FLIGHT PATH TO SAF:

Innovation, Economics, and the 2030 Mandate

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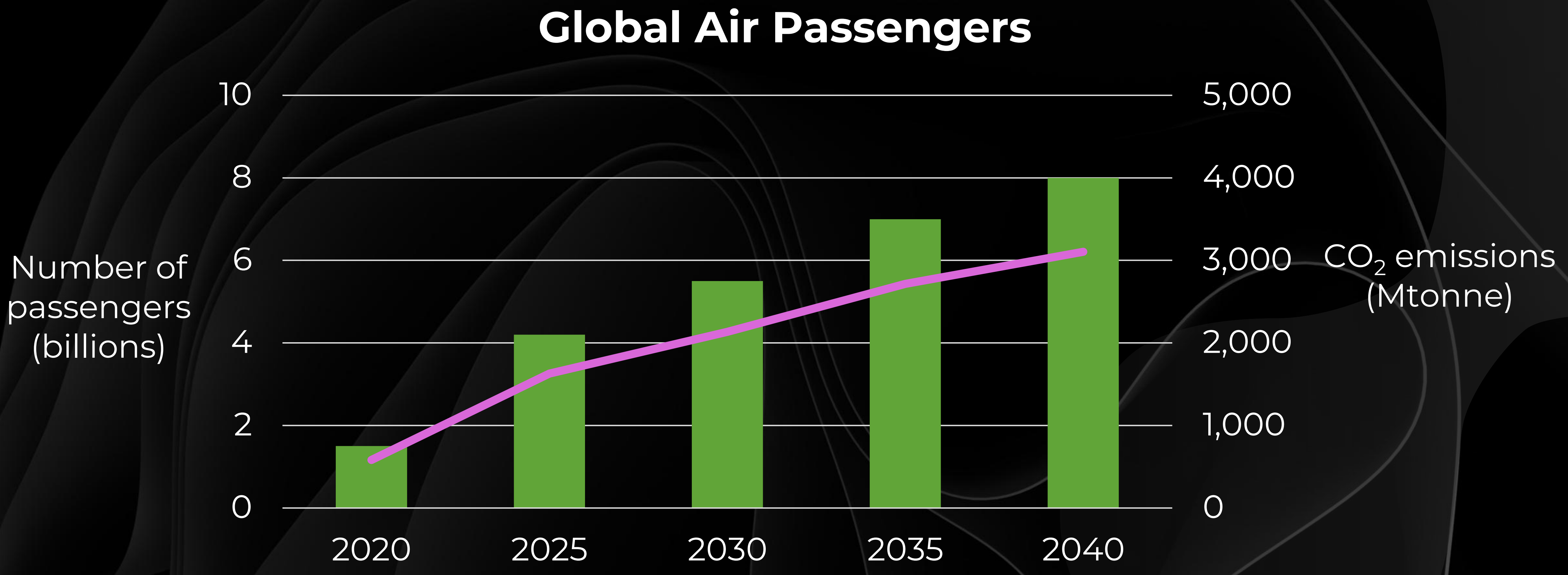
AVIATION SECTOR WILL DOUBLE IN SIZE

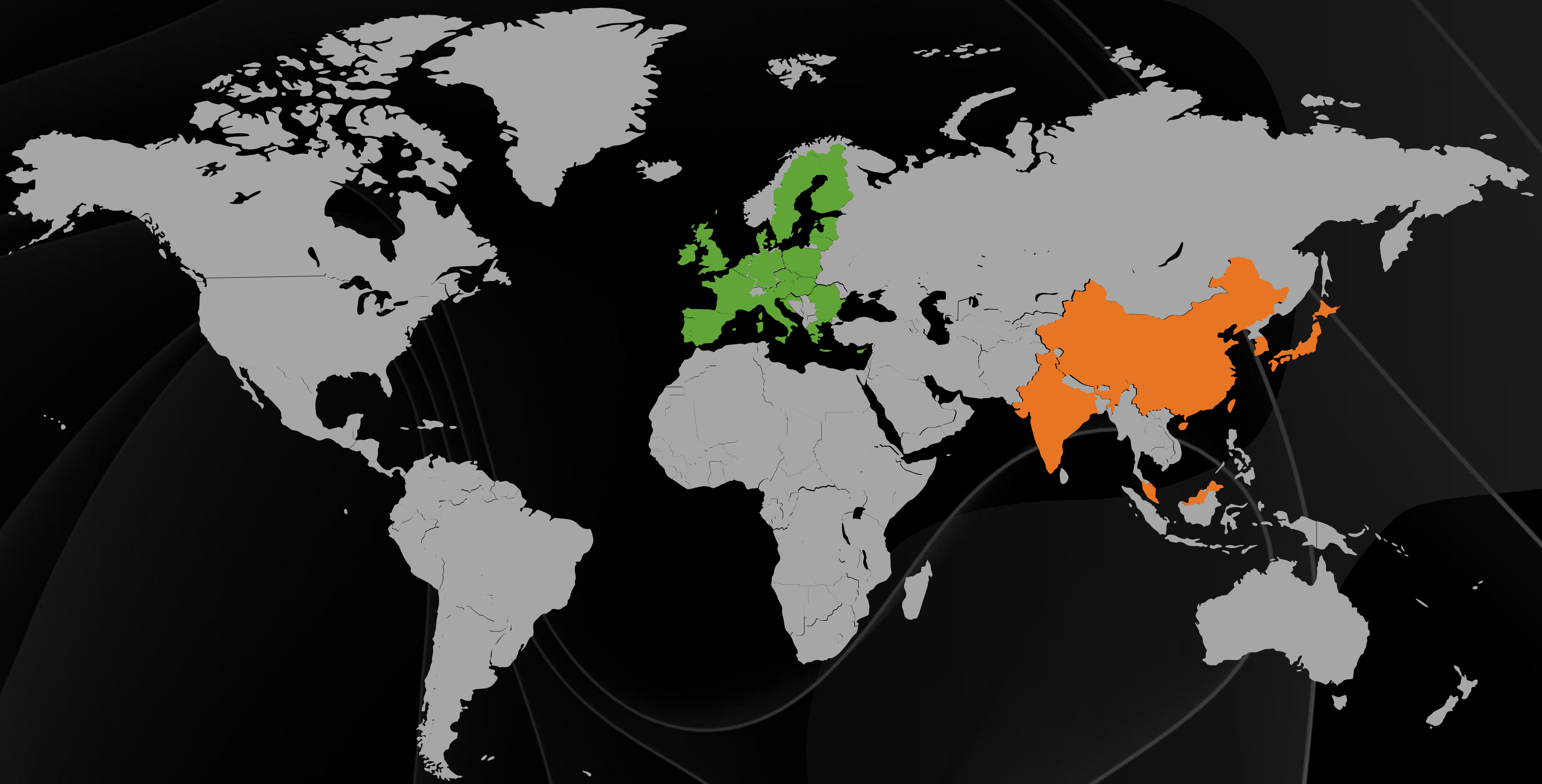
The aviation sector will grow to 8 billion passengers by 2040, leading to over 3 Gtonne of CO_2 emissions



