WE MEAN BUSINESS COALITION

GLOBAL CORPORATE STOCKTAKE: AVIATION SECTOR

October 2023

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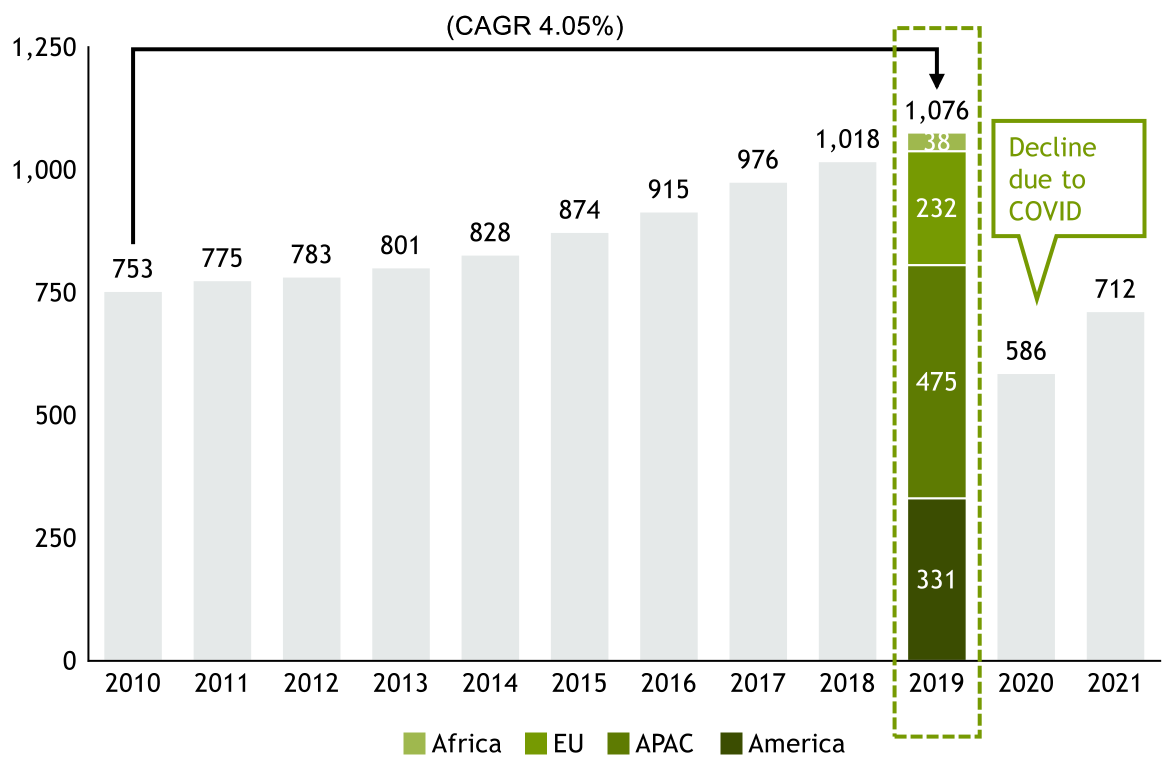
Total emissions from aviation have increased since 2010, with ~67% of emissions in 2019 coming from the EU, US and China alone

Total CO2e from aviation (PAX and Cargo)

Total CO2e from Aviation (in Mn Tons)



Notes: CO2 Intensity is defined as g CO2E per RPK
Source: CO2 emissions from Commercial Aviation, October 2020, ICCT

PAX CO2e from top 10 departure countries (in 2019)

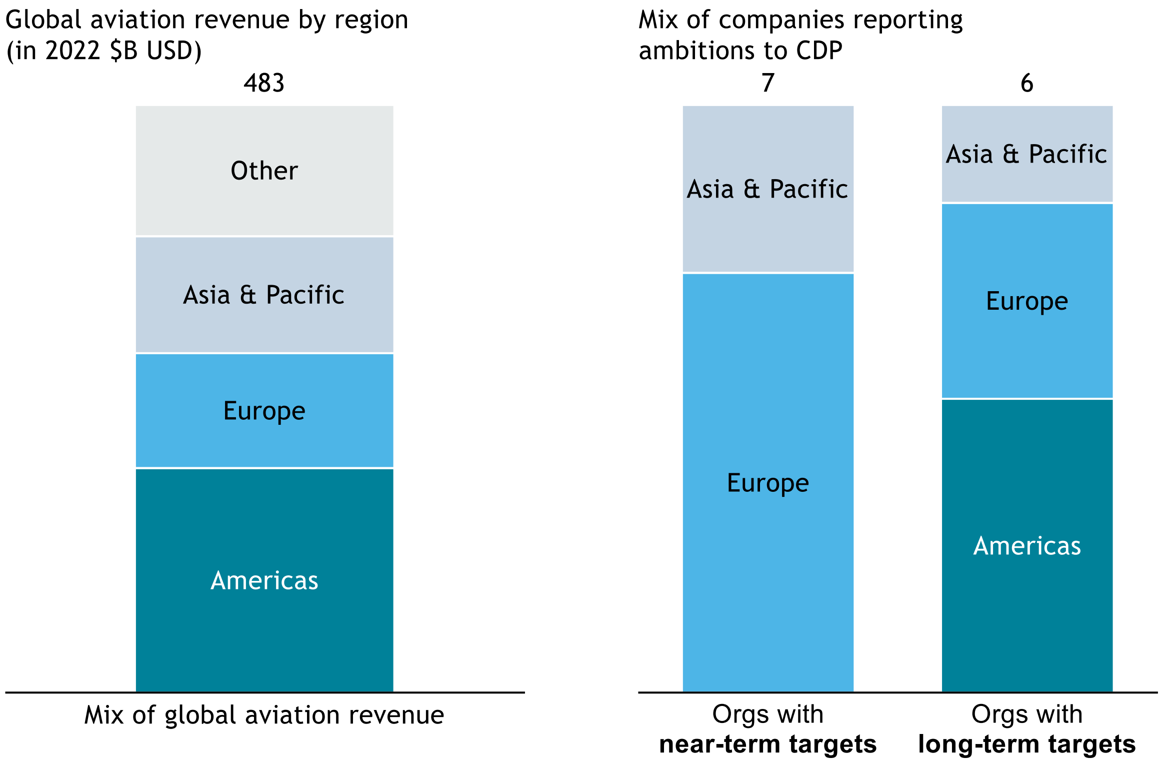
Departure country	% of total CO2e	% of total RPKs	CO2e Intensity
United States	23%	22%	95
China	13%	13%	88
United Kingdom	4.1%	4.2%	87
Japan	3.3%	3.1%	95
Germany	2.9%	2.9%	91
UAE	2.7%	2.8%	89
India	2.7%	2.9%	85
France	2.6%	2.7%	87
Spain	2.5%	2.9%	79
Australia	2.5%	2.5%	90
RoW	41%	41%	89
Total	**752 Mn Tons**	**8,710 Bn**	**90 gCO2e/RPK**

Eu accounts for ~31% of total CO2 emissions

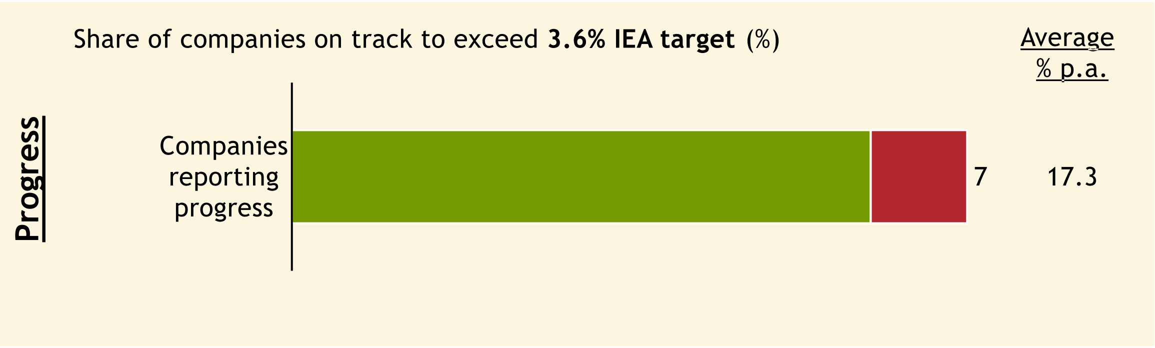
A small fraction of airlines report their CO2 ambitions to the CDP

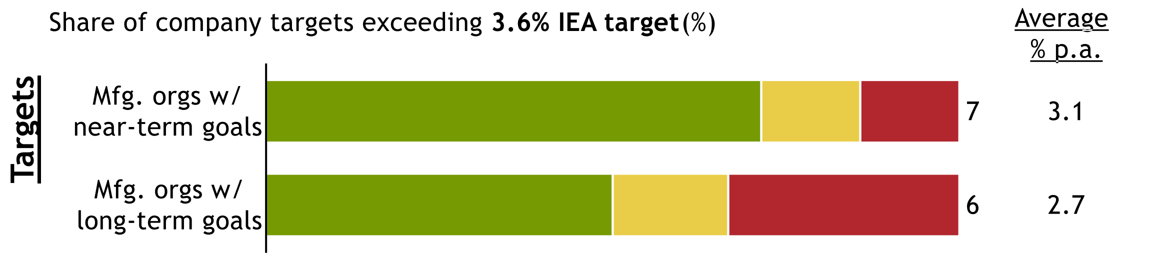
Legend: Company performance vs. Breakthrough *Missed target (<80%)* *Near miss (80-100%)* *Hit target (+100%)*

Companies reporting near-term CDP goals are skewed to Europe; companies reporting long-term goals are balanced



~86% of reporting companies are on track with IEA targets





Note: Annual reduction ambition shows the % reduction a company will need per year to reach their target from the base year (includes underway, new, or revised targets); near-term defined as target year before 2030; IEA Net Zero scenario used in absence of breakthrough targets. Scenario states global CO2 emissions from aviation fall in the IEA NZE from 640 Mt in 2020 to 210 Mt in 2050
Source: 2022 CDP Climate Questionnaire Data; 2022 Global Carbon Project; Euromonitor

There are 4 key fuel technologies in development with the potential to decarbonize aviation

Sustainable aviation fuel (SAF) includes biofuels and e-fuels

	Battery electric	Hydrogen & ammonia	Biofuel	E-fuel
Description	• Electric battery used to supply power to **electric motors**	• Hydrogen can be produced using fossil fuels (called grey or blue H2) or through **electrolysis with renewable energy (green H2)**	• Biofuels are liquid fuels **produced from organic material (biomass)** and can be **used in standard ICE engines** at different blending levels	• Electrofuels are produced through the **synthesis of CO2** (either from direct air capture or from industry emissions) **and green hydrogen**
Technology drivers	• Compared to liquid fuels, current battery technologies have **lower energy density,** and this **impacts the maximum all-electric range of planes** • In recent years, **battery improvements on both cost and energy density** have been achieved - this **development is expected to continue forward**	• To power vehicles, hydrogen can be used in **combustion engines**, **fuel cells** (converting H2 to electricity) or as **ammonia** (H2 and nitrogen) • The **cost of electrolysis and fuel cells is expected to decline** significantly in the future driven by learning and scale, making H2 a viable fuel option	• 1st generation biofuels used crop-based feedstock while **2nd generation technologies use waste and other types of biomass** • Several **2nd generation technologies expected to mature in next 5-10 years**	• E-fuel can be used as **drop-in fuel in planes** • As **electrolysis and direct air capture (DAC) technologies are expected to mature and scale**, e-fuels will become a viable fuel option
Fuel emissions potential	True zero (no emissions)[1]	True zero (no emissions)[2]	Carbon neutral[2]	Carbon neutral[1,2]

Note: 1) Given that the electricity used is renewable, 2) Can be carbon negative with CCS
Source: Literature search

Sustainable aviation fuel is made from bio-based and synthetic feedstocks

	Biofuels				E-Fuels
	1st Generation (1G)	2nd Generation (Commercial)	2nd Generation (Pilot)	3rd Generation (3G)	Power to liquid
Feedstocks	Sugarcane; Corn; Soybean oil; Molasses	Used cooking oil; Animal fat; Municipal solid waste; Food waste; Paper, wood, cardboard	Biomass: Forestry residues; Cereal straw; Corn stover; Manure; Ag prunings & residues; Oilseed crop residues	Algae: Seaweed; Micro-algae	Hydrogen; Carbon dioxide
Description	• **Produced from food crops**, utilizing the starch, sugar and fat in them • Achieve **some GHG savings** compared to fossil fuels by using food crops	• **Produced from non-food feedstock** and **substances used for biomass** after these have been used for their primary purpose • Capable of delivering **significant life-cycle GHG emissions savings** compared to fossil fuels by using non-food feedstock • Examples of forestry and agricultural residues include tree trimmings, bark, wood debris, wood chips, bagasse, husks, chaffe, etc.		• **Produced from Algae**, with higher yield and lower GHG emissions • Fuels that meet the advanced biofuel definition but are **not commercialized yet**	• Fuels produced through the **synthesis of green H2** (using renewable energy) **and CO2** (ideally from direct air capture)
GHG Emissions Reductions	~35-50%	~70-90%	~70-97%	~97%	~90%

Aviation's climate impact extends beyond CO2, with NOx, contrails and cirrus clouds also playing a significant role

Source: Literature search

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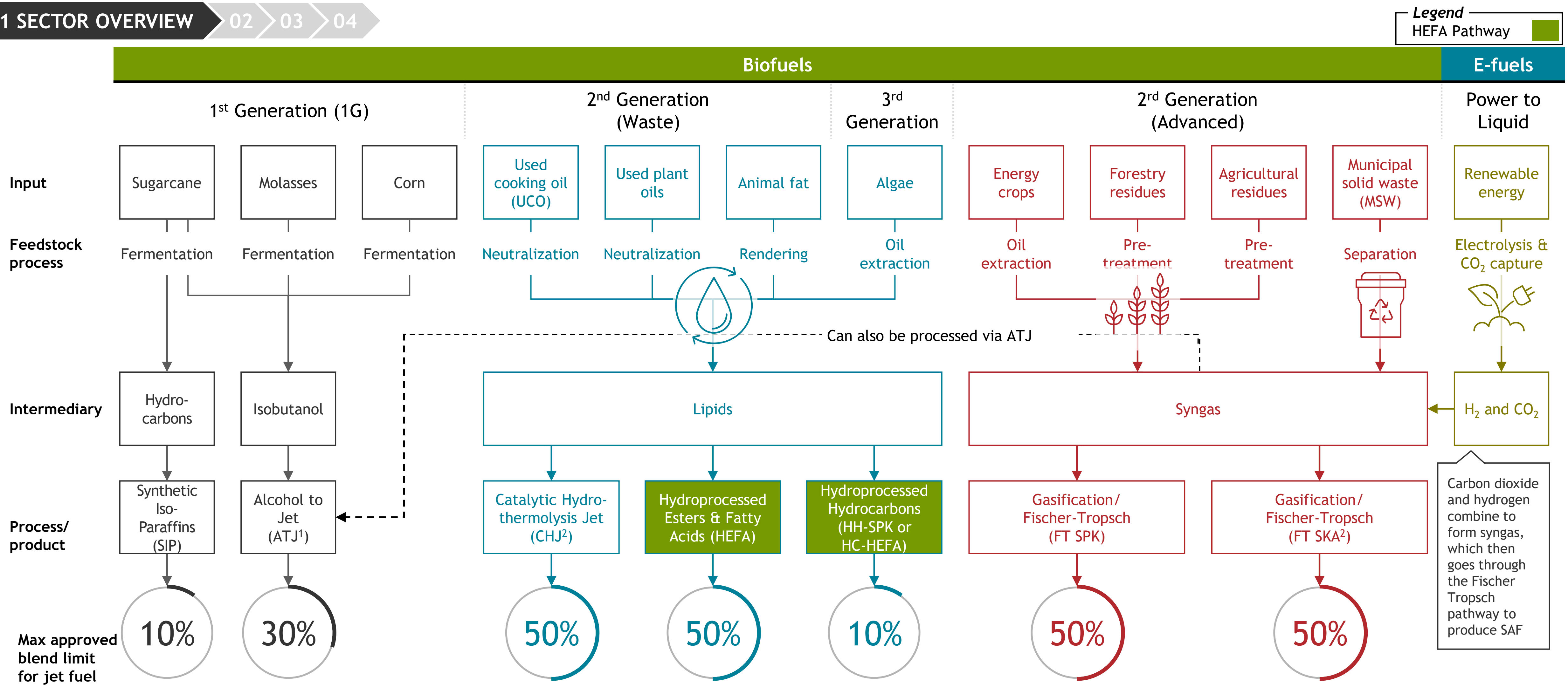
There are 7 approved SAF products, created via a range of processes and inputs, of which HEFA is the most mature pathway



Note: 1) ATJ can also utilize biomass feedstock inputs; 2) Identical to Jet A/A-1 fuel - with regulatory permissions could be 100% "drop in" without blending with traditional jet fuel; all other pathways require technical changes to use without blending
Source: IATA, Bain Analysis, ATAG

The value chains for bioSAF and jet fuel are similar, with feedstock production the key difference between the two

Feedstock production

Production, harvesting, and collection of necessary feedstocks

Harvest feedstock crops

Collect used cooking oil from hotels & restaurants

Fuel production

Processing feedstocks into SAF and blending with conventional jet fuel

Feedstocks processed at production facility into low-carbon fuels

SAF blended with conventional jet fuel and re-certified for compliance

Fuel distribution

Distributing SAF to airports, primarily using pipelines

Fuel stored in airport fuel farms

Low-carbon fuels supplied to the aircraft

	Feedstock production	Fuel production	Fuel distribution
Description	• **Grow and/or acquire** feedstocks • Example feedstocks include vegetable oils, animal fat, corn stover, forestry residues, agricultural residues, algae, and more	• **Process feedstocks into SAF at the production facility and blend** with traditional fossil fuels	• Distribute fuel to the **airport through pipelines** • Trucks or ships are also used in certain cases
Example Players	Metsä, Renewable Energy Group, Sunpine, Stora Enso, Norske Skog, ADM, Waste Connections, Inc., WM, Remondis, Neste, SCA, Raízen, Shell	Neste, Argent Energy, Preem, Cropenergies, POET, Raízen, Shell, ADM, Tropical, bp, Fulcrum Bioenergy, Renewable Energy Group, Eni, TotalEnergies, UPM Biofuels	Raízen, Shell, Tropical, bp, TotalEnergies, Argent Energy

Source: The Polish Alternative Fuels Association (PSPA); Literature search

Executive Summary: The State of the Transition in Aviation

Dimension of sector	Scaling supply of low-carbon fuels	Scaling adoption of low-carbon fuels	Improving fuel efficiency through technology
Future decarbonization scenario	Optimisation of bio feedstocks alongside the commercialization of advanced technologies boosts supply of sustainable aviation fuel	Low-carbon fuels are widely accessible and have come down the experience curve to meaningfully replace consumption of traditional jet fuel	Continued investments in traditional and emerging technologies unlock engine and aircraft efficiencies to optimize usage of low-carbon fuels
Indicators of progress towards accelerating decarbonization	**The share of SAF in jet fuels is increasing rapidly** with the growth of SAF production tripling over the last decade **Feedstock constraints** (e.g., corn, used cooking oil) **and absence of scale economics** (e.g., small scale municipal solid waste collection) create a hard limit on bio SAF supply, while **competition with other biofuel use-cases uses** limit availability of inputs for aviation Low-tech maturity of advanced technology pathways, high CapEx requirements, and fragmented investment across fuel suppliers **slow the commercialization of scalable solutions**	Demand for SAF is materializing, either through **company commitments or regulatory mandates**, despite cost premia As the hydrogen economy scales and underlying technologies go down the experience curve, e-fuels will **decline in costs over time.** Even so, there are **no technologies on horizon with less than 2-3x the cost to produce vs. traditional jet fuel** **Consistent standards and book and claim systems** are emerging, allowing for a global deployment of SAF	**Airlines and airports** are exploring innovative **operational modifications**, such as route optimization and enhanced ground operations, to **minimize fuel consumption** **Fleet renewal has accelerated** as the focus on fuel efficiency and CO2 emissions intensifies. but high CapEx costs pose a barrier for **some airlines** Hybrid fleets are likely to play a role in the medium-term, but **battery density is unlikely to evolve fast enough for full-electric**, while views differ on the role of hydrogen

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For the aviation industry “SAF is the only game in town” and production is scaling rapidly

