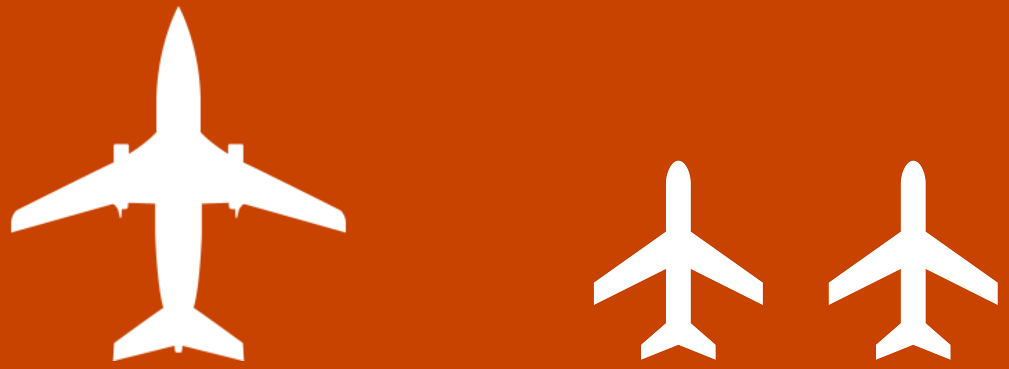
British Airways will use various technologies for net-zero operations

British Airways has five daily flights from London Heathrow to Frankfurt, for which it uses an Airbus A321neo (240 passengers).

LONDON–FRANKFURT

Airbus A321neo

LONDON–FRANKFURT



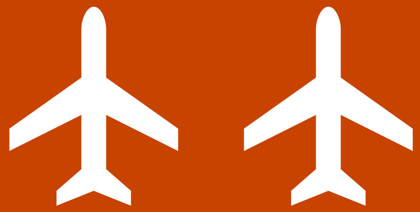
British Airways has five daily flights from London Heathrow to Frankfurt, for which it uses an Airbus A321neo (240 passengers).

Replacing one Airbus A321neo will require two all-electric Wright Electric BAe146s for the same passenger capacity.

British Airways has 8 daily flights from London Heathrow to JFK, New York, for which it uses a Boeing 777 (370 passengers).

LONDON–FRANKFURT

Airbus A321 Neo



Wright Electric BAe146

LONDON – NEW YORK

Boeing 777

British Airways has 8 daily flights from London Heathrow to JFK, New York, for which it uses a Boeing 777 (370 passengers).

Replacing one Boeing 777 will require two all-hydrogen Airbus ZEROe Turbofans for the same passenger capacity.

London Heathrow has a legal cap of 480,000 flights a year and operated at about 475,000 flights pre-COVID.

Airlines switching to an all-electric and all-hydrogen fleet will lead to over-capacity at airports.

Sources: Wired and Heathrow Airport Limited

Key Takeaways

1

SAF will remain the best option to decarbonize aviation

While recent advances in electric and hydrogen aviation are pushing the limits of alternative propulsion technologies, inherent limitations like energy density will limit the range that an electric or hydrogen airplane can fly.

2

Airport capacity will be a limiting factor to electric and hydrogen aviation

Even if the levelized cost of flying all-electric or all-hydrogen aircrafts is cheaper than SAF, there isn’t enough space in airports to accommodate the larger number of such craft needed

3

Methanol-to-jet is the most promising opportunity in SAF

Methanol-to-jet offers the industry an option to produce SAF from CO_2 and hydrogen (which are not inherently limited) through a technology that is less complex than FT.

Thank you

A link of the webinar recording will be emailed within 24–48 hours.

UPCOMING WEBINARS

FEBRUARY 15

How to Translate Consumer Perspectives into a Consumer Health Tech Assessment Roadmap in APAC

FEBRUARY 29

Balancing Consumer Perspectives and Environmental Responsibility in the Adoption of Sustainable Products

---

EMAIL

questions@luxresearchinc.com

VISIT

www.luxresearchinc.com

READ

http://www.luxresearchinc.com/blog/

LuxResearch

@LuxResearch

Lux Research | The Deciding Factor