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

SAF MANDATES WORLDWIDE

The U.K. and EU have active SAF mandates in 2025; multiple other countries plan adoption before 2030.



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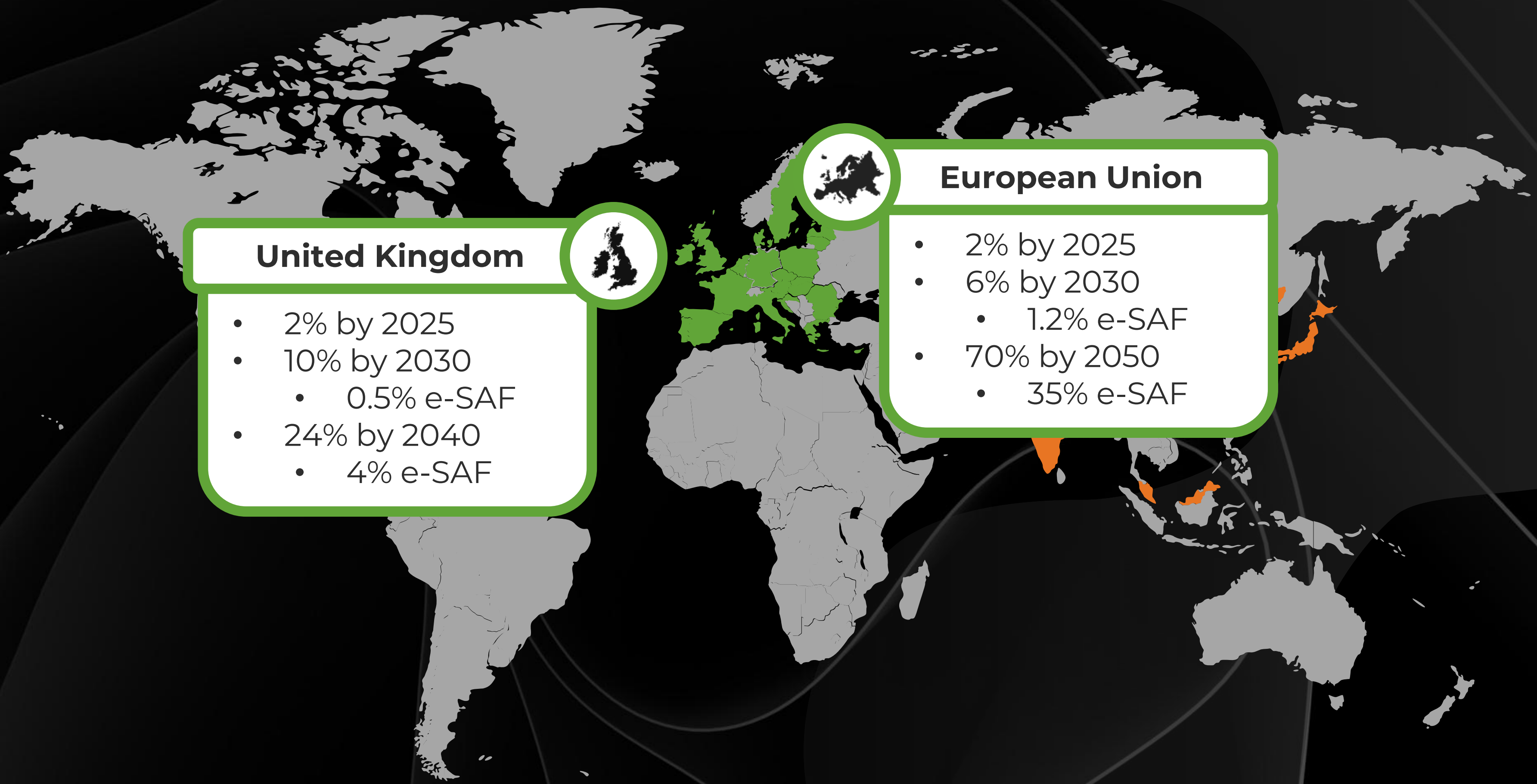
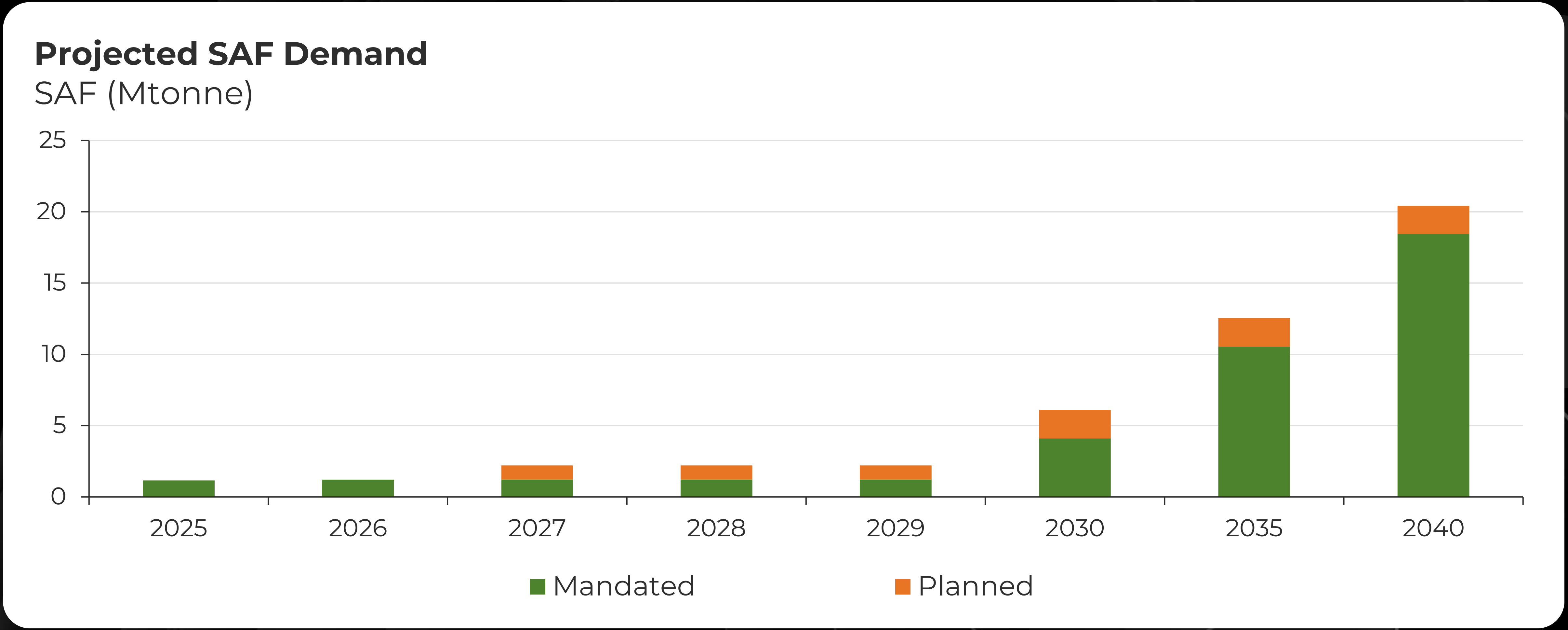
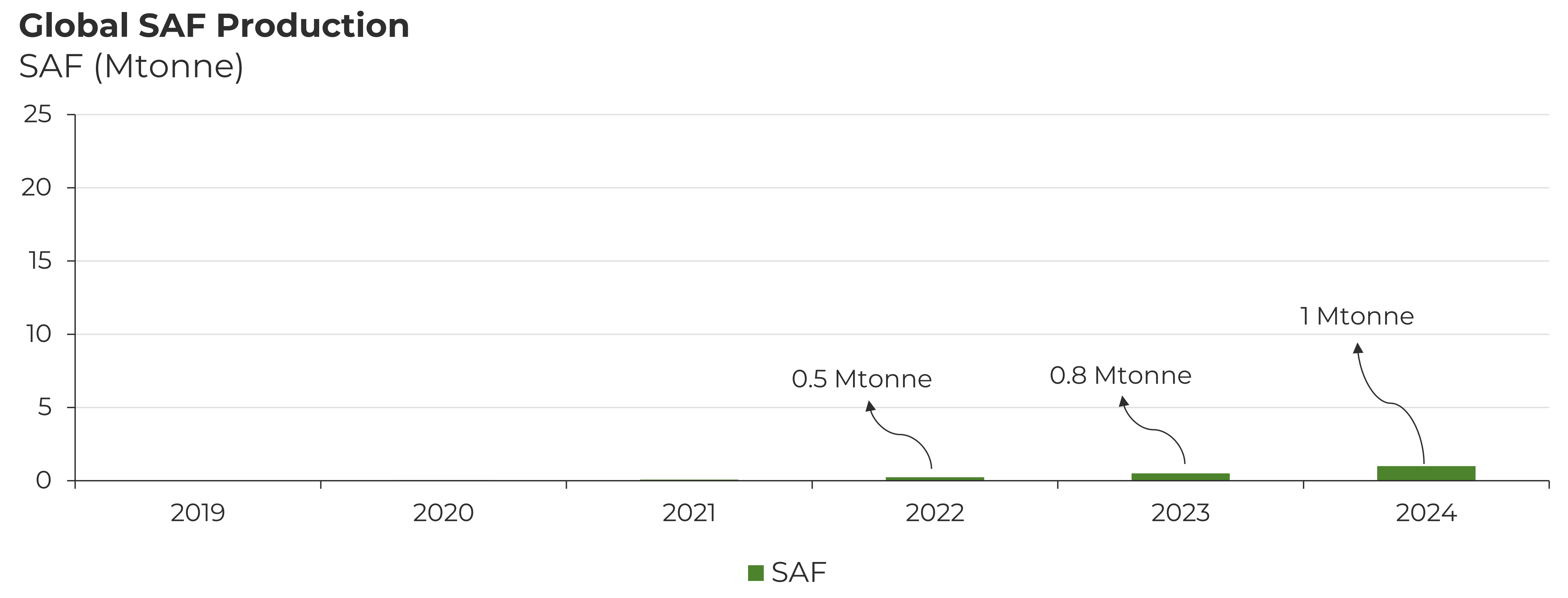