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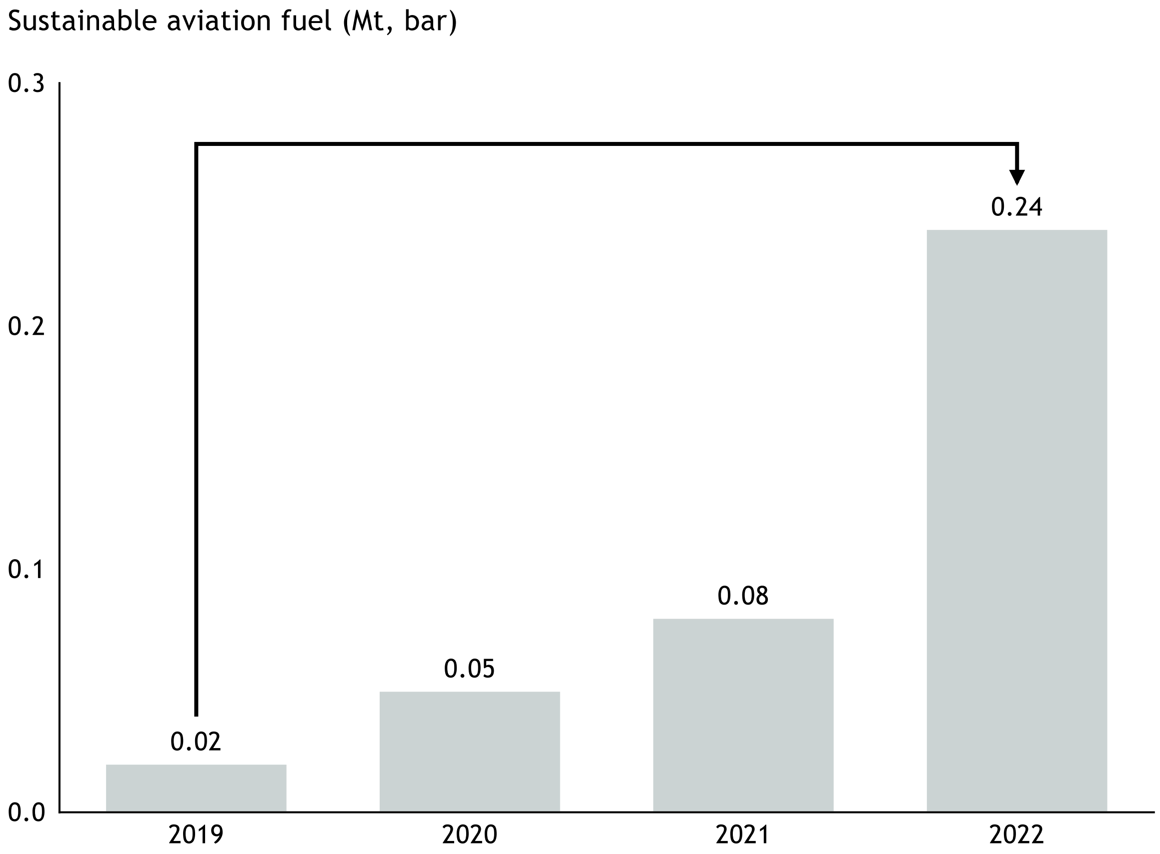
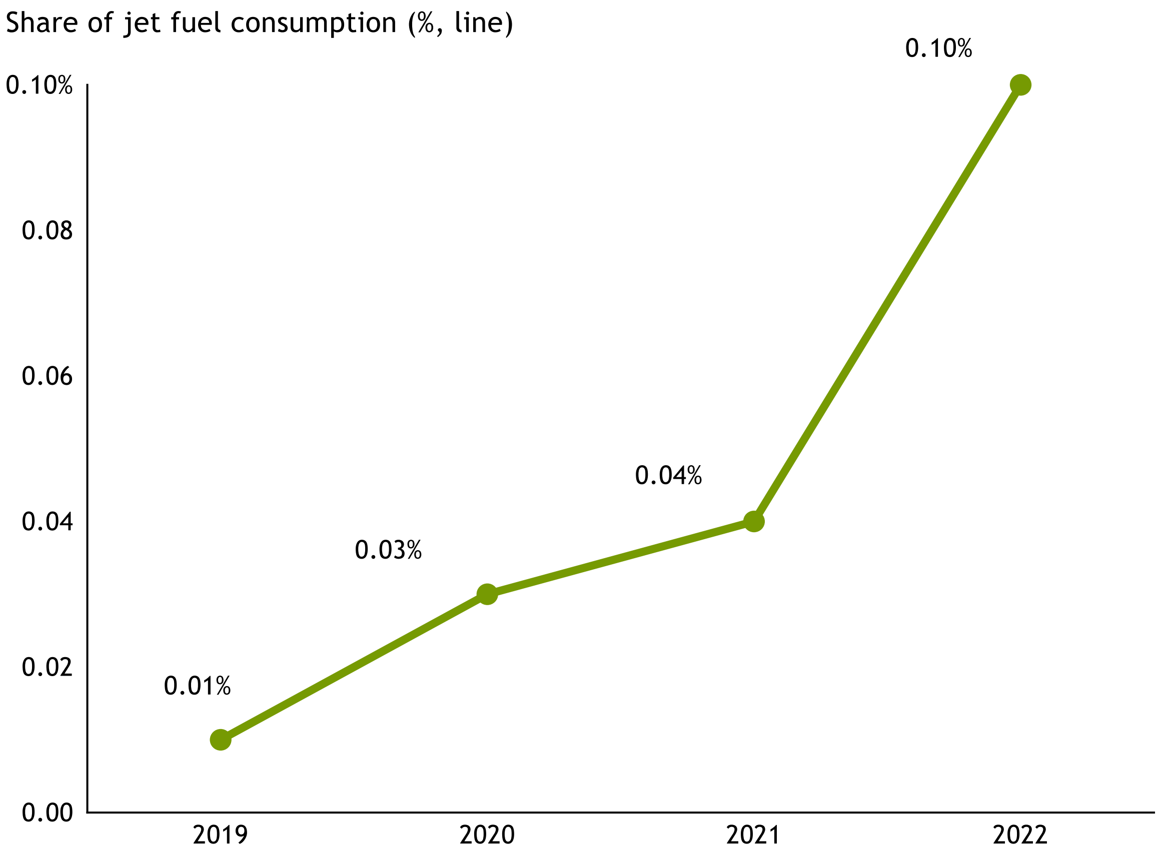
SAF production has increased rapidly, with ~3x growth in 2021-22



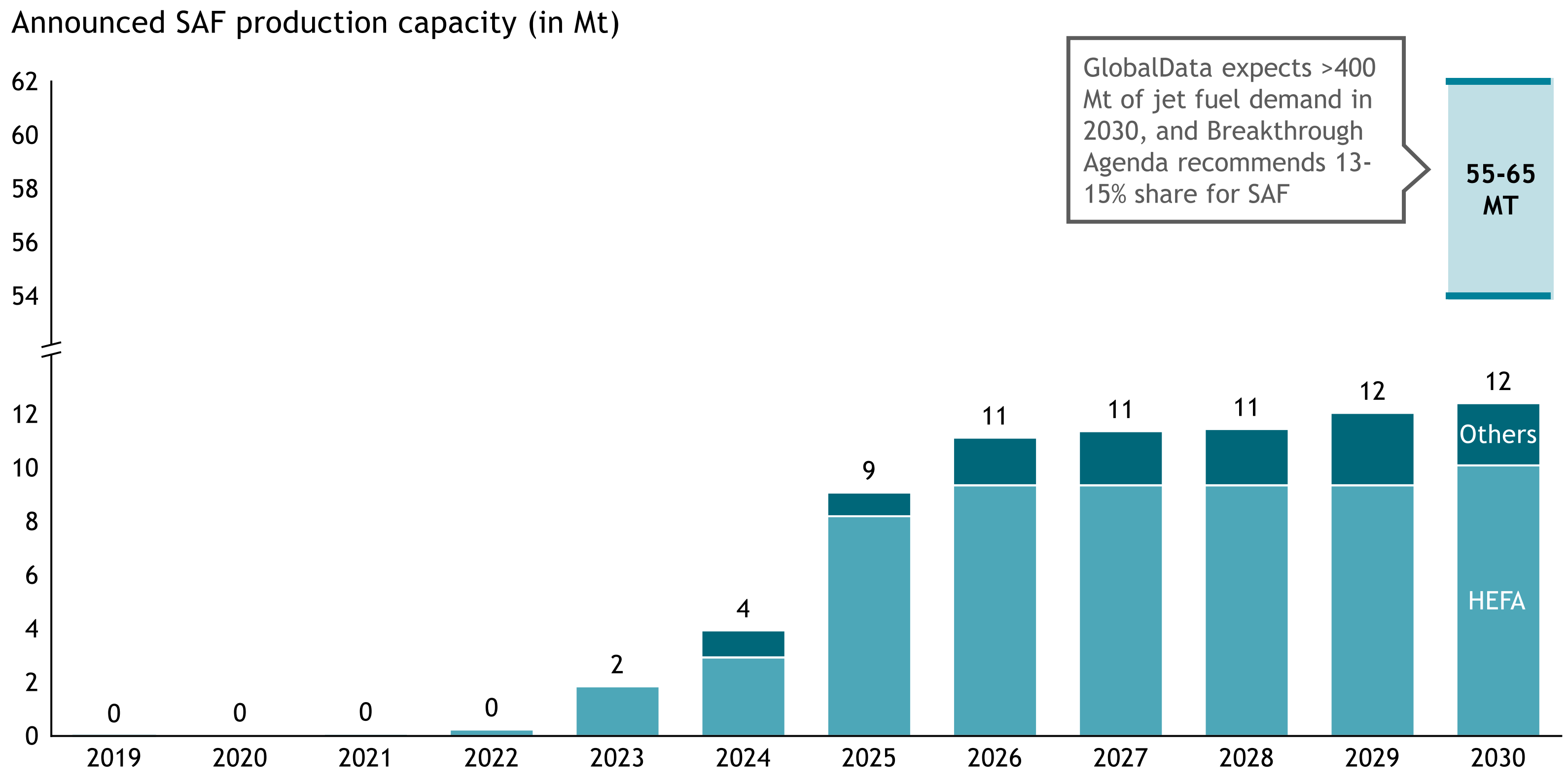
SAF has grown to account ~0.1% of jet fuel demand in 2022



Title quote from Head of sustainability, Airline #2
Source: IEA; Credit Suisse; Global Data; IATA

Projected production capacities currently fall short of Breakthrough Agenda targets; more capacity will need to come online to close the gap in the near-term

Announcements indicate SAF capacity will reach 12 Mt in 2030, short of Breakthrough Agenda's targets of 55-65 Mt and of 37Mt of offtake agreements



Note: Others include Gas to Liquid, Alcohol to Jet, and Power to Liquid; Assumes 100% of factory capacity will be utilized; Dashboard last updated in May 2023
Source: Sustainability Aerospace Together, Boeing; IEA; MPP; Breakthrough; Bloomberg NEF; GlobalData

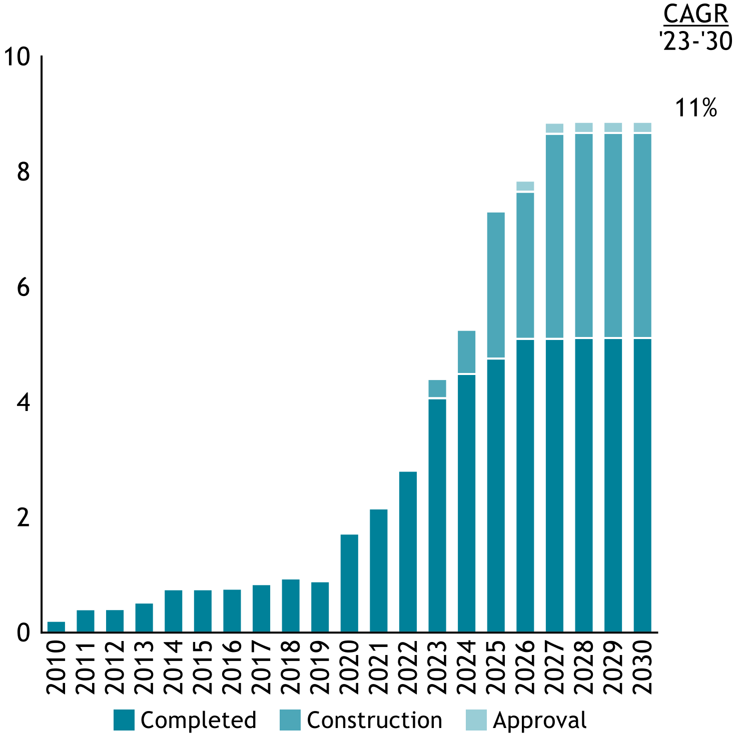
Commentary

- Meeting net-zero targets will require a rapid ramp-up for sustainable aviation fuel **from less than 0.1% of aviation fuel demand in 2022** to 13-15% by 2030, according to the Breakthrough Agenda
- Currently, **37 Mt SAF are under offtake agreements,** spanning durations between 6 months and 20 years
- **Majority of current production** and 80-90% of announced SAF volumes in 2030 **will come from HEFA**, the only pathway at commercial scale today
- **Only ~20% of production from HEFA plants is SAF**, primarily due to policies that incentivize the production of road transport fuels over SAF
- A combination of redirecting additional capacity from HEFA plants and investing in net-new production facilities **will be required to close the gap in the near-term**

1st gen feedstock supply is expected to increase, but not enough to meet targets, particularly if demand from aviation is competing with other sectors

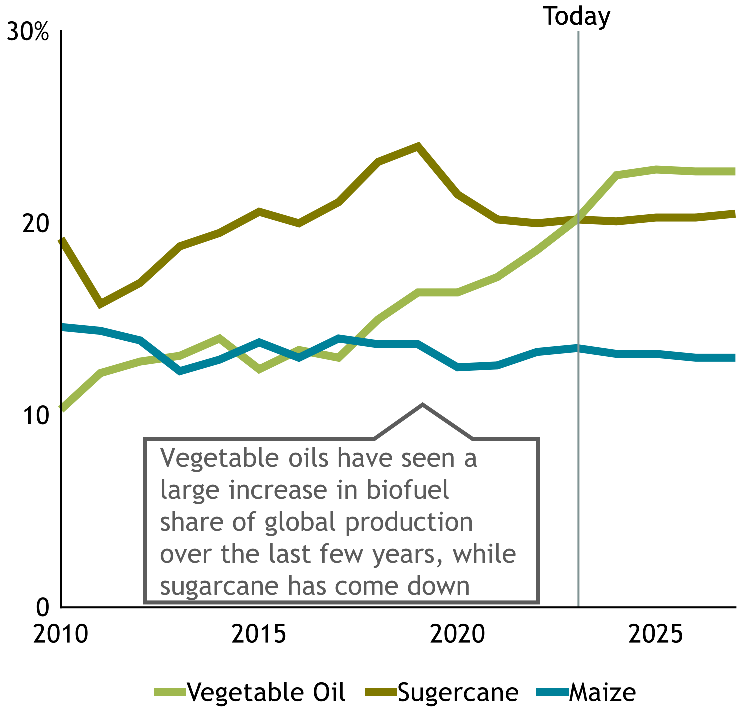
Global biofuel production from 1st gen feedstocks is increasing

Total global biofuel production capacity (Million tonnes per year)



Total share of 1st gen feedstocks has increased over the last few years

Biofuel demand share of global crop production (%, 2010-2027)



Commentary

- 1st gen feedstocks are **under regulatory pressure** (e.g., EU regulation prohibits crop. based biofuel to count towards SAF targets)
- **Emissions reductions 1st gen feedstocks are lower than for 2nd gen feedstock**, estimated at 35-50% vs 70-97%

*"We are committed to **maximizing the production of SAF** - electrification will eventually have major impact on road, the renewable diesel production today is better used by aircraft"*

\- World Energy

*"We are competing with all the transport sectors. We **need to prioritize biofuels for aviation.**"*

\- Head of Sustainability, Airline #1

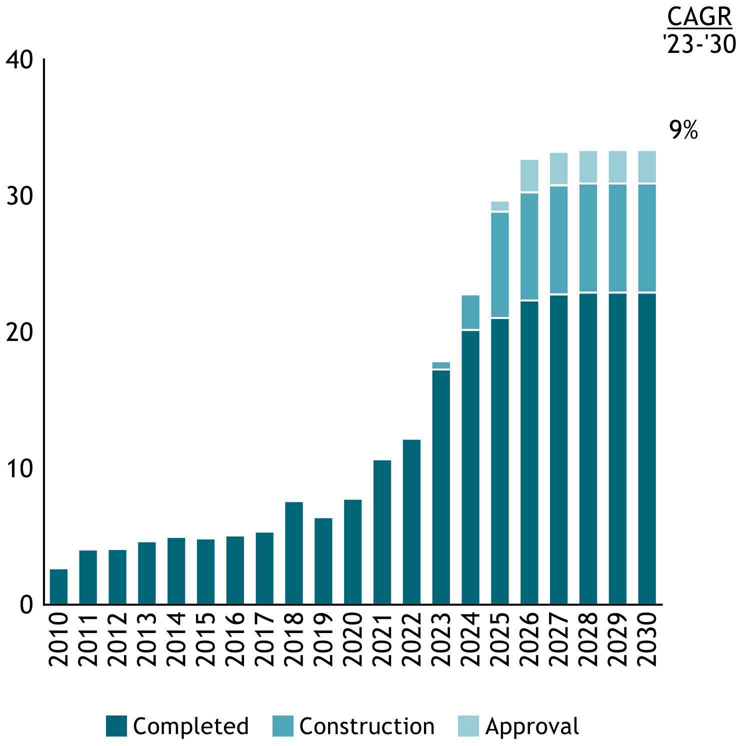
Note: 1st generation feedstocks included: vegetable oil, sugarcane, soybean oil, rapeseed oil, palm oil, corn oil, cooking oil, and canola oil; Includes 10% capacity that uses a mixture of 1st and 2nd gen feedstocks; Excluded facilities where feedstock information is unknown

Source: Global Data; IEA; European Commission; Transport Environment

2nd gen waste feedstocks are commercially viable today, but are limited in supply

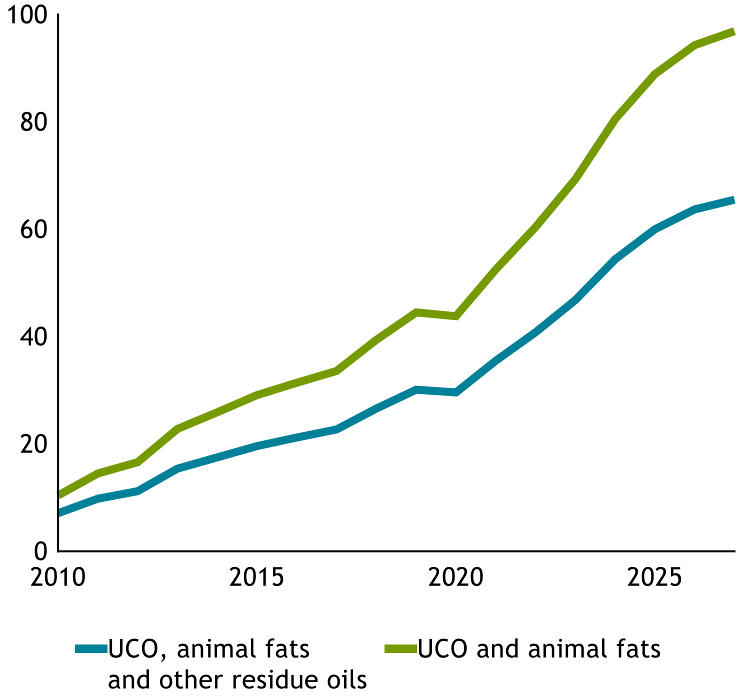
Global biofuel production from UCO, animal fat, and greases is increasing

Global 2nd generation biofuel production capacity (Million tonnes per year)



However, feedstock supply is on trend to reach theoretical limits this decade

Biofuel demand share of global wastes and residues (%, 2010-2027)



Commentary

- Technology is scalable, but UCO and animal fat supply is limited
- UCO has distribution challenges; new supply chains are essential for cost-effective biofuel production
- HEFA process, while cost-effective, has limited potential for further cost reductions due to constraints
- Absent further incentives to direct production to SAF over other fuels (e.g., diesel), **these feedstocks will not be able to close the gap**

*"**Waste oils** can **only make up a small proportion of** the total mix. That's currently what we use."*

\- World Energy

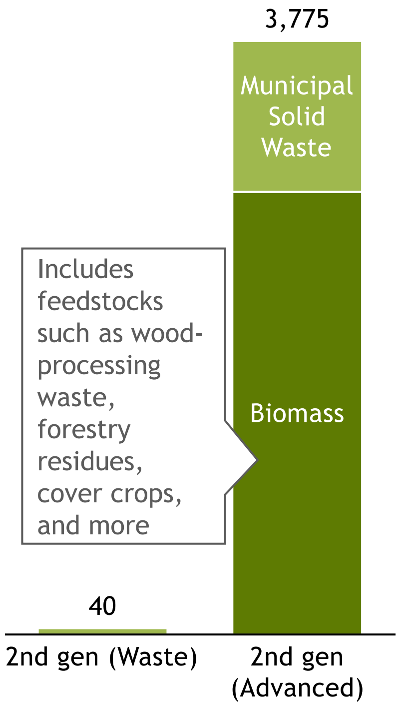
Note: 2nd generation feedstocks included: animal fat, used cooking oil, greases, tallow, yellow grease, gutter oil, non-edible vegetable oil; Includes 90% capacity that uses a mixture of 1st and 2nd gen feedstocks; Includes 90% capacity that uses a mixture of 2nd gen commercial and 2nd gen pilot feedstocks; Excluded facilities where feedstock information is unknown

Source: S&P Global; Global Data; International Council on Clean Transportation; Credit Suisse; IEA; Mission Possible Partnership; Los Angeles Times

2nd generation feedstock supply can be expanded with advanced resources, such as waste and biomass

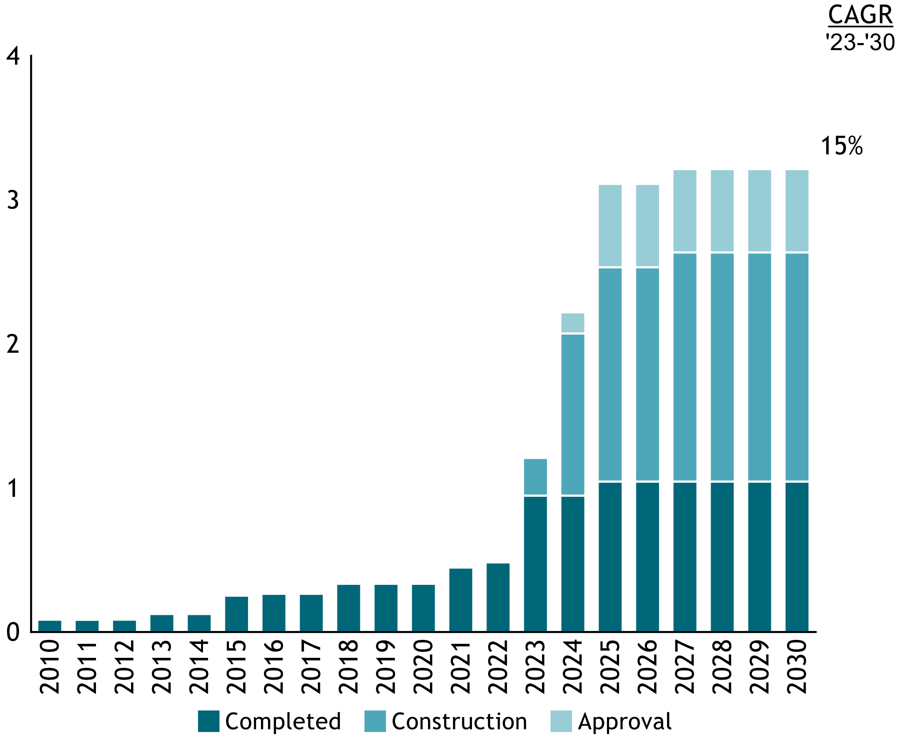
Available feedstock volumes are high

Global feedstock availability for SAF (Mt/year)



Production capacities are expected to grow significantly over the course of this decade

Global biofuel production capacity from waste and biomass (Million tonnes per year)



Technology in early stage of readiness

- **Technology has been proven at small scale**, but heterogeneous feedstocks pose scaling issues
- **SAF produced through these pathways is 2-5x the cost of jet fuel, driven by low** technology maturity and feedstock sorting costs
- **First-of-a-kind SAF** production facilities are higher risk investments, with **significant upfront costs, technology uncertainty and long development timelines.**
- **Public-private partnerships**, like government grants, can mitigate early investment risks

*"We think waste to fuels are **promising but they haven't been proven at scale***

\- World Energy

Note: Title quote is from World Energyl Includes 10% capacity that uses a mixture of 2nd gen commercial and 2nd gen pilot feedstocks; Excluded facilities where feedstock information is unknown
Source: FAO; USDA; World Bank; EPA; McKinsey; IRENA; Nordea; GAO; Global Data; Mission Possible Partnership; Neste; company websites

The industry must address scaling constraints to realize the potential of advanced 2nd generation feedstocks

Feedstock	Scaling challenges
Municipal solid waste	• **Pick-up from multiple collection sites** required to reach scale • **Difficult to scale supply beyond local availability** given low cost-effectiveness of shipping waste around the world
Forestry residues (e.g., pre-commercial thinnings)	• **Scattered locations** means distances can be longer and feedstocks are harder to access, impeding scale advantages • **High water content** and lower energy density **make long transport more economically challenging** – Pre-treatment could occur to densify feedstock, but increases pre-treatment costs
Secondary forestry residues (e.g., saw dust, shavings, tall oil, recovered wood)	• Well-suited for road transport and centrally located, but has **high impurities and contaminants** resulting in variation from batch to batch
Agricultural residue (e.g., manure, corn stover, oil crops, ag prunings)	• **Scattered feedstock supply** across various farms • **Medium water content** and lower energy density **make long transport more economically challenging**

Commentary

- Producers will **have to learn to handle solid feedstock supply,** given majority of feedstocks used at scale today are liquids or gases (e.g., vegetable oils)
- Handling solid feedstocks **is more time consuming, complex, and expensive**
- Many feedstocks **will need sorting to remove debris** (e.g., rocks and dirt) and **treatment to flow through the equipment** easily (e.g., process into uniform shape and size)

Source: IEA IRENA; Clean Skies; Fulcrum Bioenergy; Science Direct; GAO

Biofuel producers are proactively organizing their supply chain, establishing global sourcing platforms for animal fats & UCO, to enhance SAF feedstock supply

NESTE

Case Study: NESTE

Overview

- **Description:** Oil refining and marketing company that produces, refines, and markets oil products, provides engineering services, and licenses production technologies
- **Founded:** 1948
- **Headquarters:** Espoo, Finland
- **Ownership:** Public (Nasdaq Helsinki: NESTE)
- **Revenue (2022):** €25.7 Bn

Targets

2023
- Produce 5.5 Mt of renewable energy
- Reduce the share of conventional palm oil in Neste's raw material inputs to 0%

2024
- Produce 1.5Mn MT SAF per year (1Mn MT currently)

2030
- Reduce GHG emissions incurred by Neste customers by 20 Mt by using sustainable Neste products

Activities

Leading with a clear and achievable feedstock production strategy

- Neste is investing heavily in **strengthening its global feedstock platform** through:
  - Partnerships and M&A operations
  - Direct initiatives (e.g. expansion of footprint of purchasing offices)
  - R&D to explore frontier technologies (e.g. fast/catalytic pyrolysis)
- Neste has a wide and **complete range of raw material** in its portfolio:
  - Animal and fish fat from food industry waste
  - Used cooking and vegetable oil processing waste and residues (e.g., palm fatty acid distillate, spent bleach earth oil, …)
  - Tall oil based raw materials and corn oil (residue from ethanol prod.)

Strength in acquisition path to secure long-term feedstock pathway

- **Neste is pursuing a number of initiatives and partnerships**
  - R&D center in SG bringing renewables prod. capacity to 1 M ton SAF / y; investing in used cooking oil collection system in India
  - Opened office in Melbourne to source renewables in Oceania
  - Collab. w/ Hesburger to recycle UCO produced
  - Searching for new raw material suppliers to join network; launched program for suppliers to sell raw materials directly to them
- **Neste has extensive M&A pipeline for feedstocks**
  - Walco Foods (EU-Irish trader of animal fats)
  - Bunge Loders Croklaan's refinery plant (EU- Dutch producer of plant-based specialty oils and fats) located next to Neste's biorefinery with pipeline connection to Neste's site
  - Agri Trading (US renewable waste/ residue fat and oil trader)
  - Mahoney Environmental (US collector and recycler of UCO)
  - Dutch Count Companies BV's Count Terminal Rotterdam BV (EU-Dutch terminal)
  - IH Demeter B.V. (EU-Dutch animal fats and proteins trader)

Source: Neste, Literature search

The first commercial-scale facilities producing SAF from waste are being commissioned

Case Study: Fulcrum Bioenergy

Overview

- **Description:** Fulcrum Bioenergy is focused on converting municipal solid waste into net-zero carbon jet fuel
- **Founded:** 2007
- **Headquarters:** Pleasanton, CA
- **Ownership:** Private
- **Funding to date:** $281.1M

Targets

2022
- Starts operating Sierra BioFuels plant, the first commercial-scale landfill waste to low-carbon transportation fuels plant

2023
- Delivers syncrude successfully to Marathon Petroleum

2030
- Targeting 10% penetration of 4B gallon US SAF market with 12-13 operational plants

Activities

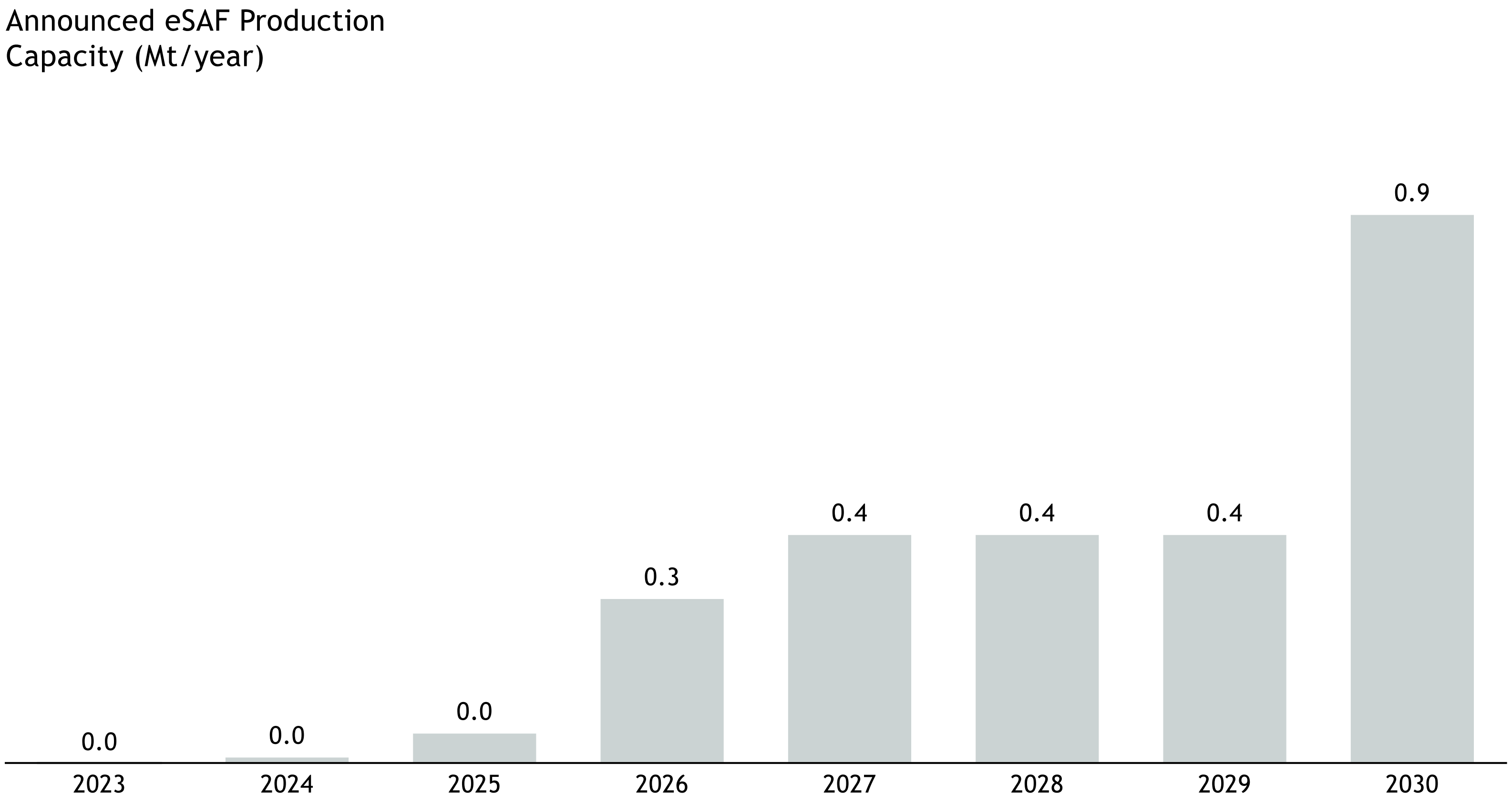
Fulcrum Bioenergy is leveraging strategic partnerships to accelerate SAF production

- **Developed and operating a proprietary, patented and proven process** to convert landfill waste into net-zero carbon transportation fuels using gasification and Fischer-Tropsh technologies
- **Entered long-term waste supply agreements with waste services partners** including Waste Connections and WM to provide necessary feedstock
- **Strategically placed its plants close to feedstock supply to reduce transportation costs**, with its first operational plant – Sierra BioFuels Plant - located adjacent to the WM's Lockwood Regional Landfill, one of the largest landfills in the western United States
  - This also benefits its waste management partners by increasing landfill life by 30-40%
- **Entered long-term offtake agreements with partners in aviation** to sell ~290 million gallons of net-zero carbon SAF annually, including bp, Cathay Pacific, United Airlines, etc.
- Fulcrum **received a $20M grant from the UK Department for Transport** to support the development of 100M liters of low-carbon SAF by 2027, helping fund the establishment of their NorthPoint plant in Chesire
- Fulcrum is **actively developing another** 2 plants in the US and has identified future plant locations

Source: Fulcrum Bioenergy, Literature search

eSAF capacity is expected to increase significantly, but technology readiness for Power-to-Liquid pathway is low

eSAF capacity is expected to increase significantly, scaling to ~0.9Mt by 2030



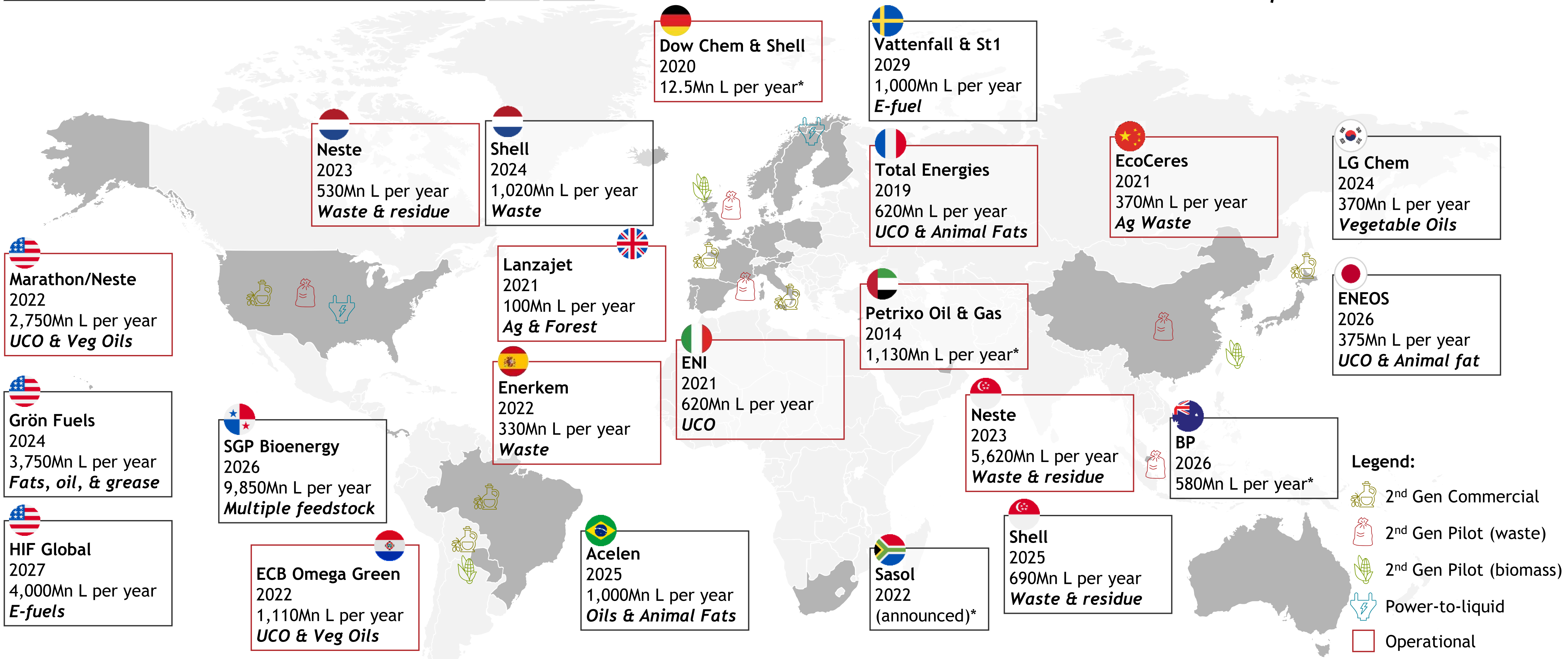
Commentary

- **E-fuels** tap into a variety of CO2 sources, **broadening supply options**
  - **Fossil** – CO2 from industrial activities: Economically viable, abundant but net-positive carbon; proximity to the facility is key
  - **Biogenic** – CO2 from biomass: Economically viable, carbon-neutral; proximity to biomass essential
  - **Direct Air Capture** – CO2 from the ambient air: Scalable, carbon-neutral but energy-intensive with high costs
- **Challenges for e-fuel** deployment include electrolyzer capacity, competition for green hydrogen, costs, and tech readiness
  - E-fuel costs are 3-9x conventional jet fuel; 85-90% comes from renewable electricity generation
  - 85-90% comes from renewable electricity generation
- **Scaling e-fuel supply** will require:
  - Technological advances for commercial scaling
  - Investments to increase supply of green electricity

Note: Title quote by Head of Sustainability, Aviation Company #1
Source: Sustainability Together Aero, Boeing; Bloomberg NEF; Mission Possible Partnership; Global Data – Low Carbon Hydrogen Database

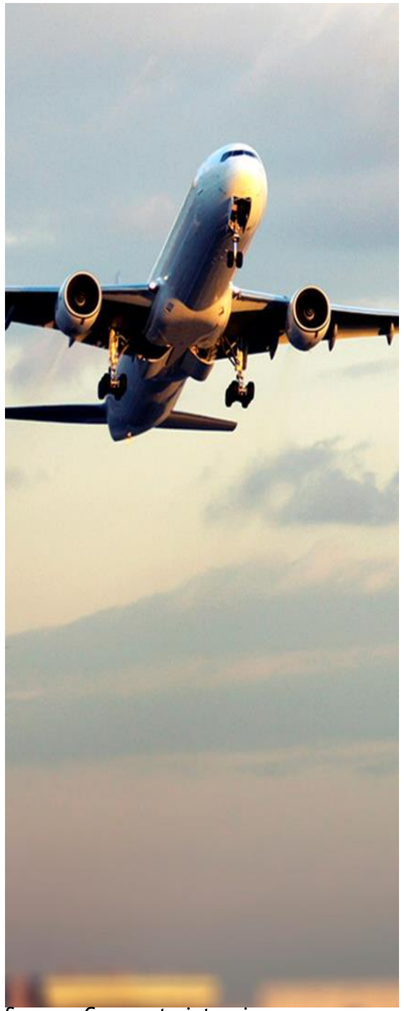
Different players are investing in different feedstocks and pathways

/ NOT EXHAUSTIVE



Notes: *Feedstock not announced; A particular country can follow multiple production pathways and feedstocks; the shading is based on the technology which has received highest investments in that country till now
Source: SAF Production Facilities, ICAO Environment; Sustainability Together Aero, Boeing

As well as physical and technical constraints, the aviation industry is concerned about the overall pace of investment SAF production



*"There is a need for a lot more investment in the production of lower carbon fuels, but the **risks need to be shared**."*

- Head of sustainability, Airline #1

"We need to support the transition of the energy sector."