4 MTONNE SAF WILL BE MANDATED BY 2030



BUT ONLY 1 MTONNE SAF WAS PRODUCED IN 2024



Where will the remaining 4 Mtonne of SAF come from?

MULTIPLE COMPANIES OFFER SAF TECHNOLOGY

BIO-OIL TO SAF

- NESTE
- Phillips 66
- bp
- Axens Solutions
- Shell
- preem
- AEMETIS
- ExxonMobil
- Honeywell UOP
- TotalEnergies
- SKYNRG
- eni
- TOPSOE
- world energy

CO2 TO SAF

- JM
- ZAFFRA
- Arcadia eFuels
- sasol
- VELOCYS
- EMERGING FUELS TECHNOLOGY
- zero
- LYDIAN LABS
- INERATEC
- twelve
- INFINIUM

ALCOHOL TO SAF

- Axens Solutions
- gevo
- Honeywell UOP
- TOPSOE
- Swedish Biofuels
- Vertimass – Low-cost, defossilized fuels. Now!
- metafuels
- Global Bioenergies
- LanzaJet
- BYOGY RENEWABLES

BIOMASS TO SAF

- Dimensional Energy
- RAVEN
- Shell
- IDUNN H2
- WASTEFUEL
- DG FUELS

THE PERFECT SAF TECHNOLOGY

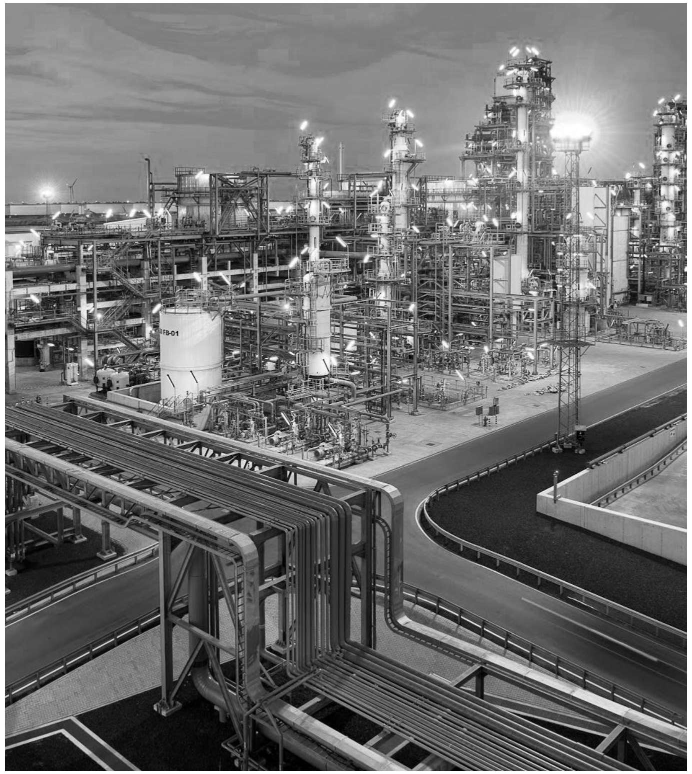
Abundant feedstock	No feedstock limitations
Sustainable feedstock	SAF should have a low carbon intensity
Scalable technology	Fuel is a commodity market
Experienced developers	Multi-billion-dollar projects

BIO-OIL – TO – SAF

Enabling Technology:

Hydrotreated Esters & Fatty Acids (HEFA) (ASTM approved, 2011)

- Vegetable oil or waste oil (used cooking oil and animal fats) is converted to SAF.
- The technology catalytically converts the feedstock in the presence of hydrogen to remove oxygen, followed by hydrocracking into renewable diesel, naphtha, and SAF
- The typical jet fuel fraction in a HEFA facility is 15%; it can be adjusted to up to 80% for maximum jet output.



- **Maturity:** Commercial
- **Key focus area:** Feedstock pre-treatment, feedstock supply chain management

NOT A PERFECT SAF TECHNOLOGY

−	**Limited feedstock**	Waste oil is limited and distributed in supply
+	**Sustainable feedstock**	Waste oil has a low carbon intensity
+	**Scalable technology**	Hydrotreatment is fully commercial
+	**Mature developers**	Multiple large corporations in the market (Neste, Honeywell UOP, Axens, etc.)

BIOMASS – TO – SAF

Enabling Technologies:

Gasification/Fischer-Tropsch (ASTM approved, 2009), biomass liquefaction

- Cellulosic biomass or MSW is converted to SAF.
- Most common approach is to gasify bio-based feedstock into synthesis gas (CO/H2), which is then fed into a Fischer-Tropsch reactor to produce diesel, waxes, and SAF.
- Emerging approaches include biomass liquefaction into biocrude, which is then refined into SAF.

- **Maturity:** Introduction (Gasification), Development (Pyrolysis and HTL)
- **Key focus area:** Gasifier capex, tar formation, O_2 content in biocrude

NOT A PERFECT SAF TECHNOLOGY

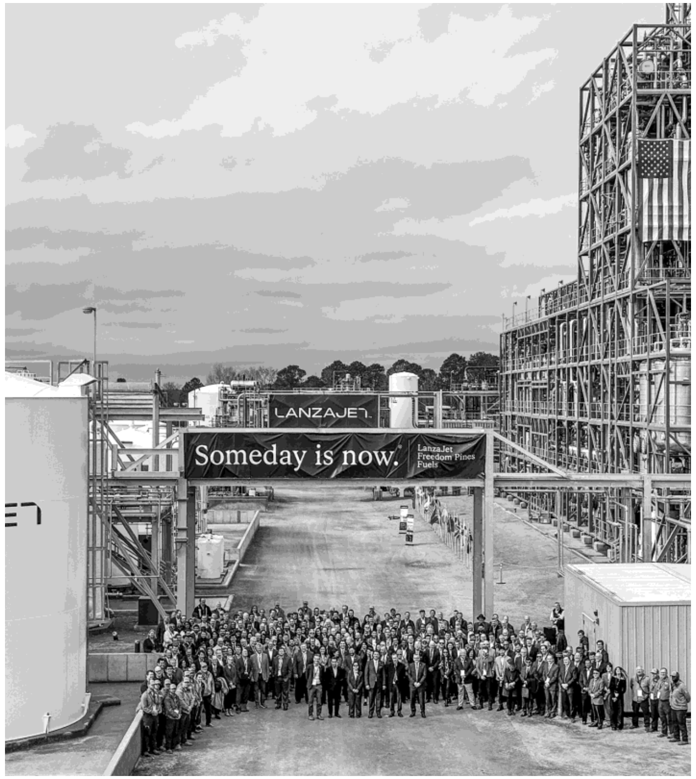
+	**Abundant feedstock**	Forestry & agricultural feedstock is widely available globally
+	**Sustainable feedstock**	Biomass has a low carbon intensity
—	**Developing technology**	Biomass/MSW gasification is under development; FT for SAF is not yet at scale
—	**Emerging developers**	No strong leader in gasification yet; experienced developers in FT

ETHANOL – TO – SAF

Enabling Technology:

Ethanol-to-jet (ETJ) (ASTM approved, 2016)

- Ethanol-to-jet (ETJ) is a three-step catalytic conversion of ethanol into jet fuel. Ethanol is first dehydrated into ethylene, which is then oligomerized into long-chain hydrocarbons before hydrogenation into jet fuel.
- The ethanol can be first generation (1G) from food crops or second generation (2G) from cellulosic sugars.



- **Maturity:** Demonstration
- **Key focus area:** Catalyst stability, product yield, 2G ethanol supply

NOT A PERFECT SAF TECHNOLOGY

+	**Abundant feedstock**	1G ethanol is a commodity and widely available globally; 2G ethanol is limited
+	**Sustainable feedstock**	1G ethanol is not sustainable; 2G ethanol has a low carbon intensity
—	**Developing technology**	ETJ is currently at demo scale; cellulosic ethanol is stagnating
+	**Experienced developers**	Multiple large corporations in the market (Honeywell UOP, Axens, etc.)

CO_2 – TO – SAF

Enabling Technologies:

Fischer-Tropsch (FT) (ASTM approved, 2009), Methanol-to-jet (MTJ)

- The conversion of CO_2 and hydrogen into SAF via multi-step pathways.
- The main pathway is via FT; CO_2 and hydrogen is converted into syngas via reverse water gas shift, which is then converted to fuel via FT.
- An emerging pathway is through methanol; CO_2 and hydrogen is converted to methanol via CO_2 hydrogenation, which is then dehydrogenated, oligomerized, and hydrotreated into jet fuel.