- Head of sustainability, Airline #1

*"Major fuel producers are lagging in producing SAF. There's currently a vacuum in the fuel supply chain, prompting airlines to step in. **We are seeding the market** because we cannot wait until investment happens organically."*

- Head of sustainability, Airline #2

Source: Corporate interviews

Low-carbon fuels are the most promising way to decarbonize quickly, but limited feedstock availability, immature technology, and high costs limit available supply

Feedstock availability

- **Feedstocks most viable today are limited in volume** (e.g., corn, sugarcane, used cooking oil) with aviation competing with road & maritime transportation for the same supply
- Scaling availability of 2nd gen feedstocks, such as municipal solid waste, will be challenging given **increasing logistics costs as demand expands beyond local supply**
- While e-fuel feedstock supply is theoretically infinite, **near-term supply of green hydrogen, green electricity, and carbon dioxide from DAC is extremely limited**

Technology readiness

- Technology for 2nd gen feedstocks with highest available volumes (e.g., municipal solid waste, biomass) is still at the development and deployment phase, with **production proven at small scales only and commercial scalability still uncertain**
- **E-fuels have the lowest technological readiness of all SAF pathways available**, with e-fuels only at the 'development' phase today

Commercial viability

- **High CapEx costs for production facilities** and high OpEx costs for sorting heterogenous feedstocks hamper growth of low-carbon fuel production
- Divergent funding across geographies for the large CapEx investments required to buildout SAF **risks market fragmentation and subscale investments for each pathway**

Scaling supply of low carbon fuels will require supporting production and scaling through international coordination

Support production of more sustainable SAF

- Leading governments can support the longer-term development of SAF through **targeting price support and R&D funding on advanced biofuels and synthetic fuels**
- Policy support such as **tax exemptions and production incentives are most effective when they mirror the lifetime of a project** and can improve the bankability of investments
- In the case of early-stage technology such as synthetic fuels, **contracts for difference can play an important role in helping to de-risk first of a kind investments**

Scaling production through international coordination

- **Multilateral approaches to aviation are needed** to ensure investment is targeted towards those geographies where bio feedstock is most abundant or with the highest potential for synthetic fuels
- Stronger international coordination is also needed to align measures to **ensure the sustainability of feedstocks, harmonize common approaches to sustainability and GHG intensity assessments,** and prioritize the use of limited biofuels for aviation

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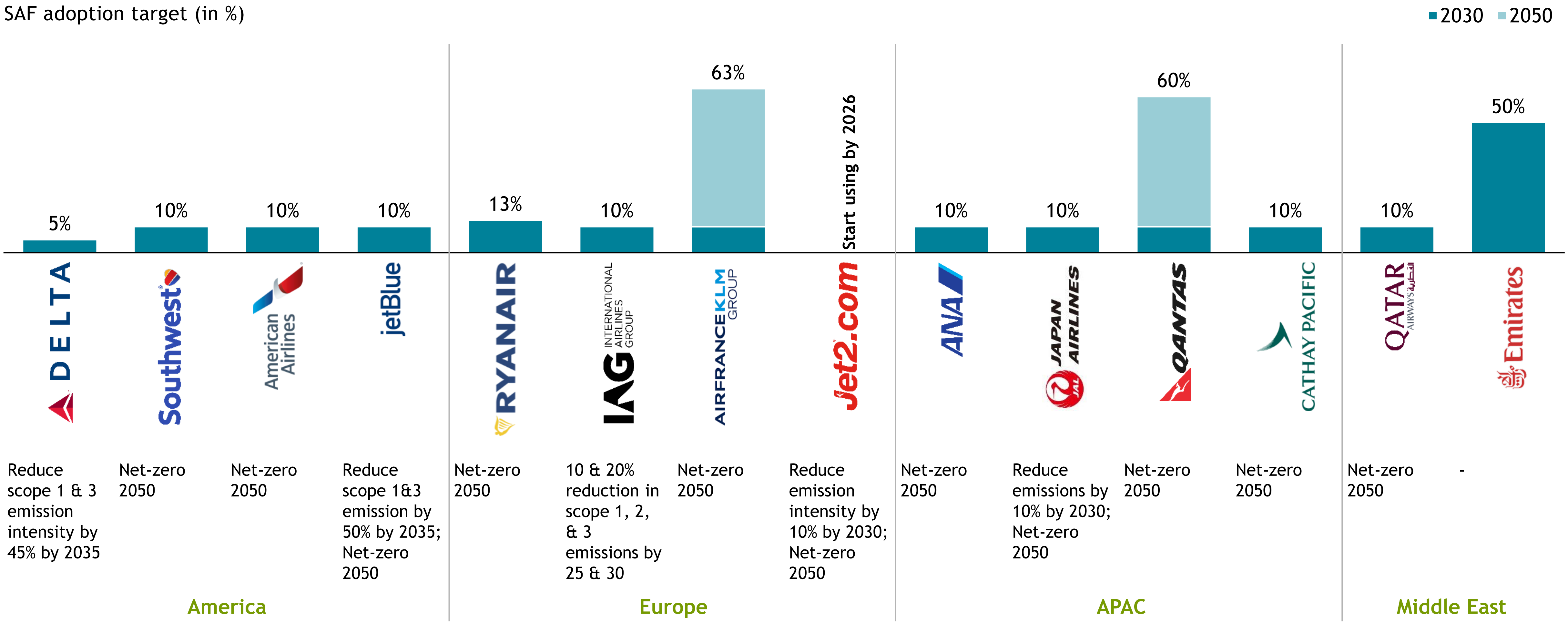
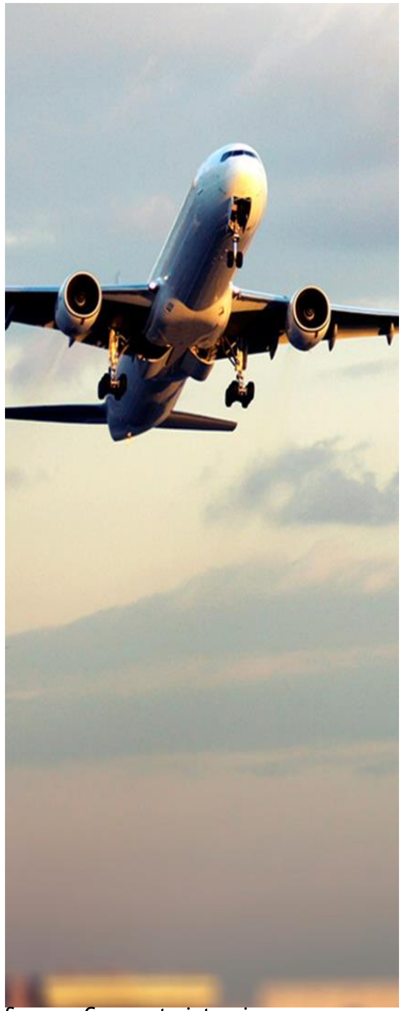
“Multiple airlines have issued SAF targets - a few heroic ones are even going beyond the mandates“



Note: United Airlines, Lufthansa, EasyJet, Wizz Air, China Southern Airlines, Singapore Airlines, and Etihad have issued emission reduction and net-zero targets, however, have not yet issued any SAF adoption targets; Title quote by Head of sustainability, Airline #1

Source: Sustainable Aviation Fuels Primer - Credit Suisse, March 2023

Corporate contracts and carbon markets can be important for risk sharing – particularly for smaller or emergent suppliers



*"We are securing customers beyond airlines. We created a mechanism so that corporates could buy credits without having to own physical fuel. This is important for us because they are taking the market risk. Contracts with large-scale corporate clients with fixed revenue streams allows us to **secure lower cost financing, make investments and grow more rapidly**."*

- World Energy

"Subsidies at scale may be difficult for governments but voluntary markets can help enable investment outside the US and EU, enabling technology transfer and ultimately reducing costs."

- Head of Sustainability, Airline #2

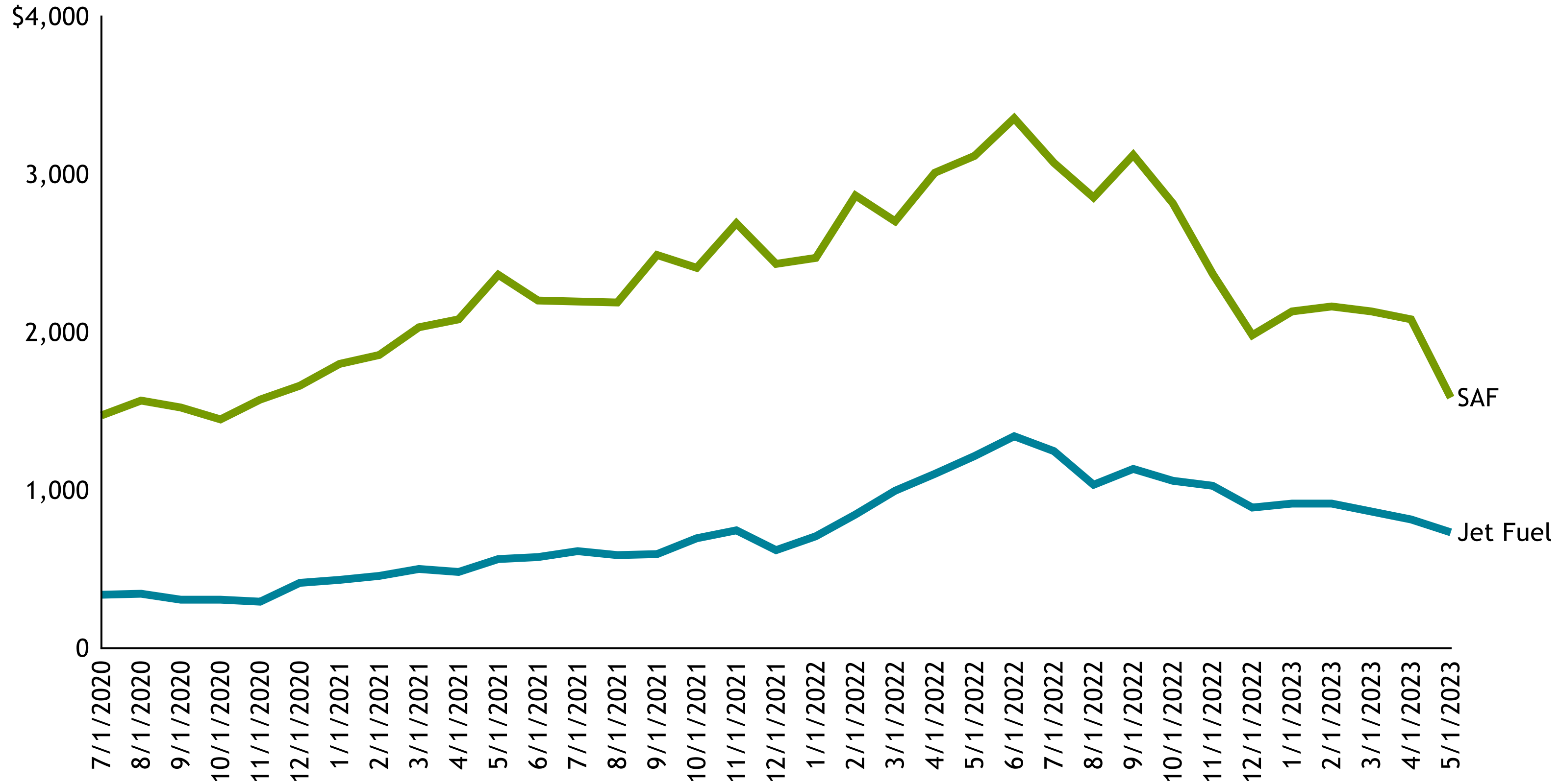
*"Aviation is low margin business, they will be under **enormous stress if the competition doesn't move together**, so we need more members of the supply chain involved in creating voluntary demand."*

- World Energy

Source: Corporate interviews

SAF has consistently been 2-3x as expensive as jet fuel

Price of sustainable aviation fuel vs. jet fuel (in $)



Note: SAF pricing is based on fuel delivered to the Northwest Europe
Source: European Airlines & Aerospace, JP Morgan (November 2022), S&P Global Platts, Bloomberg Finance L.P. (May 2023)

"Still don't see that people are to pay for greener fuels [consumers] – but someone needs to pay

- Head of Sustainability, Airline #1

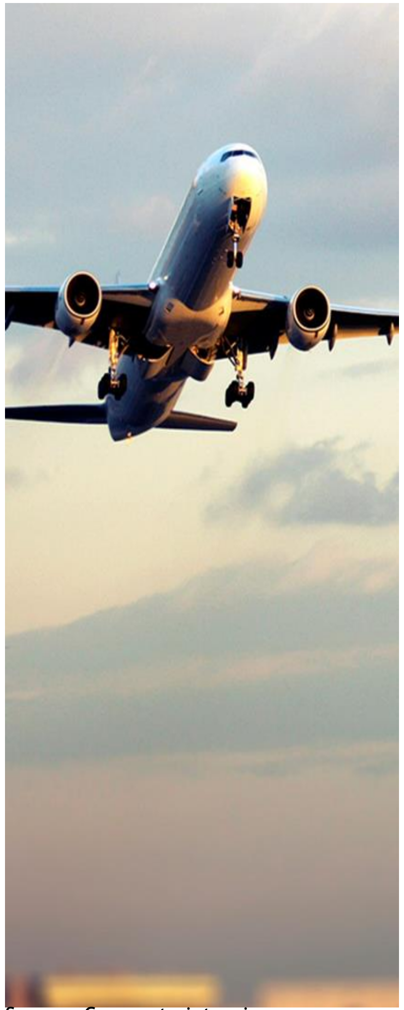
"There's no doubt that SAF is expensive, but mandated volumes are only 2%, that means the aggregate premium is not prohibitive, providing there's no competitive distortion"

- Head of Sustainability, Airline #2

"There has historically been a low willingness to pay for SAF, but as awareness increases that this is the only solution, we see increased acceptance to pay the price premium"

- World Energy

Given cost barriers, industry view policy as essential important for enabling the adoption of SAF - with a need to supplement mandates with supply side policy



*"Policy, policy, policy.. **Regulation is plugging the gap** – this is not optional any longer and we are starting to see serious investment"*

- Head of Sustainability, Airline #2

*"**Policy certainly is really important** – in the US, we've been able to rely on the Renewable Fuel Standards which has been around for over 15 years, the California low carbon fuel standard, which also has a long implementation date, and then the blenders tax credit"*

-World Energy

"The UK has a 10% SAF mandate by 2030, but that doesn't necessarily drive investments in plants"

- Head of Sustainability, Airline #2

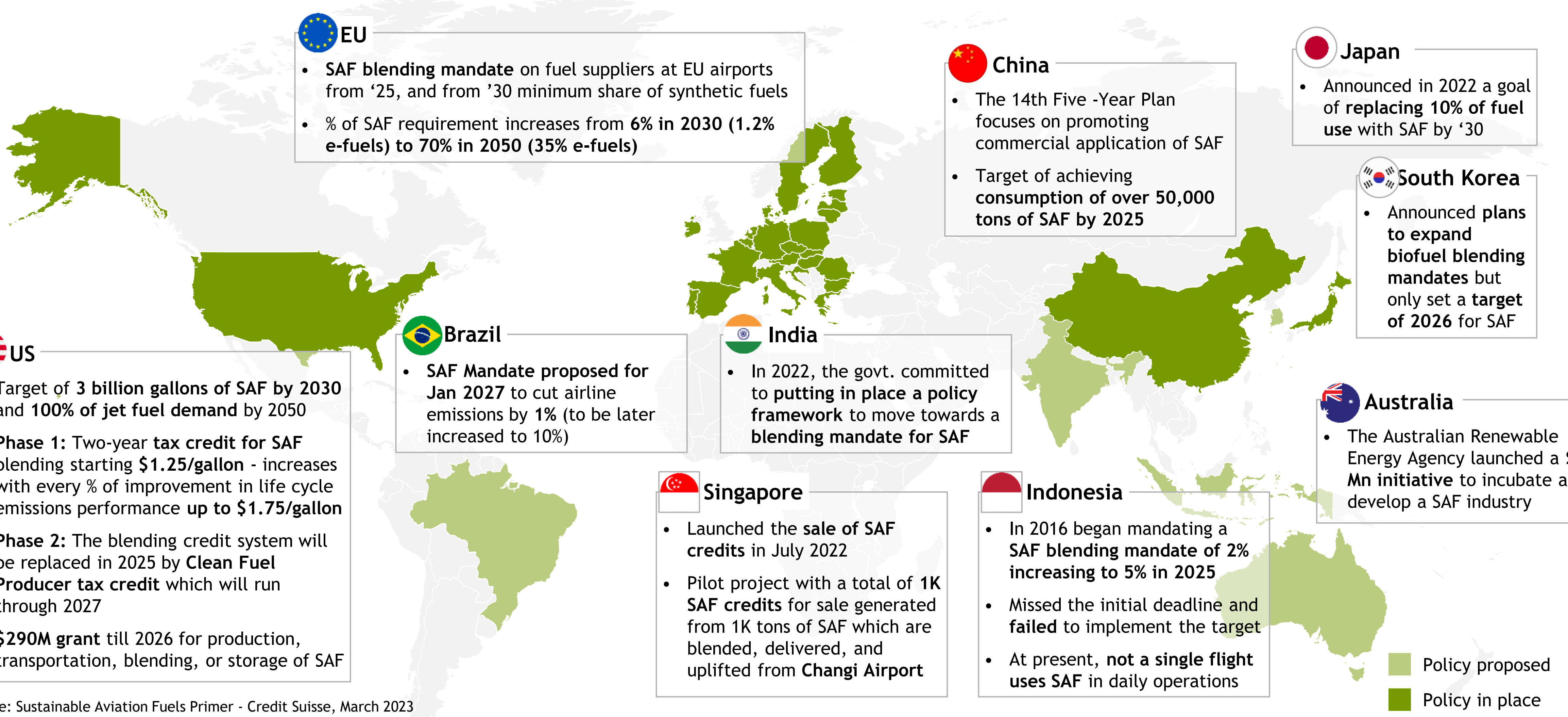
*"A system based on only on **mandates will be supply constrained**, so won't necessarily reward efficient producers."*

-World Energy

Source: Corporate interviews

The EU and US have adopted strong policies to increase the uptake of SAF, with aviation markets in APAC likely to follow, increasing regulatory demand for SAF

/ NOT EXHAUSTIVE



EU
- **SAF blending mandate** on fuel suppliers at EU airports from ‘25, and from ’30 minimum share of synthetic fuels
- % of SAF requirement increases from **6% in 2030 (1.2% e-fuels) to 70% in 2050 (35% e-fuels)**

China
- The 14th Five -Year Plan focuses on promoting commercial application of SAF
- Target of achieving **consumption of over 50,000 tons of SAF by 2025**

Japan
- Announced in 2022 a goal of **replacing 10% of fuel use** with SAF by ‘30

South Korea
- Announced **plans to expand biofuel blending mandates** but only set a **target of 2026** for SAF

US
- Target of **3 billion gallons of SAF by 2030** and **100% of jet fuel demand** by 2050
- **Phase 1:** Two-year **tax credit for SAF** blending starting **$1.25/gallon** - increases with every % of improvement in life cycle emissions performance **up to $1.75/gallon**
- **Phase 2:** The blending credit system will be replaced in 2025 by **Clean Fuel Producer tax credit** which will run through 2027
- **$290M grant** till 2026 for production, transportation, blending, or storage of SAF

Brazil
- **SAF Mandate proposed for Jan 2027** to cut airline emissions by **1%** (to be later increased to 10%)

India
- In 2022, the govt. committed to **putting in place a policy framework** to move towards a **blending mandate for SAF**

Australia
- The Australian Renewable Energy Agency launched a **$30 Mn initiative** to incubate and develop a SAF industry

Singapore
- Launched the **sale of SAF credits** in July 2022
- Pilot project with a total of **1K SAF credits** for sale generated from 1K tons of SAF which are blended, delivered, and uplifted from **Changi Airport**

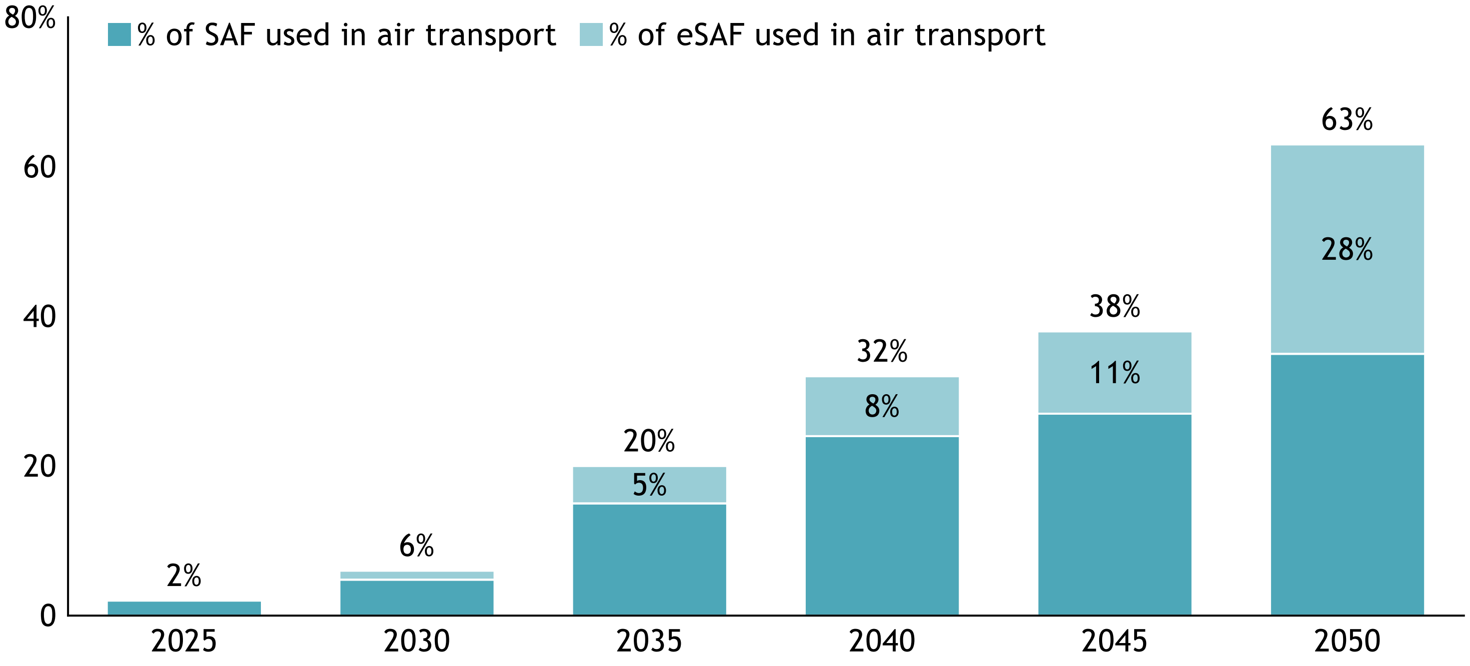
Indonesia
- In 2016 began mandating a **SAF blending mandate of 2% increasing to 5% in 2025**
- Missed the initial deadline and **failed** to implement the target
- At present, **not a single flight uses SAF** in daily operations

Source: Sustainable Aviation Fuels Primer - Credit Suisse, March 2023

EU's ReFuelEU Aviation regulations drive demand-side policy for SAF through blending mandates

EU enforces blending mandates for SAF and e-Fuels starting 2025

Minimum share of SAF (% of all fuel)



EU SAF blending mandates

- Beginning 2025, fuel suppliers at EU airports must blend SAF; by 2030, this blend must include synthetic fuels
  - Mandate covers all planes at major EU airports[1], inclusive of non-EU airlines
  - Non-compliance will result in stringent penalties
- Planes must refuel to 90% capacity for their subsequent flight at EU airports
- Only certified biofuels that meet RED standards are acceptable

The good news is that mandates are all on volume uplift – so competitive distortions are limited. Everyone is affected. But it does mean ***travel to and from Europe and within Europe is more expensive.*** *"*

- Head of sustainability, Airline #2

Note: 1) Proposed to include airports where passenger traffic > 1 million passengers, or where freight traffic was higher than SAF mandates already in place in France, Sweden and Norway 100,000 tonnes in a reporting period
Source: ReFuel EU Aviation initiative report

“There is some incentive in the US to use SAF today, but it needs to be expanded and extended to be effective in driving adoption"

US aims to boost SAF supply 600x by 2030 through subsidies and 100% jet fuel by 2050

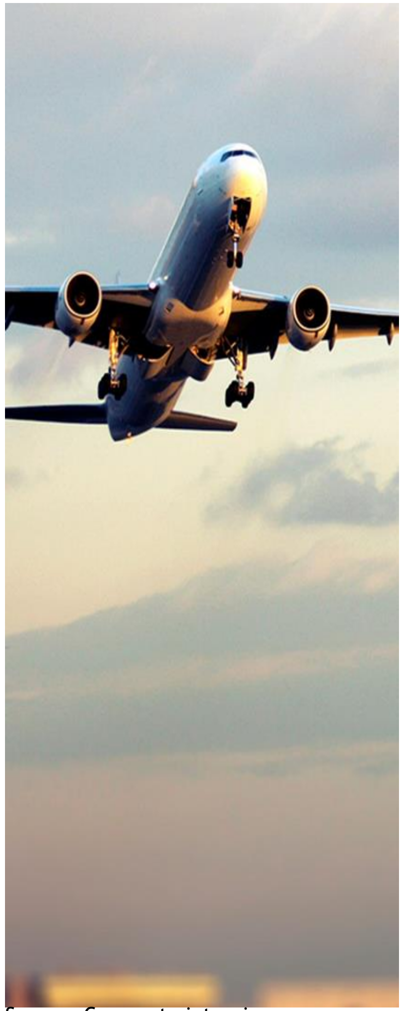
- **Objective: Produce 3 billion gallons** of SAF per year by 2030 and **100% of jet fuel demand** by 2050
- **Phase 1: Two-year tax credit for SAF blending** starting at **$1.25/gallon, and** increasing with every % of improvement in life cycle emissions up to $1.75/gallon
  - SAF must meet minimum reduction of 50% in lifecycle greenhouse gas emissions to qualify for credit
- **Phase 2:** The blending credit system will be replaced by the **Clean Fuel Producer tax credit from 2025-2027**
  - Factors determining SAF credit: a) $1.75 Base Credit, adjusted for inflation; b) Emissions Factor for full lifecycle GHG emissions
- Allocates funding for **alternative fuel & low-emission aviation technology program**
  - **$290 million** grant until 2026 for production, transportation, blending, or storage of SAF and low-emission aviation technology
- **States are running their own incentive programs,** including California, Oregon, Washington, Illinois, New York, Minnesota, and New Mexico

US may establish a different accounting methodology for SAF emissions reductions that will impact the use of 1st generation feedstocks

- SAF subsidies **only apply for fuels that deliver a minimum reduction of 50%** in lifecycle greenhouse gas emissions
- Congress is **divided over whether SAF derived from corn-based ethanol and other agricultural crops should qualify** for these credits
- The primary decision point is **the accounting methodology**, with two options available today
  - CORSIA – Carbon Offsetting and Reduction Scheme for International Aviation, created by the United Nations International Civil Aviation Organization and the current methodology mandated by the IRA
  - GREET – Greenhouse Gases, Regulated Emissions and Energy use in Transportation, created by the US Department of Energy
- CORSIA is more likely to exclude ethanol-based SAF from qualifying for subsidies than GREET **because of the way it evaluates indirect land-use change emissions**
  - Land use change emissions are caused by the displacement of existing farmland or natural vegetation to grow crops for fuel
- Major environmental organizations, including RMI and EDF, **recommend CORSIA’s more holistic methodology** while the ethanol industry and farm state lawmakers **advocate for GREET**
- The decision has not been finalized, and is **slated to become public in September**

Note: PTC = Production Tax Credit; ITC = Investment Tax Credit; CHTC = Clean Hydrogen Tax Credit; CCTC = Carbon Capture Tax Credit; H2 = Hydrogen; CC = Carbon Capture; Title quote by Head of sustainability, Fleet operator #4
Source: Joint Committee on Taxation, Congressional Budget Office Estimated Budgetary Effects of the Inflation Reduction Act, Congressional Research Service, Congressional Progressive Caucus Center; Bain IP Commission

Policy certainty - which matches the timeline of assets - can help increase investor confidence



“Subsidies are helpful but if the horizon is too short – as it is with the blenders tax credit, banks won’t even include it as part of the picture in corporate lending. We need supportive ***policy which matches to the asset lifespan to investment****, so we could bank on the numbers.”*

-World Energy

Source: Corporate interviews

US and EU have launched various policy measures in the form of standard setting and subsidies to support eSAF

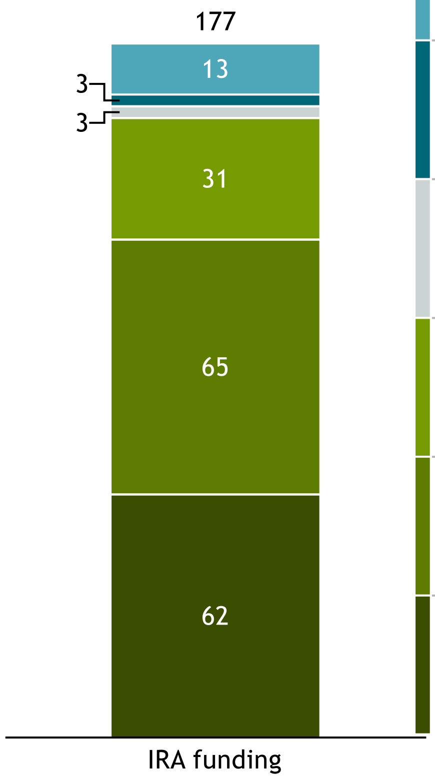
EU has instituted blend mandates to drive adoption

- EU has established a **minimum share of e-fuels from 2030 onwards**
  - **1.2% of total jet fuel demand** must be met from e-fuels in 2030 increasing to **35% in 2050**
- Germany outlined a roadmap for the **use of power-to-liquid (PtL) fuels** for its aviation industry that **mandated blending of 0.5% PtL-SAF to aviation fuel by 2026**
- E-fuel blend mandates **create critical niche demand for a high-cost immature technology** that is likely to be the long-term SAF solution

US has established tax subsidies to incentivize the production of SAF, with stackable credits giving e-fuels a right to play through

- Under the IRA, US announced a **tax credit of $1.25 per gallon of SAF** that reduces GHG emissions by 50%
  - Given eSAF can **reduce GHG emissions by up to 90%**, subsidy scales to up to **an additional $0.40 per gallon**
- IRA subsidizes other parts of the e-fuels value chain, with stackable credits further reducing **the difference between kerosene and eSAF**
- In some states (CA, OR, WA), there are **additional benefits that could reduce this gap even more**

IRA funding relevant to PtL (USD B)

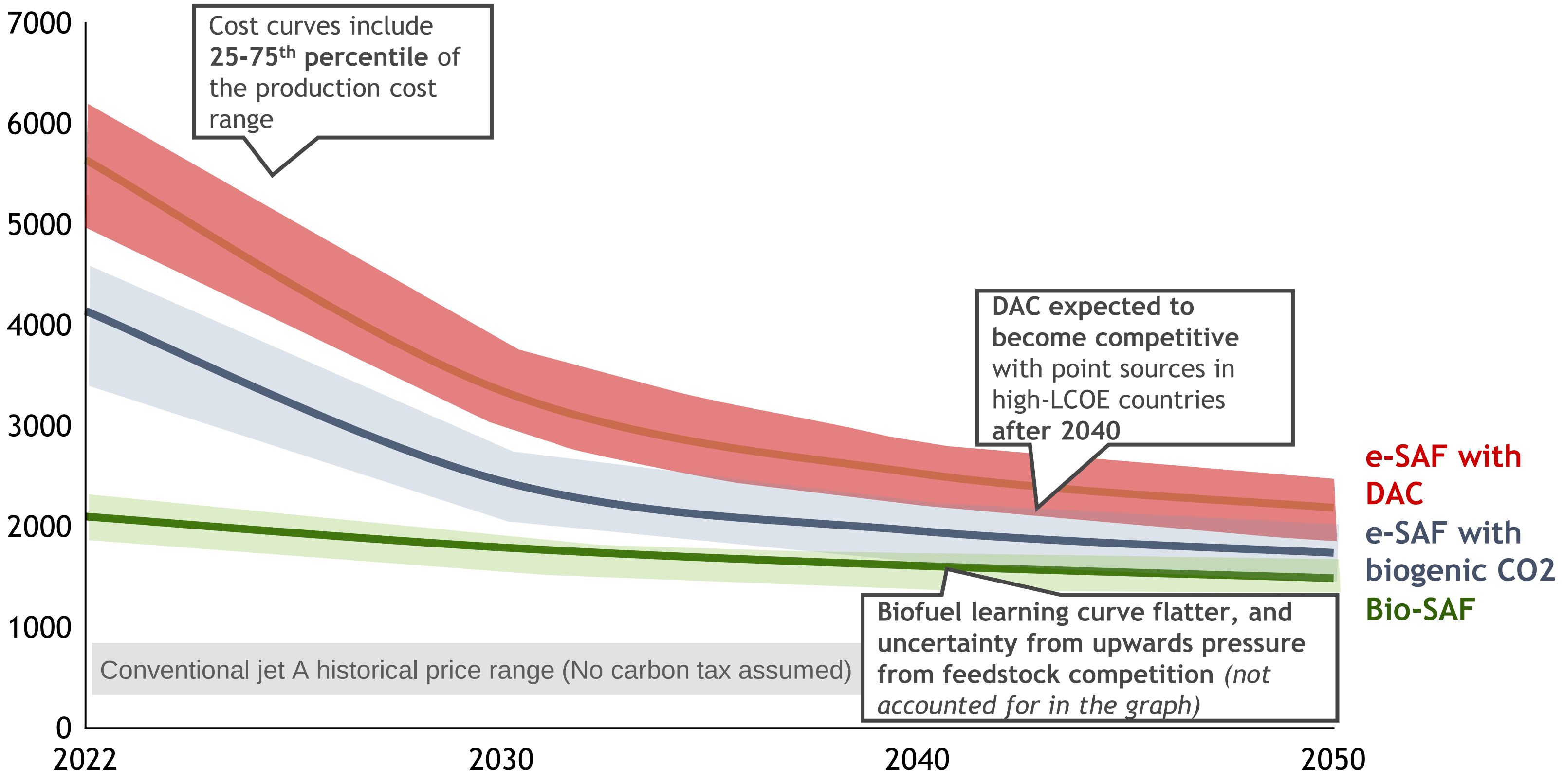


Clean hydrogen PTC	New production tax credit for clean hydrogen
Alt. & clean fuels PTC	New, technology-neutral tax credit for low-carbon fuels (incl. SAF)
Carbon capture tax credit	Extends existing CC tax credit and increases credit for reused CO_2
Advanced manufacturing PTC	Production tax credit for clean energy components
Clean Energy ITC	Investment tax credits for renewable facilities built for specific technologies
Renewable/ Clean energy PTC	Production tax credits for renewable facilities (continues existing subsidy beyond 2025)

Source: Lit search

E-fuels are currently 3-7x as expensive as jet fuel, but costs will decrease as technologies come down learning curves

Levelized cost of aviation fuel (EUR/tonne, 2022-2050)



“There's a lot of interest in the power from CO2 fuels. They're still pretty early stage."

- Freya Burton, Chief Sustainability Officer, LanzaTech

“e-fuels will be a challenge unless we also have huge investment in renewable energy."

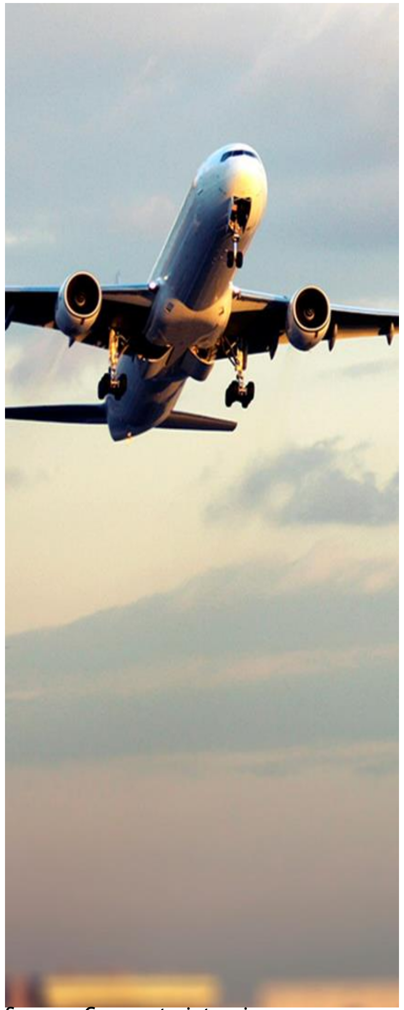
- Head of Sustainability, Airline #1

“PTL presents a financial challenge, costing 10-12 times more than traditional jet fuel, in contrast to HEFA's 2-4 times. Achieving efficiencies will take time, and recognizing this, our strategy is to start modestly and gradually scale."

- World Energy

Notes: Solid line: average costs; shaded region: interquartile range
Source: IEA, 2022; GCCSI; GAP; European Power Service, 2023; Eurostat, 2023, Bain analysis

Carbon capture regulations should be enhanced to promote the production of e-fuels, not just sequestration



*"Under ETS regulations, carbon is not considered to be sequestered in a product unless it is locked up for 150 years. The **only people who will win are people who are sequestering carbon underground** or mineralizing it, which is great but doesn't help us replace fossil carbon in our daily lives"*

- Freya Burton, Chief Sustainability Officer, LanzaTech

*"I would like to have **CCU on parity with CCS** in any sort of incentives - the US being a good example. I'd also like to see CCU treated equally, in all European legislation, because right now CCS is prioritized"*

- Freya Burton, Chief Sustainability Officer, LanzaTech

*"I'd like to see a financial benefit. For example, an **ETS credit spread along the value chain**. So not just in one place, because that will help incentivize others from using the carbon"*

- Freya Burton, Chief Sustainability Officer, LanzaTech

Source: Corporate interviews

Startups are pioneering novel methods to transform waste gases into sustainable aviation fuel

LanzaTech **Case Study: LanzaTech**

Overview

- **Description:** LanzaTech converts waste carbon into sustainable fuels and product
- **Founded:** 2014
- **Headquarters:** Skokie, IL, USA
- **Ownership:** Public (Nasdaq: LNZA)
- **Revenue:** $37.3 million (2022)

Technology overview

LanzaTech proprietary bioreactor

- LanzaTech's technology is a proprietary microbe that can consume waste gases and convert them into ethanol

Activities

Producing SAF

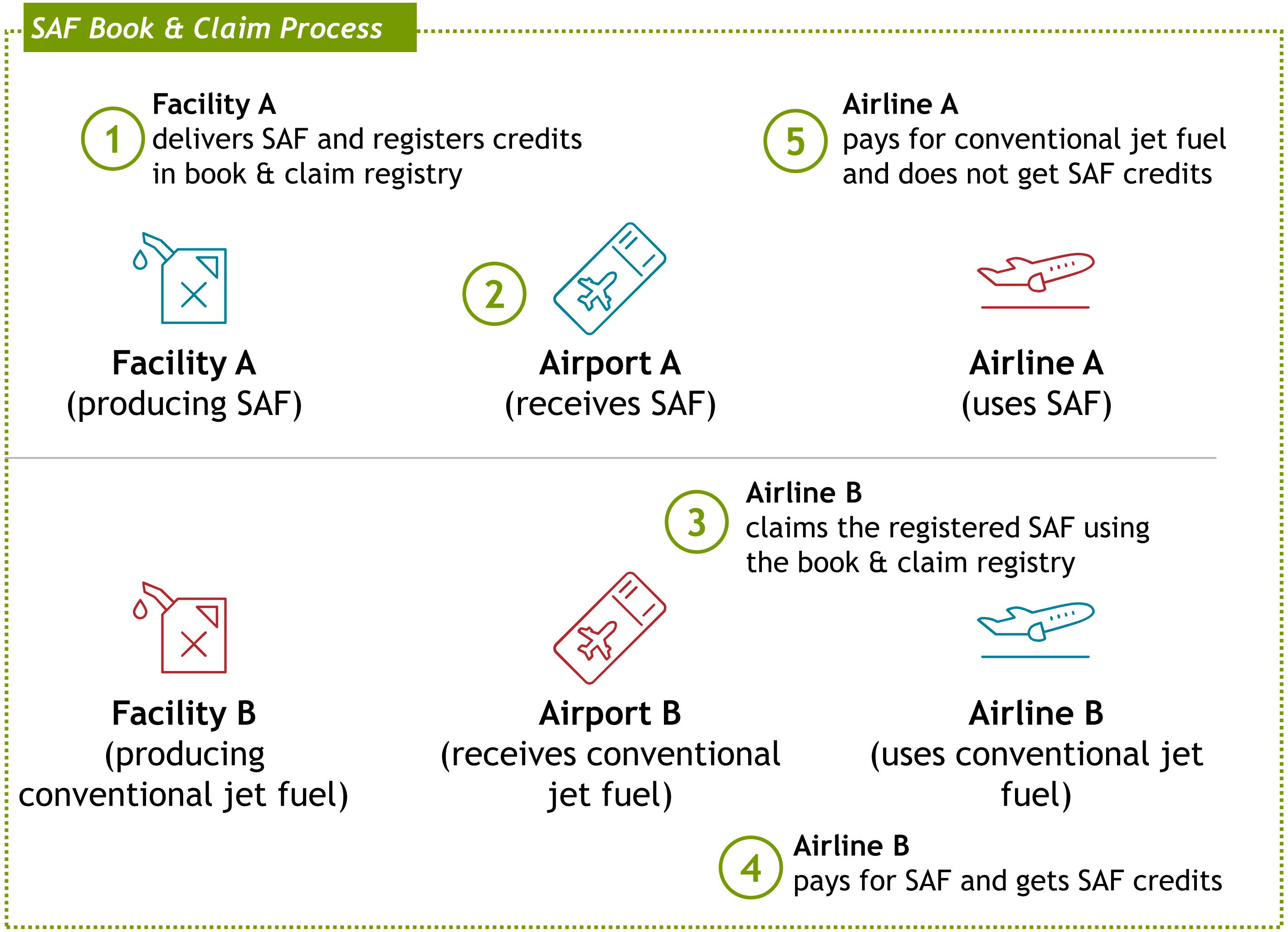
- LanzaTech's bioreactor processes compressed, gasified waste gases into ethanol through a bioreactor
- LanzaTech's operates 3 commercial plants in China, producing cumulatively 47M gallons of ethanol since 2018, and has three more plants under construction
- In 2020 LanzaTech founds LanzaJet to develop commercial process to produce sustainable aviation fuel

LanzaJet

- LanzaJet develops an alcohol-to-jet technology to convert ethanol into sustainable aviation fuel
- LanzaJet technology received ASTM approval in 2018 and was trialed the same year, with 4,000 gallons of SAF produced, powering a Virgin Atlantic flight from Orlando to London

Source: LanzaTech

Book and claim systems can help optimize location of SAF production and regulate regional supply and demand imbalances



Benefits of SAF Book & Claim

- Optimizes **geographical location of production to leverage cheaper feedstocks** (e.g., cheaper renewable electricity in the US)
- Reduces the **emissions involved in transporting SAF**
- Enables airlines to purchase globally recognized, auditable emission reduction certificates, irrespective of local SAF availability

SAF Book & Claim Procedure

1. SAF producers **"book" SAF production**
2. SAF is **delivered to a nearby airport**
3. Airlines can **"claim" the SAF they want to purchase**
4. Airlines receive a **certificate stating amount of SAF purchased**
5. While any aircraft can use the SAF, only paying airlines receive credits

Source: BP; SkyNRG; Literature search

"The number of registries is not important - but establishing a common standard that all the registries use is"

RSB and Air bp Book and Claim

- Air bp's book and claim solution, **certified by the RSB**, provides customers with wider market access to SAF
- Launched in 2021 Currently, it can be used for jet fuel purchases in **France, Germany, Spain, Switzerland, the UK and the US**
- Both SAF and traditional jet fuel is **supplied by Air bp**

Shell, Accenture, Amex GBT

- Jointly launched **Avelia in 2022** - blockchain-powered SAF book-and-claim for **business travel**
- Largest SAF book-and-claim **pilot** offering **1 Mn gallons** SAF – for ~**15K business travel flights** from EU to US
- Shell, Accenture, and Amex GBT are the **first customers** and other corporations are **invited to join**

Etihad Airways and World Energy B&C

- Signed a **MoU** in 2022 to establish partnership to decarbonize flights
- Displacing ~**26K gallons** conventional jet fuel using World Energy's SAF at **Los Angeles Airport**
- Currently, the partnership is **just between these two companies** and is **limited to Los Angeles Airport only**

Jetex and Jet Fuel Ltd. Green Fuel B&C

- Jetex signed a agreement with 360 Jet Fuel Ltd. to offer SAF book and claim option to **its customers globally**
- Allows Jetex customers to source SAF based on their aviation footprint in one transaction, rather than sourcing through each location
- Global system but **limited to Jetex customers**

Note: Title quote from World Energy
Source: air BPl; Shell; Etihad; Jetex; Literature search