- **Maturity:** Development
- **Key focus area:** Electrolysis scale-up, source of CO_2,

NOT A PERFECT SAF TECHNOLOGY

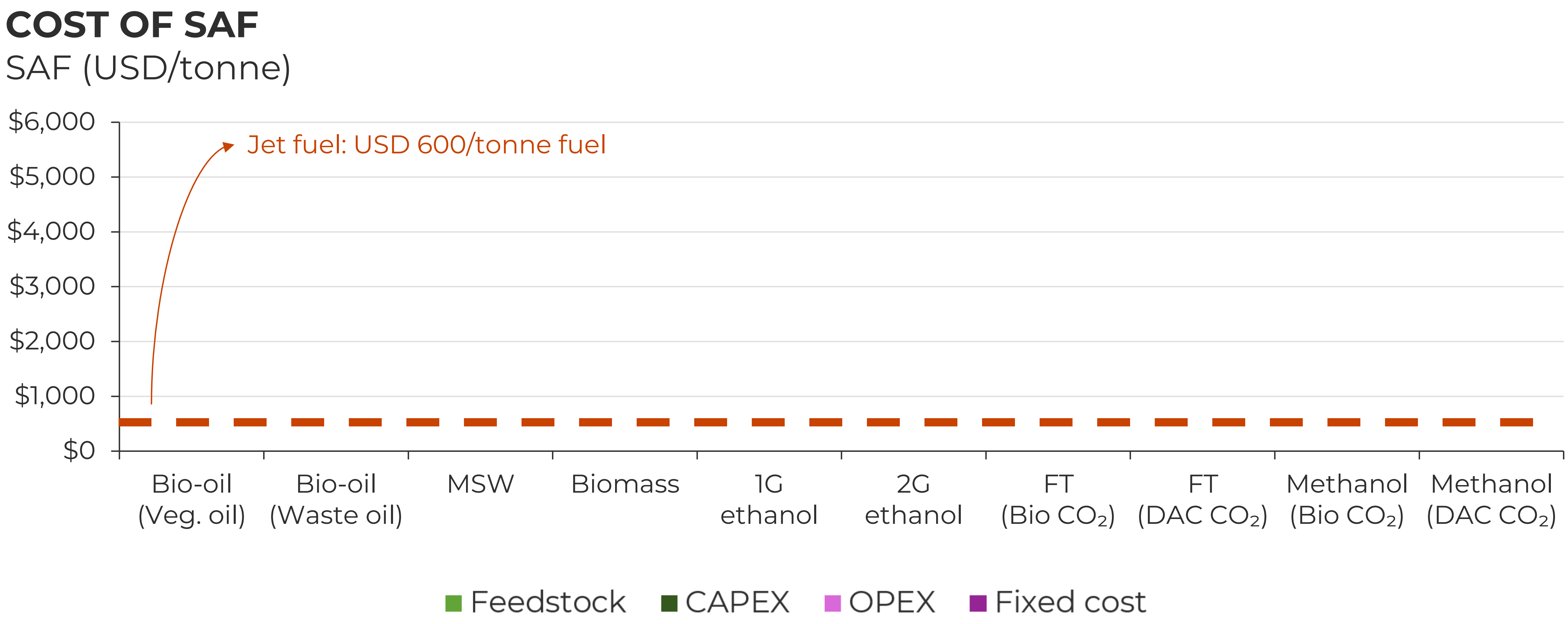
+	**Abundant feedstock**	CO_2 from ambient air and green hydrogen are (theoretically) abundant; biogenic CO_2 less so
+	**Sustainable feedstock**	(Ambient or biogenic) CO_2 and green hydrogen have a low carbon intensity
–	**Developing technology**	DAC and electrolysis are emerging; FT and MTJ for SAF are not yet at scale
+	**Experienced developers**	Multiple large corporations for electrolysis, FT, and MTJ

BUILDING A PERFECT SAF TECHNOLOGY

Bio-oil to SAF	Biomass to SAF	Ethanol to SAF	CO_2 to SAF
– Limited feedstock	+ Abundant feedstock	+ Abundant feedstock	+ Abundant feedstock
+ Sustainable feedstock	+ Sustainable feedstock	+ Sustainable feedstock	+ Sustainable feedstock
+ Scalable technology	– Developing technology	– Developing technology	– Scalable technology
+ Mature developers	– Emerging developers	+ Mature developers	+ Mature developers

At what cost?

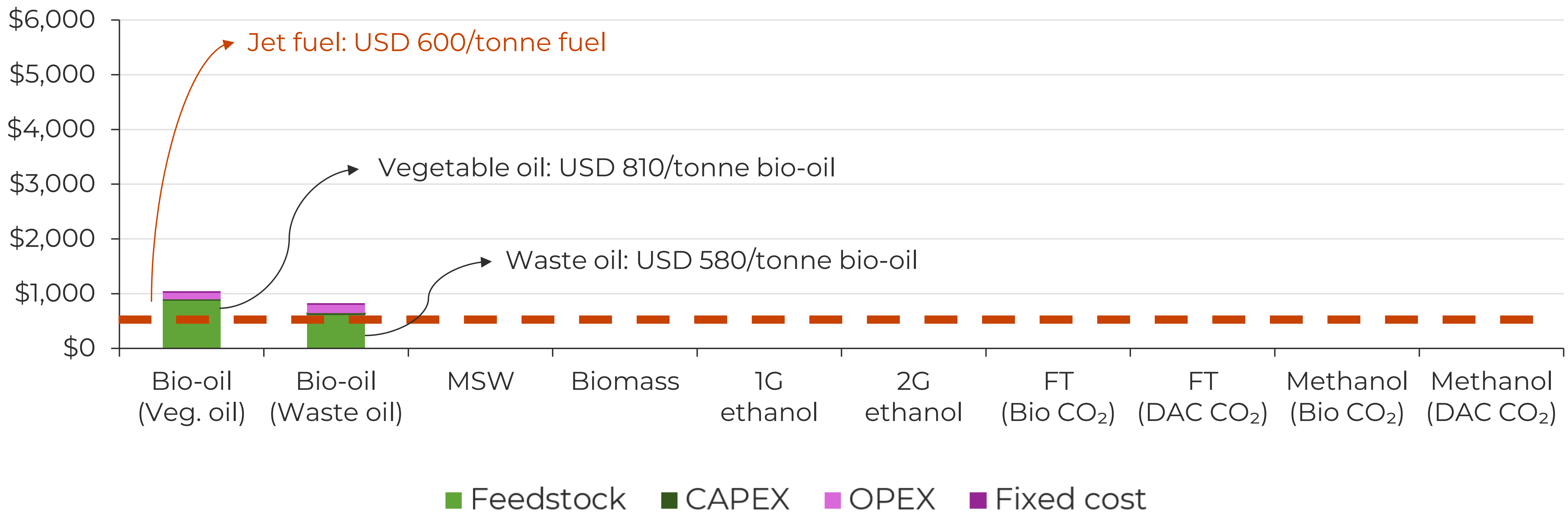
ECONOMICS OF SAF



ECONOMICS OF SAF – BIO OIL TO SAF

COST OF SAF

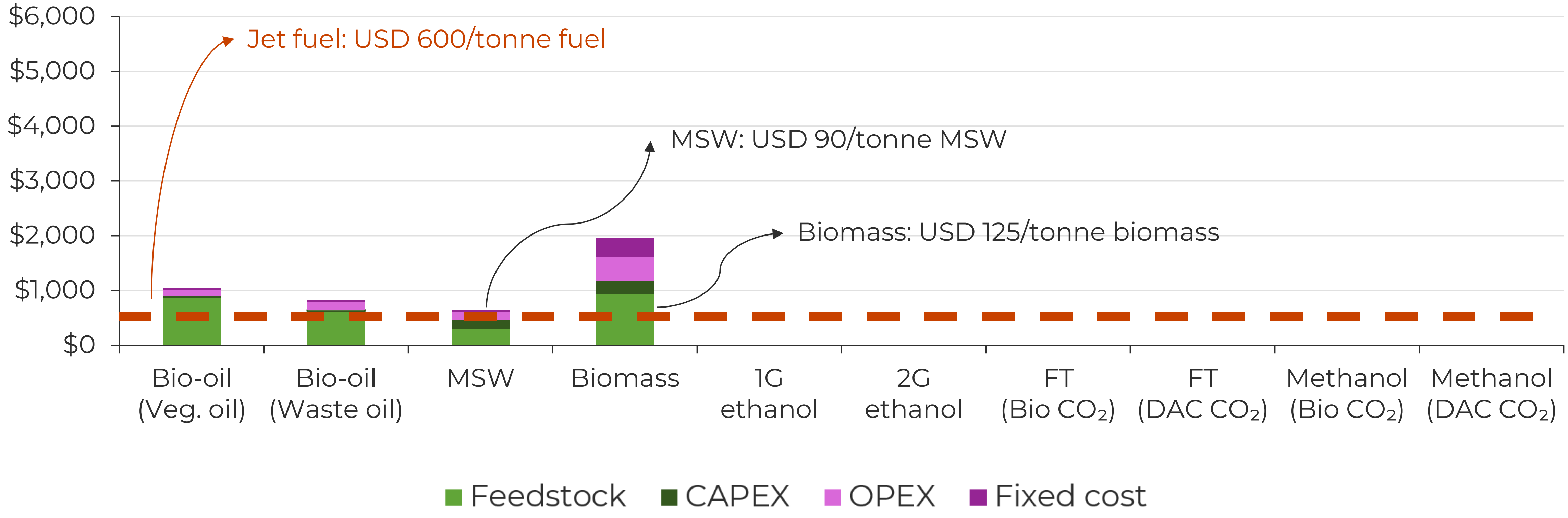
SAF (USD/tonne)