Implementing a shared framework for a book and claim systems for SAF will help address existing hurdles in SAF adoption

Barrier	Commentary
Limited supply chain visibility	• Limited **visibility in the production of feedstocks**, especially when imported • **May incentivize fraud** to sell virgin oil as used cooking oil for example, leading to further environmental issues (i.e., deforestation)
Complex auditing	• **Lack of a stringent third-party auditing** system today • Can lead to issues such as **double counting of emissions reductions** across various players in the aviation sector (e.g., airlines, corporate end-users, freight-forwarders)
Regulatory recognition	• Ineligible to count towards emission reduction targets, **given lack of approval from regulatory bodies** - Not eligible in the EU towards RED II targets - Not accepted by US regulatory bodies for claiming emissions reductions
Fragmented criteria	• Different regions and countries **have their own criteria for evaluating sustainability and eligibility of SAF,** creating complexities for aviation players operating in an international sector
Virtual use	• Allows airlines to claim benefits of SAF **without having physical custody** of the fuel • Makes it difficult for governments **to achieve their country-specific emission reduction targets**

*"I do think the **carbon accounting** piece is a barrier right now. You need the accounting to help implement market-based mechanisms and encourage international investment."*

- Head of Sustainability, Fleet operator #4

Source: Lit search

CoSAFA Case Study: CoSAFA introduced a methodology for SAF accounting and auditing to support book and claim systems

CoSAFA description

The aviation industry established the **Council on SAF Accountability (CoSAFA)** to accelerate SAF adoption

Airlines for America® We Connect the World

EBAA European Business Aviation Association

IATA

IBAC International Business Aviation Council

NBAA National Business Aviation Association

GAMA

NATA National Air Transportation Association The Voice of Aviation Business

SAF accounting & auditing procedures for global book & claim

- COSAFA released **Global Methodology for Sustainable Aviation Fuel Environmental Attribute Transactions** in May 2023
- The CoSAFA SAF transactions methodology incorporates **two parallel information data flows** that **mirror the SAF chain of custody** to ensure the integrity of SAF claims while supporting business and regulatory practices
  - Data will be used to **track the physical flow of SAF** from feedstock to aircraft wing or airport storage
  - Additional data will track the **creation and disposition of the environmental attributes**
  - The **export of data to a Master Registry** ensures no fraudulent double counting occurs
- It **specifies the key components that SAF transactions and a book and claim registry should have** to provide transparent information to the end user while also protecting business-sensitive information
- The standards are publicly available for **voluntary use** by any party in the aviation sector
- These standards will ensure **transactional transparency**, **prevent double-counting of emissions savings** and other potential accounting questions that could undermine market confidence in the benefits of SAF production and use

Source: Global Methodology for Sustainable Aviation Fuel Environmental Attribute Transactions, COSAFA

“The pathways are clear, but we need to move together as a global industry. Being front runners comes with a huge cost”

In the long run, demand side policies will be necessary to drive adoption

- As commitments and SAF production continue to increase, **demand-side policies will be required to drive long-term adoption**
- Only Europe currently has a **clear pathway to mandating the uptake of SAF** through ratcheting SAF blend mandates and sub-mandates for e-fuels
- These mandates are critical to **serve as a clear and consistent signal on future demand,** enabling these technologies to reach commercial scale and come down the experience curve
- **Demand-side policies across more geographies are required** to reach greater scale of adoption globally

However, regional adoption of these policies may create market distortion…

- EU’s mandates are **only limited to participating nations**, with limited to no adoption of demand-side policies in other geos
- Given SAF is more expensive today and in the near-future, **these mandates will increase fuel costs for flights that refuel in Europe**
- **Increase in fuel costs will increase ticket prices for consumers** on affected flights, with airlines starting to experience these impacts already
- Transfer flights would be most impacted since **passengers can choose to transfer via alternative destinations** that are not subject to the same mandate

AIR TRAVEL

Lufthansa boss warns SAF mandate will push up fares

News

Air France increases ticket prices to pay for sustainable aviation fuel

16 Jan 2023 by Tom Otley

…which could negatively impact emissions and economics

Economic impact

European aviation industry could **struggle for survival within a fiercely competitive international environment** as demand shifts to other airlines and through other stopovers

Carbon leakage

Reallocation of demand could shift carbon emissions to **places with less environmental and social regulation** for aviation

- Airlines could **re-route passenger movements onto longer flights** that transit through airports without these mandates, increasing resulting emissions

“National policy approaches which constraint industry growth may simply drive more air traffic to other airports.”

\- World Energy

Source: WEF Clean Skies for Tomorrow; SkyNRG; European Commission; Title quote by Head of sustainability, Airline #1

Reducing SAF costs and optimizing its usage will determine the rate of adoption in the medium- and long-term

Cost of low-carbon fuels

- Demand for low-carbon fuels is accelerating with airlines making bold commitments and policies incentivizing usage, but **costs are 2-5 times higher than traditional jet fuel today**
- Despite developing technologies and growing productions of feedstocks, **costs are still likely to remain more expensive going forward, stalling demand until costs come down significantly**
- **Unlike biofuels, e-fuels are expected to meaningfully decline in costs over time**, but face high CapEx and hydrogen costs in the near-term to test Power-to-Liquid technology at commercial scale and bring e-fuels down the experience curve

International coordination

- Given low-carbon fuels are available in limited supplies today, minimizing costs by producing in lowest-cost regions and optimizing emissions reductions potential by co-locating production and offtake is critical, **but no system exists today to enable cross-border procurement and use**
- Setting up a global book and claim system is critical in the near-term, but **limited visibility, complex auditing, and lack of regulatory recognition** make it difficult to establish

Scaling will require prioritizing multilateral approaches to demand creation and enabling the rationale development of supply and demand

Multilateral approaches to demand creation

- **Mandates are an important policy tool for scaling the adoption of SAF,** given the fiscal limitations governments will face in providing long term price support
- **The adoption of SAF would be most effectively accelerated through multilateral approaches to aviation regulation;** a voluntary inter-governmental agreement to introduce common, ratcheting SAF blending mandates across the major airport hubs by leading governments could be a catalyst for wider adoption
- The agreement could start with a small group of countries - **mandates would ideally be cost-neutral for airlines at the point of re-fuelling to avoid market distortions,** with cost differentials subsidized through increased air passenger duties in participating states

Rationale development of supply and demand

- **Book and claim systems are fundamental** for the most rational production of SAF at early stages of adoption
- **A common effective international framework would enable investment in SAF production** where it could be produced more cost effectively, while stimulating low carbon investment in developing countries

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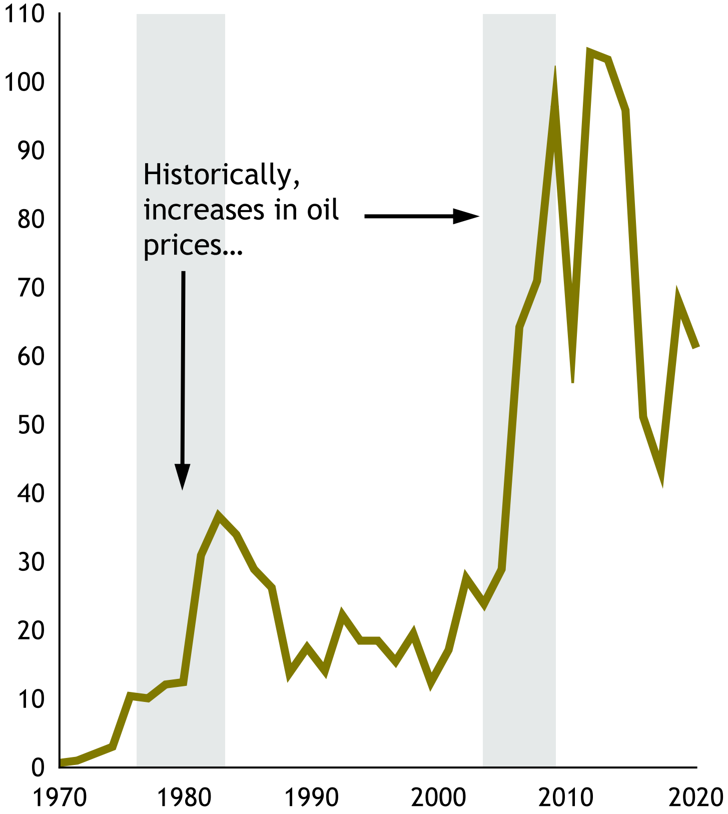
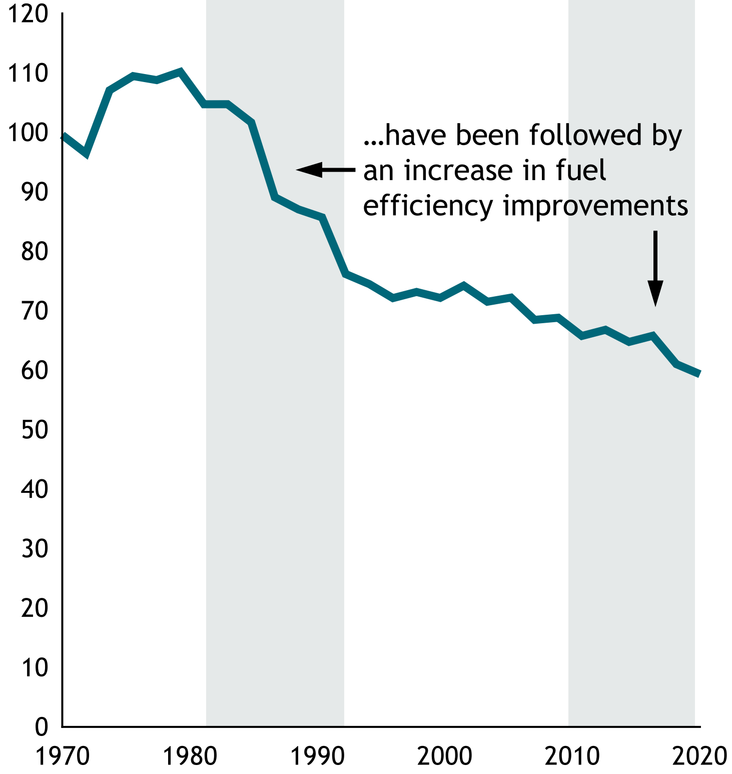
Historically, high fuel prices have driven fuel efficiencies; increasing fuel costs due to SAF will encourage further efficiency gains

High fuel prices have corresponded with fuel efficiency improvements

Oil barrel, $/barrel



Fuel economy (in fuel/tonne-km), relative to 1970 (1970 = 100%)



Source: MPP; World Bank; ICCT; Aviation Benefits

Commentary

- Aviation players have historically **responded to rising fuel prices with greater fuel efficiency,** given fuel comprises 25-30% of operating costs
- **SAFs will be the only viable option** to decrease emissions until next-gen engines come to market
- Since SAF prices will remain higher than for jet fuel, **improving fuel efficiency is a critical cost reduction lever** for aviation players
- In the near-term, improving fuel efficiency is possible through **instituting operational changes and accelerating fleet renewal**
- In the long-term, replacing SAF with battery-electric and hydrogen fleets **can deliver significant efficiency benefits** and reduce the total energy required to decarbonize aviation

Airlines can further improve fuel efficiency through operational changes such as route optimization, load management, and engine maintenance

Operational changes to improve fuel efficiency for airlines

Flight Planning and Route Optimization	• Utilize **advanced flight planning systems** that consider factors like wind patterns, weather conditions, and optimal altitudes • Implement **continuous climb and descent procedures** to **minimize fuel use during takeoff and landing**
Weight Reduction and Load Optimization	• Minimize onboard weight by **optimizing cargo and baggage loads** • Use **lightweight materials** for cabin interiors and amenities, removing unnecessary items and **avoiding excessive fuel reserves**
Operational Practices	• Implement **single-engine taxiing** when feasible • Optimize ground operations to **reduce taxiing and turnaround times**
Engine Maintenance and Monitoring	• Implement regular engine maintenance and monitoring programs to **ensure engines operate at peak efficiency** • Utilize **predictive maintenance techniques** to address engine performance issues before they lead to inefficiencies
Collaboration with Air Traffic Control	• **Optimize flight routes** and **reduce congestion**, minimizing unnecessary fuel consumption due to **holding patterns**
Data Analytics and Performance Metrics	• Data analytics to monitor and analyze **fuel consumption patterns**, establish **KPIs for fuel efficiency** and regularly track progress

Case studies

Emirates

- Implementation of **Green Standard Operating Procedures** by their pilots
  - Green SOPs include measures such as: **using reduced engine taxi, idle reverse, prudent judgement on extra fuel, optimized flap landing, inflight speed management to minimize fuel burn, and use of direct routing opportunities**
  - In 2022-23, Green SOPs helped to **reduce fuel burn by more than 50K tons** and **carbon emissions by over 160K tons**

FINNAIR

- Pilots use **Briefing Fuel Dashboard** which produces data to support the fueling decisions
- **Catering and water are optimized** according to passenger numbers
- Over **90% arrival to Helsinki-Vantaa** airport are made with a **continuous descent**
- Aircrafts calculate an **optimal flight profile for fuel efficiency** basis speed and altitude

Sources: 1) Emirates - Reducing emissions; 2) Finnair - What would a perfectly fuel-efficient flight look like?

AI-enabled routing optimization can reduce contrails, offering a cost-effective climate solution for airlines

Case Study: American Airline / Google

Overview

- Contrails are condensation trails that form when hot jet exhaust cools quickly in the cold upper atmosphere
- Contrails and the clouds they induce can trap outgoing radiation and contribute to global warming
- Contrails and other non-CO_2 climate forcers account for 66% of the Effective Radiative Forcing of aviation (i.e., 66% of aviation's total climate impact)

Targets

Con-trails AI

- A joint venture between Google's research arm, American Airlines, and Bill Gates's Breakthrough Energy developed an AI technology used to develop contrail forecast maps, reducing airplane contrails by 54%

Activities

Highlighting the path to tracking the climate impact of aviation

- Contrails – the thin, white lines produced by airplanes in the sky – **account for roughly 35% of the aviation sector's emissions**
  - They form when planes fly through layers of humidity and can persist as cirrus clouds, trapping heat in the atmosphere
  - Avoiding flying through areas that create contrails can reduce warming, so the challenge is identifying which routes will create contrails
- Over 6 months, **American Airlines flew 70 flights using Google's AI predictions,** to avoid altitudes that created contrails
- **Google then analyzed satellite imagery and found pilots reduced contrails by 54%,** proving commercial flights can avoid contrails and thereby reduce their climate impact
  - Flights that avoided creating contrails burned 2% more fuel
- Only a small percentage of flights would have to be altered to avoid the majority of contrail warming, meaning the total fuel impact could be as low as 0.3% across an airline's flights and suggesting **contrails could be avoided at scale for around $5-25/metric ton of CO_2e**
  - These savings **would already make it a cost-effective emissions reduction measure,** but further improvements are expected

Source: Google, American Airlines, Breakthrough Energy, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, Literature search

Airports can enable fuel efficiency improvements by optimizing operations, fuel management processes, and infrastructure design

Operational changes to improve fuel efficiency for airports

Ground Operations Optimization	• **Streamlining taxiing routes** to minimize fuel consumption • Implementing advanced **taxiway guidance systems** • Employing optimized **pushback procedures** and reducing engine idling
Aircraft Handling and Turnaround	• Efficiently coordinating aircraft turnaround processes to **minimize ground time** and **optimize gate utilization**
Fuel Management and Storage	• Advanced fuel storage and management systems to **prevent leaks, spillage, and evaporation losses** • Improving prediction accuracy for fuel needs to **minimize overstocking**
Infrastructure Design and Modernization	• Designing **terminals and taxiways for more efficient aircraft movement** to reduce taxiing distances
Data Analytics and Monitoring	• Utilizing real-time data analytics to **monitor and optimize fuel consumption** across various airport operations • Implementing **predictive maintenance** to keep **ground equipment and vehicles operating at peak efficiency**
Sustainable Infra Investments	• Installing **renewable energy sources** to **power airport facilities** • Exploring use of **H2 or biofuels for ground vehicles and equipment**

Case studies

Schiphol Amsterdam Airport

- Schiphol Airport released a roadmap to **reduce fuel consumption of taxiing**
- This plan aims to make **sustainable taxiing standard procedure at Schiphol by 2030**
  - The first step will be the deployment of **two special aircraft towing vehicles** for a follow-up pilot study at Schiphol in mid-2022
  - Aircraft are taken to and from the runway by a **semi-robotic taxiing system** and the **plane's engines remain turned off for a longer period**

مطارات دبي DUBAIRPORTS

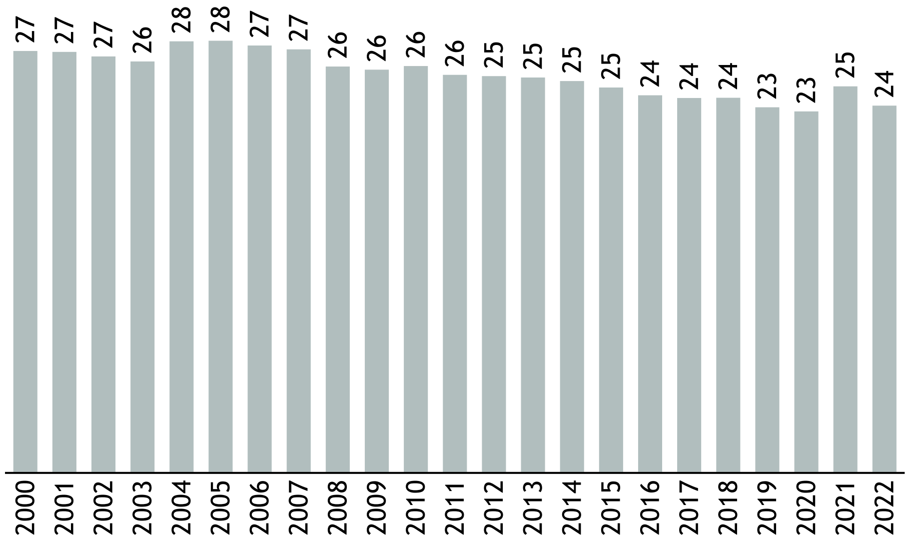
- A new air traffic management procedure was implemented to improve its **ATM capacity** and **reduce fuel consumption**
- The **approach peak offload** procedure is based on re-allocation of aircraft with a lighter wake to DXB runways, during peak times
  - The procedure has also **reduced peak arrival delays by 40%** at DXB and expected to **cut CO2 emissions by up to 447 tons per month**

Sources: 1) International Airport Review, Schiphol Airport; 2) Airport Technology, Dubai Airport

“We view our fleet renewal program as an operational and commercial opportunity”

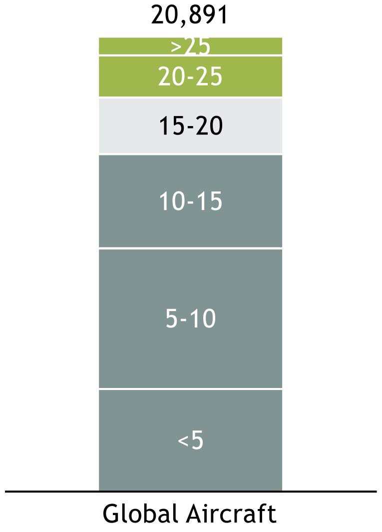
Average retirement age has declined by 15% in the last 20 years

Average retirement age



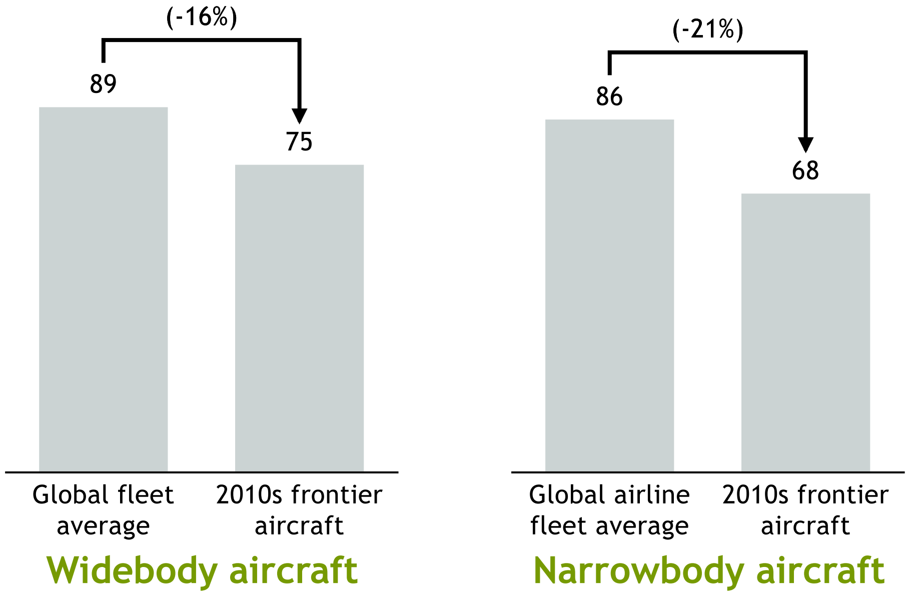
~15% of fleet is likely to retire in 5 years*

of aircrafts by age (2023)



The most efficient aircraft available today are 15-20% more efficient than the global average

CO2 intensity (as proxy for fuel efficiency) for aircraft g CO2/RPK



With average retirement age declining by 15% in the last 20 years, airlines have the opportunity to continue accelerating fleet renewal to transition to lower-emissions frontier aircraft

Notes: *Assumes an average retirement age of 23.5; Only Narrowbody and Widebody jets have been considered for fleet renewal as regional are likely to be replaced with electric or hydrogen jets in the future; Title quote by Head of sustainability, Airline #1
Source: Cirium Fleet data; Mission Possible Partnership

Airlines must consider a number of financial tradeoffs associated with accelerated fleet renewal

Fleet renewal can impact an airline's economics in many different ways

Cost category	Impact on cost	Commentary
CapEx	↑ (red)	• **High CapEx costs required** to purchase a new aircraft, with many local airlines likely unable to finance new tech • With rising interest rates, **airlines are incentivized to wait until rates come down** given rising costs of capital
Fuel	↓ (green)	• New generation aircraft are **15-20% more fuel-efficient than prior generation** • Renewing fleet can deliver significant cost benefits, given **fuel is ~25-30% of an airlines' operating costs**
Maintenance	↓ (green)	• New aircraft engine contracts **cap maximum operational cost growth**, while older aircraft maintenance costs grow with age
Training	↑ (red)	• New generation aircraft have **higher upfront costs for training**
Depreciation	↑ (red)	• Newer aircraft have **higher asset values and experience accelerated depreciation of assets**
Revenue	↑ (green)	• Old aircraft require **downtime for maintenance**, reducing availability by ~5% (e.g., overhauls) with an opportunity cost vs. newer aircraft • Newer aircraft engines **provide more thrust and allow for additional weight** to be carried (e.g., passengers and cargo)

Commentary

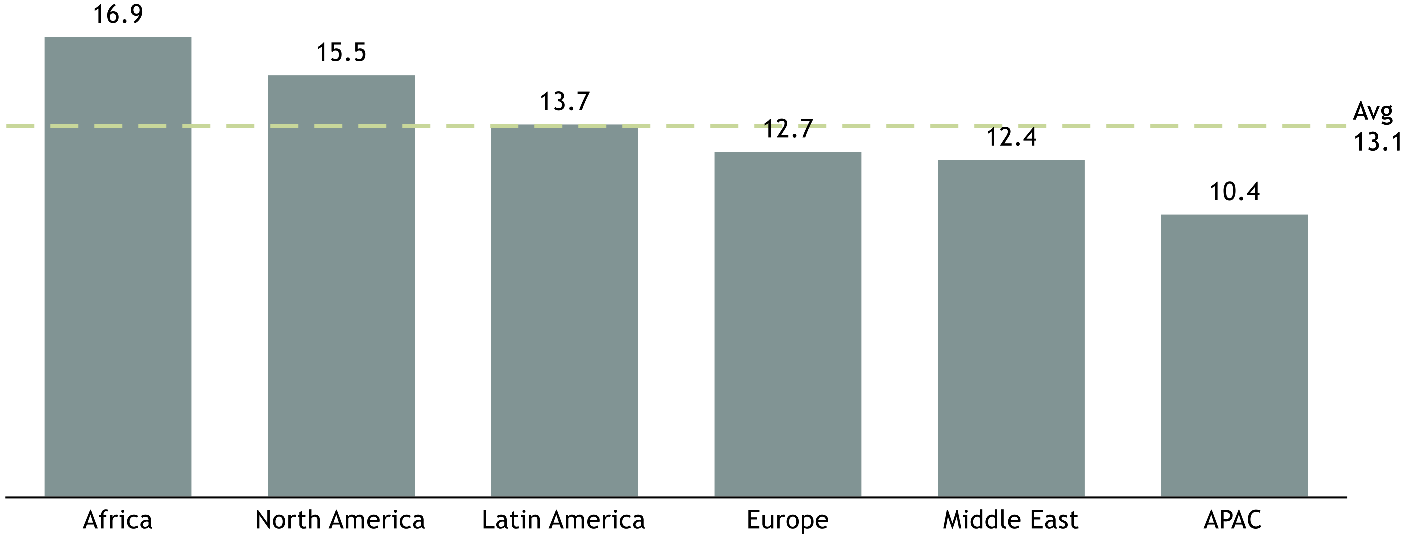
- Higher SAF blends and correspondingly higher fuel costs will provide a tailwind for fleet renewal **as lower-emissions aircraft can drive fuel efficiency savings**
- Regions that individually mandate **higher SAF uptake may cause market distortion and disadvantage players** that cannot afford to retire their current fleet early
- **International coordination for supporting policy** is required to enable an organized transition across regions

Given aircraft age varies regionally, international support will be required to enable a just transition

/ AS OF 2022

Africa and North America have fleets older than the global average, with remaining regions relatively in line with or below the global average

Average age of current fleet



	Africa	North America	Latin America	Europe	Middle East	APAC
Total # of aircraft	1,030	9,063	1,711	6,862	1,590	8,730
% of global fleet	4%	31%	6%	24%	5%	30%

Note: Data includes all passenger and freighter aircraft except unassigned
Source: Jeffries

Commentary

- Africa **has the oldest fleet globally**, but only comprises 4% of aircraft in-service
- North American fleet is the largest globally, and is 2 years older than the global average, **with high emissions reductions possible by accelerating renewal**, especially for widebody aircraft
- Middle East and Asia Pacific have the youngest fleets, given **new deliveries have far outpaced retirements** to service newer, high growth markets
- International policy will be **required to support countries in upgrading to ensure costs don't disproportionately** impact certain regions more than others

CORSIA is best equipped to drive broad adoption of measures to improve fuel efficiency

CORSIA is a global scheme by the ICAO

- Stands for **Carbon Offsetting and Reduction Scheme** for International Aviation; adopted in 2016
- Targets emissions from international travel not covered by national climate actions
- CORSIA implemented since Jan 2019: most airlines were required **to start monitoring, reporting, and verification of CO2 emissions**
- From 2021, airlines offset emissions growth above 85% of 2019 levels

CORSIA is in the voluntary pilot phase

- CORSIA outlines 3 phases of implementation:
  - Pilot phase: 2021-2023 with voluntary participation
  - First phase: 2024-2026 with voluntary participation
  - Second phase: 2027-2035 with mandatory participation from all international flights, with a few exceptions
- **115 states volunteered,** 10 more joining in 2024, covering **80% of the growth in air traffic emissions**
- In the mandatory phase, only members with >0.5% of international aviation activity must participate

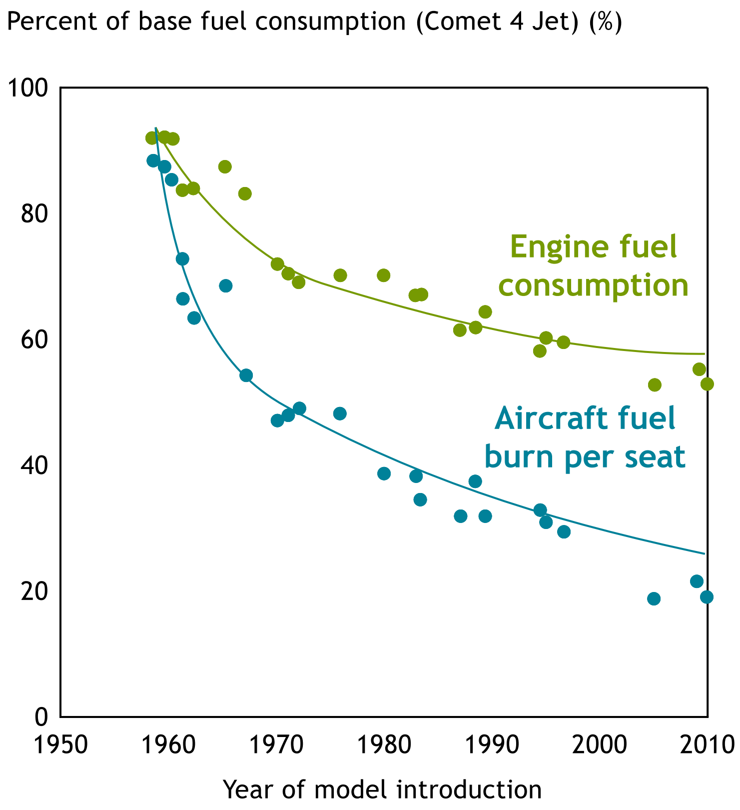
Limits to CORSIA and decarbonization

- CORSIA risks **diverting funding to SAF** projects in favor of offsets given offset allowance for current operations
- Thus, additional international coordination is required to **incentivize improvements in fuel efficiency,** with for example
  - Governments could **link passenger duties to aircraft sustainability**
  - **States could commit to zero emission airports** (e.g., standardizing aircraft gate equipment)

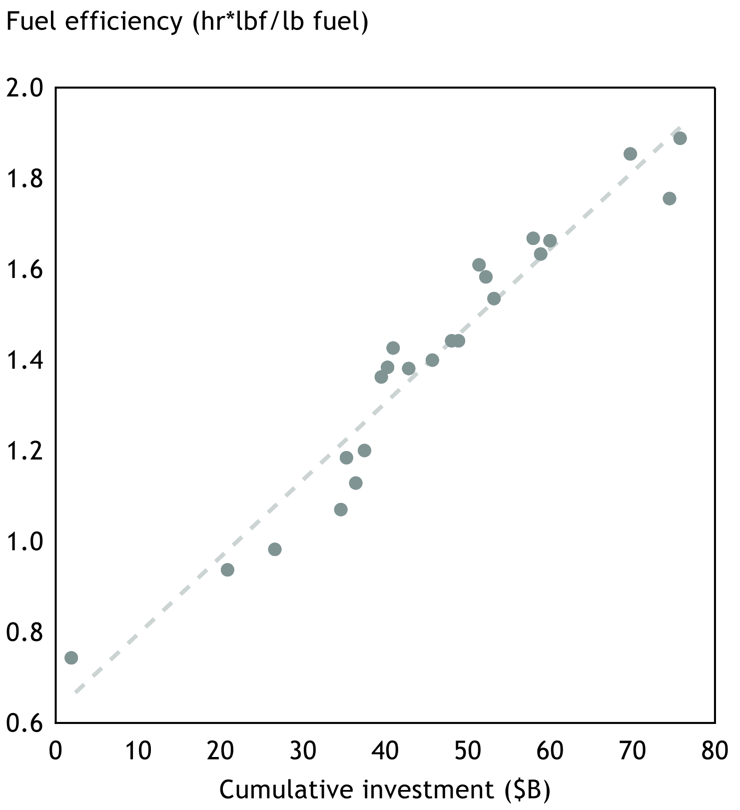
Source: ICAO; Literature search

Further engine evolution would require considerable investment to realize incremental gains

Fuel efficiency per seat declined



Steady efficiency gains from investments



Turbofans' physical limitations

- Turbofans have improved efficiency with rising bypass ratios, transitioning from 5-6 in the 1970s with CFM 56 to 9-11 with CFM LEAP in the 2010s. These high ratios correlate with larger fan sizes.
- Turbofan improvements face challenges, making additional efficiency gains more difficult, including:
  - **Size**: High bypass ratios lead to bigger engines, posing design and ground clearance concerns
  - **Weight** : Bigger engines add weight, impacting aircraft performance and fuel use
  - **Aerodynamics** : Expanded fans alter airflow around the nacelle and wing, necessitating design changes
  - **Structure**: The added size and weight stress engine mounts and aircraft frameworks

Source: Air Transport Action Group, "Guide to Aviation Efficiency," Air Transport Action Group, 2010, "Air Transport and Energy Efficiency," Transport Papers, 2012, "Air Freight: A Market Study," World Bank, 2009

Engine manufacturers are exploring innovative solutions to turbofan limitations

cfm **Case Study: CFM**

Overview

- **Description:** CFM International is an aircraft engine manufacturer originally formed as a JV to build and support CFM56 series of turbofan engines. To date, it has delivered 37,500+ engines to more than 570 operators. As of 2019, it holds 39% of the world's commercial aircraft engine market share
- **Founded:** 1974
- **Headquarters:** Cincinnati, US
- **Ownership:** Joint Venture between GE Aerospace and Safran Aircraft Engines (50% each)

Targets

RISE Initiative

- In 2021 the it started working on developing engine technologies that will get 20% fuel efficient than today's engines

Open Fan Design

- Attempting to perfect the open-fan design, in which the fan blades won't be surrounded by a case allowing high volume of air to circulate through the engine

Activities

Utilizing existing internal innovations

- CFM is utilizing the following technologies to perfect the open-fan design
  - **Carbon fiber composite blades** manufactured with a 3-D weaving to enable a larger fan diameter to improve propulsive efficiency
  - **Advanced compact core** that will increase thermal efficiency and significantly decrease fuel consumption
  - Hybrid electric systems
  - Advanced metal alloys and ceramic matrix composites
- The engine will be **100% compliant with alternative energy sources** such as SAF and Hydrogen

Collaboration with Airbus for flight-testing

- The **Flight Test Demonstrator** aims to mature and accelerate the development of **advanced propulsion technologies for an Airbus A380**
- The test campaign will be performed in the **2nd half of this decade** from **Airbus Flight Test facility** in Toulouse, France
- The flight test program will achieve several objectives, including enhanced understanding of engine-wing integration, aerodynamic performance, propulsive system efficiency gains, validating benefits, evaluating acoustic models, and ensuring compatibility with 100% SAF

Source: GE Newsroom; CFM Aero Engines, Press Articles

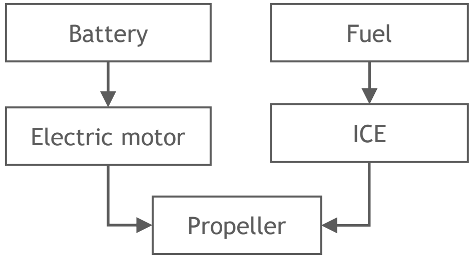
Electric planes will require significant redesign to mechanical, electrical, power, and engine systems, with smaller disruption required for hybrid planes

Legend: Sig. redesign/high disruption | Moderate redesign | Minor adaptations

Technological functionality

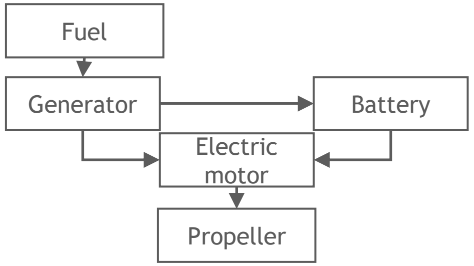
Hybrid

Parallel ICE Hybrid



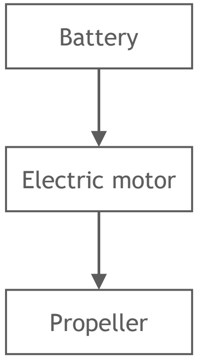
Propeller is rotated either by an **ICE-powertrain** or **electro-motor** while a **mechanical system** switches b/w them

Serial ICE Hybrid



Propeller driven by electric **motor** through generator or battery

Full-electric



Propulsive energy is provided by a **battery** that drives an **electro-motor** rotating the propeller which then gives a **thrust to an aircraft**

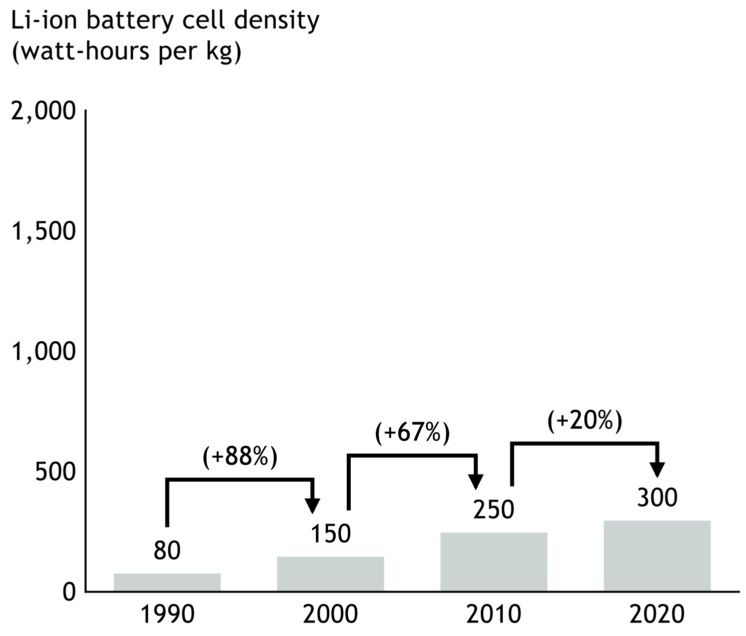
Source: Literature search, company websites

Aircraft architecture adaptations

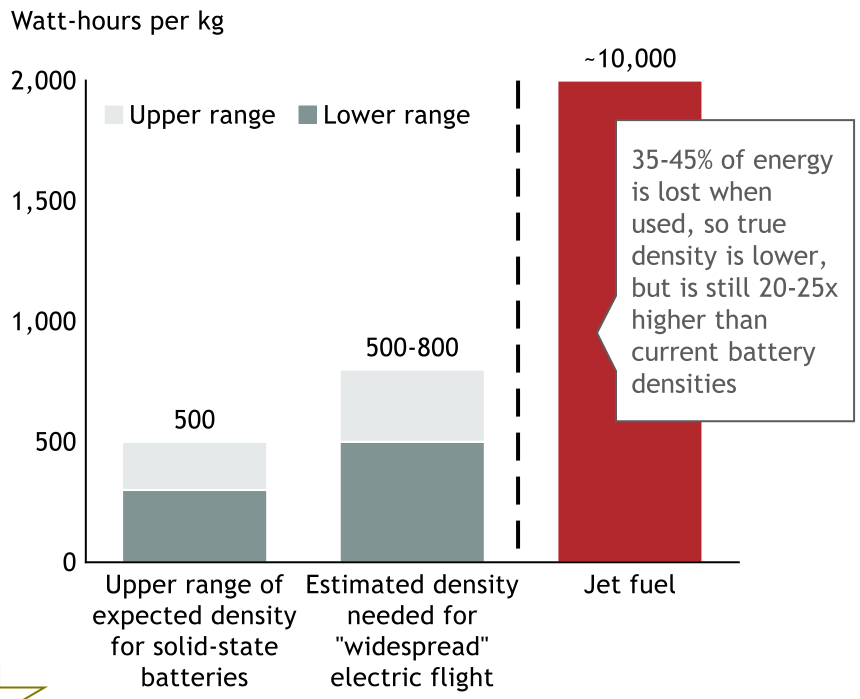
Key systems	Changes required	Ease of implementation: Hybrid	Ease of implementation: Full electric
Structures	Redesign or adaptations of fuselage, wings, tails, and flight control surfaces	Minor adaptations	Moderate redesign
Avionics	FADEC and fly-by-wire system, cockpit displays, new controls	Moderate redesign	Moderate redesign
Mechanical	Engine control, thrust reverser, flight control and fuel system, hydraulic systems	Moderate redesign	Sig. redesign/high disruption
Electrical	High-voltage or high-power cabling, power electronics, system integration of electric generators	Moderate redesign	Sig. redesign/high disruption
Power	Power systems and batteries in addition to or to replace gas turbines	Moderate redesign	Sig. redesign/high disruption
Engine	Addition of electric drive to power gear for hybrid and a novel propulsion system architecture for electric	Moderate redesign	Sig. redesign/high disruption

Battery cell energy density is the main hurdle to achieving full electric flight in large commercial aircraft; hybrid is achievable but has significant range tradeoffs

Lithium-ion battery densities have improved over time



Battery energy density trails jet fuel



Commentary

- Despite a 3.75x improvement in Li-ion battery densities, they **remain 40-60% short of density needed** for "widespread" electric flight
- Low energy density compared to jet fuel **creates challenges in providing sufficient power** for large aircraft
- Weight limitations of aircraft restricts the total number of batteries that can be used; **battery endurance will limit the range** of aircraft, reducing the number of serviceable routes
- There are new batteries that are **expected to have higher densities** than lithium-ion, **but are not yet commercially available**
- Solid-state batteries **could reach the lower range of density requirements** for widespread aviation
  - E.g., CATL launched a solid-state battery **with an energy density of up to 500 Wh/kg earlier this year**

Key challenge to fully electric engines in larger aircraft applications is the energy density for batteries versus jet fuel

Source: Physics World; Energy Impact Partners; Air Transport Action Group; NBF

High-density metal batteries could pave the way for electric propulsion in short-haul flights, presenting an alternative to SAF

northvolt **Case Study: Northvolt / Cuberg**

Overview

- **Description:** Northvolt is a developer of sustainable battery technology in conjunction with R&D, industrialization, and recycling to support the clean energy transition – recently acquired battery technology company Cuberg
- **Founded:** 2016
- **Headquarters:** Stockholm, Sweden
- **Ownership:** Private
- **Valuation (2022):** $11.75B

Targets

Lithium-metal batteries

- Unlike lithium-ion batteries that use graphite for the anode, Northvolt's batteries use full lithium metal anodes
- Historically, lithium-metal batteries have had inadequate rechargeability, but Northvolt technology has achieved >670 cycles without degradation
- Compared to lithium-ion batteries, lithium-metal can offer improved energy density

Activities

Developing battery technology for aviation applications

- Cuberg aims to develop aviation-certified lithium metal battery packs
- Cuberg has developed a **20 Ah commercial-format lithium metal pouch cell** with specific energy of 405 Wh/kg, **significantly higher than high-performance lithium-ion cells** used in commercial electric vehicles (250 Wh/kg)
- Cuberg is undergoing tests of its 5.1 Ah lithium cells to ascertain their suitability for aviation, assessing factors such as power output (crucial for takeoffs and landings), power density, cell safety, and energy efficiency
- Successfully showcasing of these cells for aviation applications would represent a step towards electrifying short-range flights

Source: Northvolt; Cuberg; Literature search

Norway has announced ambition to shift domestic air travel to electric by 2040

Case Study: Norway airport system

Overview

- Norway's state-owned airport operator, **Avinor, will host 100% electric aircraft by 2040** for short-haul domestic travel
  - Avinor operates **43 airports** across the country
- Domestic civil aviation accounts for ~**2.3% of national GHG emissions**, presenting significant opportunity for emissions reductions
- **Norway is conducting studies** to evaluate the impact of supporting policy and identify potential locations to demonstrate aircraft

Targets

2023
- Norwegian government presents new national aviation strategy

2025
- National Transport Plan 2025-2036 to be published outlining government support for decarbonizing aviation

2030
- First commercial electric flights to begin in 2030

2040
- All short-haul flights within the country to be electric by 2040

Activities

Setting targets to accelerate adoption of electric planes

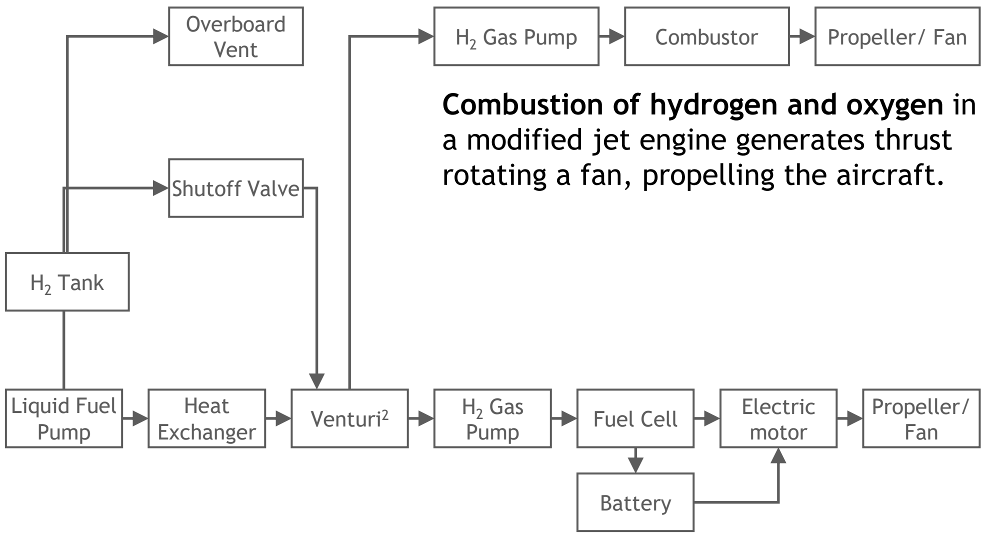
- Due to Norway's rugged mountains and myriad offshore islands, **short-haul flights frequently offer an easier travel** option than road or rail
- Avinor, the state-owned entity overseeing 43 airports in Norway, envisions having **100% electric aircraft operations by 2040**
- Widerøe, Norway's leading domestic airline, is set to introduce **its inaugural electric aircraft by 2025**
- Key players in Norwegian aviation anticipate governmental backing like that provided for electric cars to hasten the uptake of electric aircraft
- Recent Nordic aviation research has pinpointed **203 potential air routes where electric aircraft would significantly cut travel time**, deemed as being 1.5 times faster than equivalent journeys by car or public transport

Source: Nordic Labour Journal, Forbes, Literature search

"Hydrogen will play a role in emission reduction, contributing to 5-10% by 2050 but has its limitations, especially in medium to long-haul flights"

Technological functionality

H_2 Fuel System | **H_2 Combustion**



Combustion of hydrogen and oxygen in a modified jet engine generates thrust rotating a fan, propelling the aircraft.

High-level **common layout for H_2 fuel distribution systems** used in both applications.

Hydrogen and oxygen are transformed into electricity by the fuel cell, which then powers a motor rotating a propeller or ducted fan to generate thrust.

Note: 1) Airport infrastructure configured as energy hubs depicted as most likely scenario of deployment, 2) Flow measurement instrument to control supply pressure; Title quote from Head of sustainability, Airline #2
Source: Literature search, company websites

Aircraft architecture adaptations

Key systems	Changes required	Ease of implementation: Gas turbine	Ease of implementation: Fuel cell
Structures	Design changes to accommodate hydrogen storage tanks		
Avionics	Cockpit displays and flight control computer		
Mechanical	Engine control and fuel systems		
Electrical	Electrical generation and distribution	No changes	
Power	Replacement of traditional APU	No changes	
Engine	Engine combustion dynamics and propulsion system architecture		

Hydrogen will also require significant changes to and investment in airport logistics and infrastructure

01 02 03 **04 IMPROVING FUEL EFFICIENCY THROUGH TECHNOLOGY**

/ NOT EXHAUSTIVE

H_2 process flow[1]

Outside airport | **Inside airport**

Power Generation
Green electricity production from off-site renewable energy generation system

- Water electrolysis requires large amount of electricity
- Sufficient supply of low-carbon renewable resources

Electrolysis
Process of using electricity to split water into hydrogen and oxygen

- Sufficient scale to become cost competitive
- Developments in high-temperature electrolysis

H_2 Gas Pipeline
Hydrogen delivery infrastructure for transportation of gaseous hydrogen

- Disconnect between where H_2 is produced and where it is used
- Technical limitations when using existing networks with H_2

Liquefaction
Conversion of hydrogen gas into liquefied hydrogen

- Efficient placement of liquefaction facilities
- Sufficient local electricity generation or grid connection

Cryogenic Storage
Storage of liquid hydrogen at cryoge nic temperatures

- Increased volume requirements compared to kerosene
- Mitigation and control of boil-off losses

Refueling
Transferal of liquid hydrogen as aviation fuel into the aircraft

- Physical delivery of cryogenic hydrogen from tank facility to individual aircraft
- Substantial changes to refueling protocols

Airport infrastructure and logistics need to transform considerably for hosting H_2 powered aircraft

Note: 1) Showcasing airport infrastructure configured as energy hubs depicted as most likely scenario of deployment
Source: Literature search

Major airports are exploring the potential of hydrogen in aviation

London Heathrow Airport

- **Heathrow Airport launched Project NAPKIN in 2022** to demonstrate the viability of an entirely hydrogen-based UK domestic flight network by 2040
- The project yielded **5 key findings:**
  - Hydrogen-based, zero-carbon flights are feasible in the UK by 2030
  - The UK's goal for carbon-neutral aviation by 2040 depends on adequate green hydrogen production
  - National supply, and the price of green liquid hydrogen, will be critical
  - Airport infrastructure requirements will be critical by 2040
  - There is a potential noise benefit and opportunity from a shift to hydrogen-based aviation

Berlin Brandenburg Airport

- In 2022, Brandenburg Airport initiated Project H2-BER, to integrate a wind park, hydrogen production site, and refueling station for **carbon-neutral aviation refueling**
- The project's steps include:
  - Coupling of renewable energy and mobility applications through the **production of hydrogen as a fuel from wind energy**
  - Demonstration of the **dynamic operation** of electrolysis, compression of hydrogen and storage **depending on prevailing wind**
  - **Standardizing interfaces** between equipment to develop modular refueling strategies at BER airport

Los Angeles Airport

- In 2023, Los Angeles Airport partnered with Universal Hydrogen to **explore hydrogen-based aviation**
- A successful demonstration was carried out on a 40-passenger jet flying from WA to LAX.
- Their forward-looking objectives include:
  - **Modifying regional planes** for green hydrogen fuel cells by 2025, with 247 conversion orders already in place from 16 clients
  - Introducing hydrogen-fueled **single-aisle jets** by 2035 and larger jets by the mid-2040s.

Source: Literature search

Startups are developing hydrogen-electric propulsion and fueling solutions to address net-zero emission air travel by 2025

Case Study: ZeroAvia

Overview

- **Description:** ZeroAvia develops electric powertrains for aviation and is on the forefront of hydrogen fuel-cell propulsion systems
- **Founded:** 2017
- **Headquarters:** Hollister, California, USA
- **Ownership:** Private
- **Total funding:** $229M (2022)

Targets

- ***2023*** – ZeroAvia flies the world's largest aircraft (19 seats) powered by hydrogen technology
- ***2025*** – Targeting a 300-mile range, 9-19 seat aircraft
- ***2027*** – Targeting a 1000-mile range, 40-80 seat aircraft
- ***2032*** – Targeting a 3000-mile range, 200 seat aircraft
- ***2040*** – Targeting a 5000-mile range, 200+ seat aircraft

Activities

Proving technical feasibility of hydrogen-based aviation

- In 2023, aviation startup ZeroAvia began **test flights for small propeller planes equipped with hydrogen fuel cells** with the hopes of commercial adoption as early as 2025
- Assuming the hydrogen is produced using renewable electricity, retrofitting a propeller plane with fuel cells and liquid-hydrogen tanks could result in a **90% reduction in life-cycle emissions compared to the original aircraft**
- ZeroAvia and Birmingham Airport (BHX) have recently proposed an **onsite hydrogen production facility** powered by solar panels to serve future hydrogen powered aircraft
  - The facility could produce enough hydrogen to support 1,250 regional flights and 3,000 buses or trucks per year
  - While no target date has been set, BHX has the ambition to become a net-zero carbon airport by 2033

Source: ZeroAvia, Literature search

“It’s about technology availability – there will always be a mix of technologies”

/NOT EXHAUSTIVE

Portfolio | Engine technology platforms

		WB	NB	RJ	SAF	Hybrid & Electric	Hydrogen Fuel Cell
Airframers	BOEING	✓	✓	✗	Doubles SAF purchase for commercial operations, buying 5.6 Million gallons for 2023	Previous investments in startups/ joint ventures for development of electric aircrafts (e.g., Zunum, eVTOL)	Top product developer doubts hydrogen-powered airliners will be viable until 2050 – SAF remains a higher near-term priority
Airframers	AIRBUS	✓	✓	✗	First manufacturer to offer customers the option of delivering new aircraft with a blend of SAF	ASCEND project to mature cryogenic and superconducting technologies to boost performance of hybrid/electric propulsion	Three ZEROe concepts for hybrid-hydrogen aircraft zero-emission, with hydrogen fuel cell-powered aircraft ready for service by 2035
Airframers	EMBRAER	✗	✗	✓	First initiative to test use of aviation biofuels on regular flights in collaboration with KLM in 2016	On track to meet its goal of starting commercial operations in 2026 and already has 2,700 orders prior to the start of production	Announced Energia H2 Fuel Cell (19 seats) and Energia H2 Gas Turbine (35-50 seats) to be technically feasible by 2035 and 2040
Engine OEMs	ROLLS ROYCE	✓	✗	✓	First tests of 100% SAF in business jet engine	ACCEL program successfully built world’s fastest all-electric aircraft ‘Spirit of Innovation’ setting three new world records	Development of roadmap to build enabling technology to overcome hydrogen-associated hurdles
Engine OEMs	GE Aviation	✓	✓[1]	✓	All GE and GE partnership engines in service today are approved to blend up to 50% SAF	Advanced Air Vehicles Program with NASA developing electric aircraft propulsion system	CFM (a JV between GE and Safram) and Airbus announced collaboration on tests of an aircraft engine fueled by hydrogen
Engine OEMs		✓	✓[1]	✓	All jet engine types are SAF compatible with aim to expand adoption of SAFs in the future	Study of next-generation turbofan; turboelectric hybrid engine with up to 5% efficiency gain	Selected by the U.S. DoE to develop high-efficiency H2 propulsion technology for commercial aviation
Suppliers	SAFRAN	✓[1]	✓[1]	✓	Research on suitability of biofuel processes, including production, and validation of tech compatibility	Safran plans to begin certification testing on its ENGINeUS 100 electric engine in 2023, with flight tests expected around the same time	Development of a fuel cell system for electrical power supply as part of PIPAA project with partners easyJet, Dassault, Tronico, Ad Venta
Suppliers	MTU Aero Engines	✓[1]	✓	✓	Active research into SAF with aim to shift away from burning fossil fuels	Partnership with DLR to study fuel cell propulsion system for avia-tion	Hydrogen fuel cells included in *Technology Roadmap* for achieving emissions-free flight

Development stage: Commercial application | Exploratory | Announced

Note: 1) Predominantly developed as part of risk-and-revenue sharing partnerships; Title quote by Head of sustainability, Airline #1
Source: Lit search

Simultaneous development of various engine technologies could lead to several disruptions, especially for aircraft OEMs

Increased R&D costs

Significant R&D costs are required to develop next-gen commercial aircraft programs

- Engine platforms require **billions of dollars** of investment **spent over several years** to reach commercial viability
- Spreading this investment over multiple engine technologies (e.g., hydrogen, battery-electric, open-rotor) **reduces technology learning rates and results in smaller production runs**

Fragmented global market

Customers could see viability for the same aircraft differ considerably across geographies

- Commercial aircraft customers benefit from the **economies of scale of a global market** centered around fuel dependent turbofan engines
- **Regional divergence in policy** will make some engine technologies more commercially viable than others resulting in **smaller, specialized fleets**
  - E.g., Norway expects to be all-electric while certain regions may incentivize hydrogen aviation while others subsidize SAF production and usage
- Operation of different fleets may require **costly and fragmented supply chain infrastructure**
  - Two new value chains for 1) onsite renewable electricity and 2) H_2 production, storage, transport, and distribution

Subscale production volumes

Aftermarket-centric business models would rapidly degrade with subscale volumes

- OEMs typically make the **initial engine sale at low or no margin** in exchange for lucrative aftermarket maintenance, repair, and overhaul services (MRO)
- Smaller, specialized fleets would result in **fewer aftermarket customers** to recoup program development costs, all while fleet renewals place current revenue at risk
- Without a shift in business model, airframe and engine OEMs could face **unsustainable erosion of life-of-program profitability,** making it difficult to invest in future technological innovations, especially when it's not clear which technology will win

Engine OEMs make a significant share of their revenue in the first ~15 years of maintenance, with fleet acceleration placing that revenue at risk

ILLUSTRATIVE NARROW BODY PBH EXAMPLE

	Year 0	Years 1-5	Year 5	Years 5-10	Years 10-15
Activities as per agreement	Service agreement **signed** between Airline and Engine OEM	Simple **on-wing maintenance** preformed by airline MRO	Category 1-6 **service bulletin** issued requiring component replacement	**LLP warranty** expires; **LRU repair** serviced by Airline MRO partner	Service Agreement **Rebid**

Ongoing line maintenance in all years and component repairs as needed

	Early Operation *(Years 0-7)*	**First major overhaul** *(Year 7)*	**Second major overhaul** *(Year 15)*
Role of Engine OEM	• Ensure **engine specs hit target** operating metrics; monitor available data to ensure no early-stage issues	• Build **production capacity** for LLPs to ensure inventory • Ensure MRO **supply chain partners** are operating effectively	• **Win re-bids** via competitive pricing for low-IP parts; continue economics of scale for high-IP parts; limited role in repair services
T&M Price and OEM costs	• *No T&M price, OEM costs limited to service bulletin and on-condition part cost*	• *~$7M T&M* • *$1-2M OEM costs per engine*	• *~$7M T&M* • *$1-3M OEM costs per engine*
Risks to OEM	• **Internal:** Inaccurate scoping leads to production time or cost overages	• **External:** 3rd party MRO could exert price pressure, but PMA only impacts ~20% of parts	• **External:** 3rd party MRO threat, competition from salvage/spares for 3rd overhaul

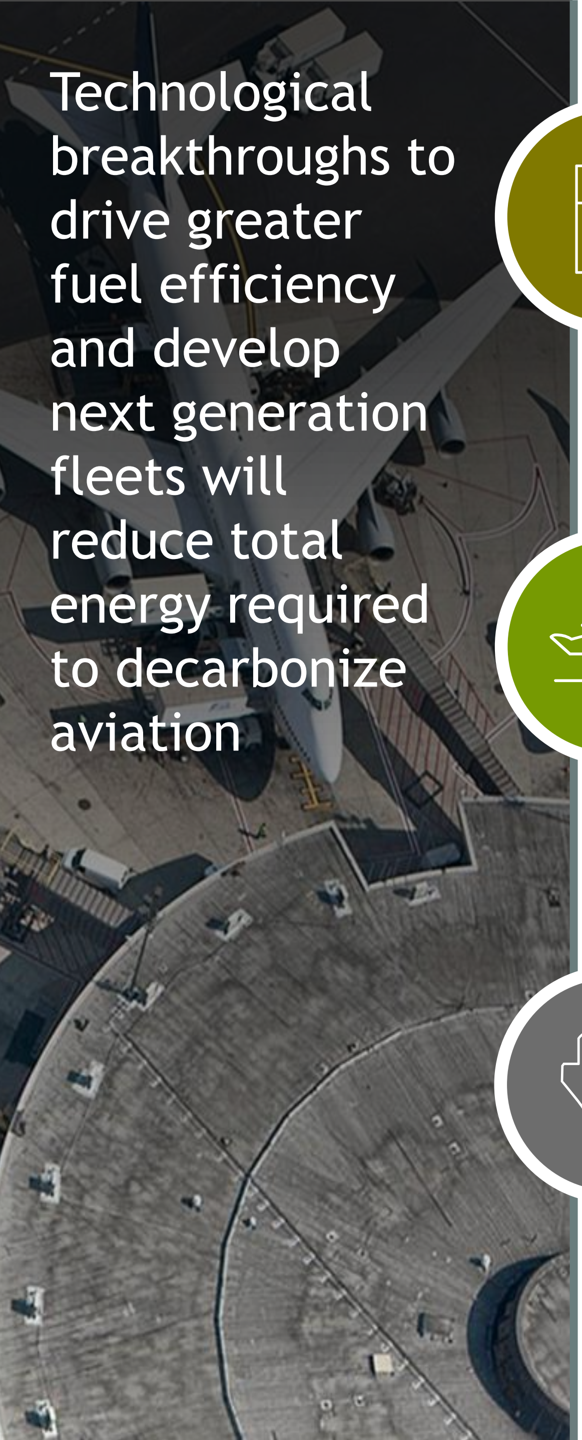
Note: Level 1-3 service bulletins indicate mandatory part replacement to correct safety related issue
Source: SEC filings; Company press releases; Market participant interviews

“This is a global problem – we need to change the way we collaborate together and share the risks”

- An intergovernmental framework for decarbonising aviation would need to be negotiated by a group of governments big enough to drive change, but small enough to reach agreement on the key measures required to accelerate the rational and coordinated decarbonisation of the industry
- The idea would be to start small to ensure an ambitious agreement, and then expand the agreement over time, with the ultimate aim of the main elements being adopted by ICAO
- Although joining the initiative would be **voluntary**, the requirements placed on membership would be binding, and the agreement and compliance would need to be supported by an international secretariat which could be most appropriately housed within an existing international institution
- In the first instance it would ideally cover the largest international aviation hubs so would need to involve the following governments at a minimum: EU, HK/China, Singapore Turkey, UAE, UK, US
- It would need to be driven by one or two leading governments – ideally including one from within and one outside the OECD, with a world leading climate policy and aviation sector
  - France would be ideally placed
  - UAE might be another good target for a founding state, from a non-OECD country.
- It would require significant commitment by leading industry players to develop the idea further and a dedicated campaign to get something over the line ahead of COP28, but this could be built quickly by leveraging existing initiatives

Note: Title quote by Group Chief Sustainability Officer, Aviation Company #1
Source: Bain analysis; Literature search

Technological breakthroughs to drive greater fuel efficiency and develop next generation fleets will reduce total energy required to decarbonize aviation



Transition financing

- Operational changes by airlines and airports can optimize fuel usage in the air (e.g., flying in straighter lines) and on the ground (e.g., minimizing ground time), but **lack coordination and standard procedures to enforce these changes in a consistent way globally**
- **Early retirement of less fuel-efficient aircraft is uneconomical** given they are amortized over an expected 20-30-year lifespan

Power and charging infrastructure

- Next generation engines are expected to unlock 15-20% improvements in fuel efficiency, **but require significant R&D investment and time before commercialization**
- Engine manufacturers make the majority of their revenue in aftermarket, but fleet acceleration could place that revenue at risk, **limiting available R&D budgets required to develop next generation engines**

Modifying consumer behavior

- Investments required to scale SAF production, and build the next engines are massive, but with each player placing their own bets on a fragmented array of solutions, **it limits the ability for any one to reach commercial scale rapidly**
- Hybrid aviation is viable in the near-term, but full-electric aviation will need significant technological breakthroughs **to improve battery densities, update aircraft architecture (e.g., engine), and ramp up battery charging at the airport**
- Although hydrogen could decarbonize long-haul flights, **lack of technology in airport and aircraft architecture coupled with limited green hydrogen supply hamper viability**

Improving fuel efficiency through technology will require accelerated deployment of energy efficiency technologies and de-risking frontier technologies

Accelerate deployment of energy efficiency technologies

- **The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is the most effective mechanism** to drive the widespread adoption of energy and operational efficiency
- Other mechanisms could include **joint measures among leading countries to more aggressively link air passenger duties to aircraft sustainability criteria**

De-risk frontier technologies

- **An "all-of-the-above" approach will be necessary** to decarbonize aviation
- However, **greater government intervention** to concentrate investment in the most promising pathways and frontier technologies could accelerate progress

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