ECONOMICS OF SAF – BIOMASS TO SAF

COST OF SAF

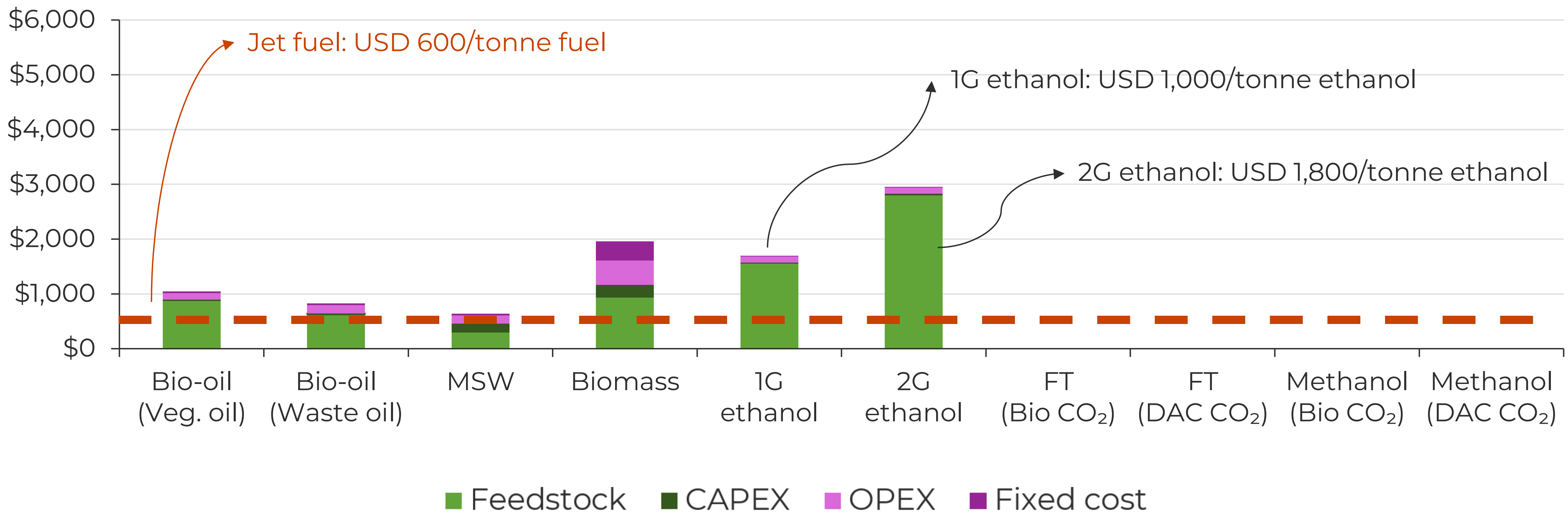
SAF (USD/tonne)



ECONOMICS OF SAF – ETHANOL TO SAF

COST OF SAF

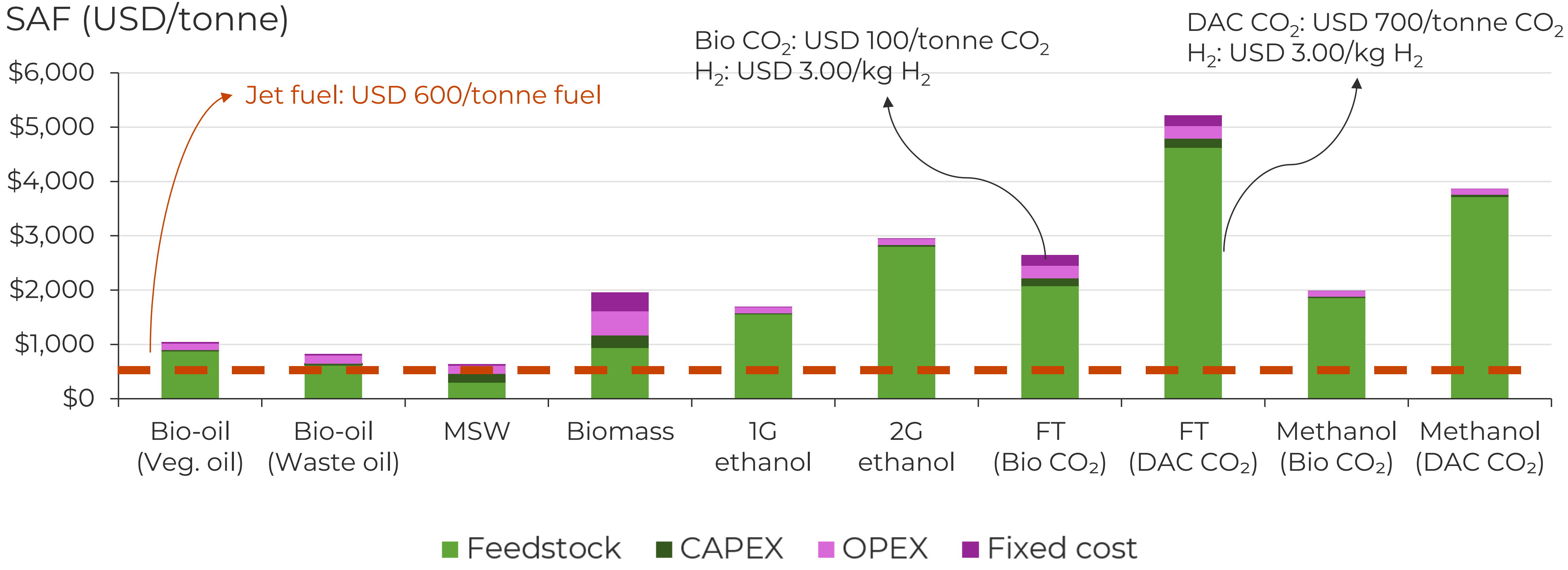
SAF (USD/tonne)



ECONOMICS OF SAF – CO_2 TO SAF

COST OF SAF

SAF (USD/tonne)

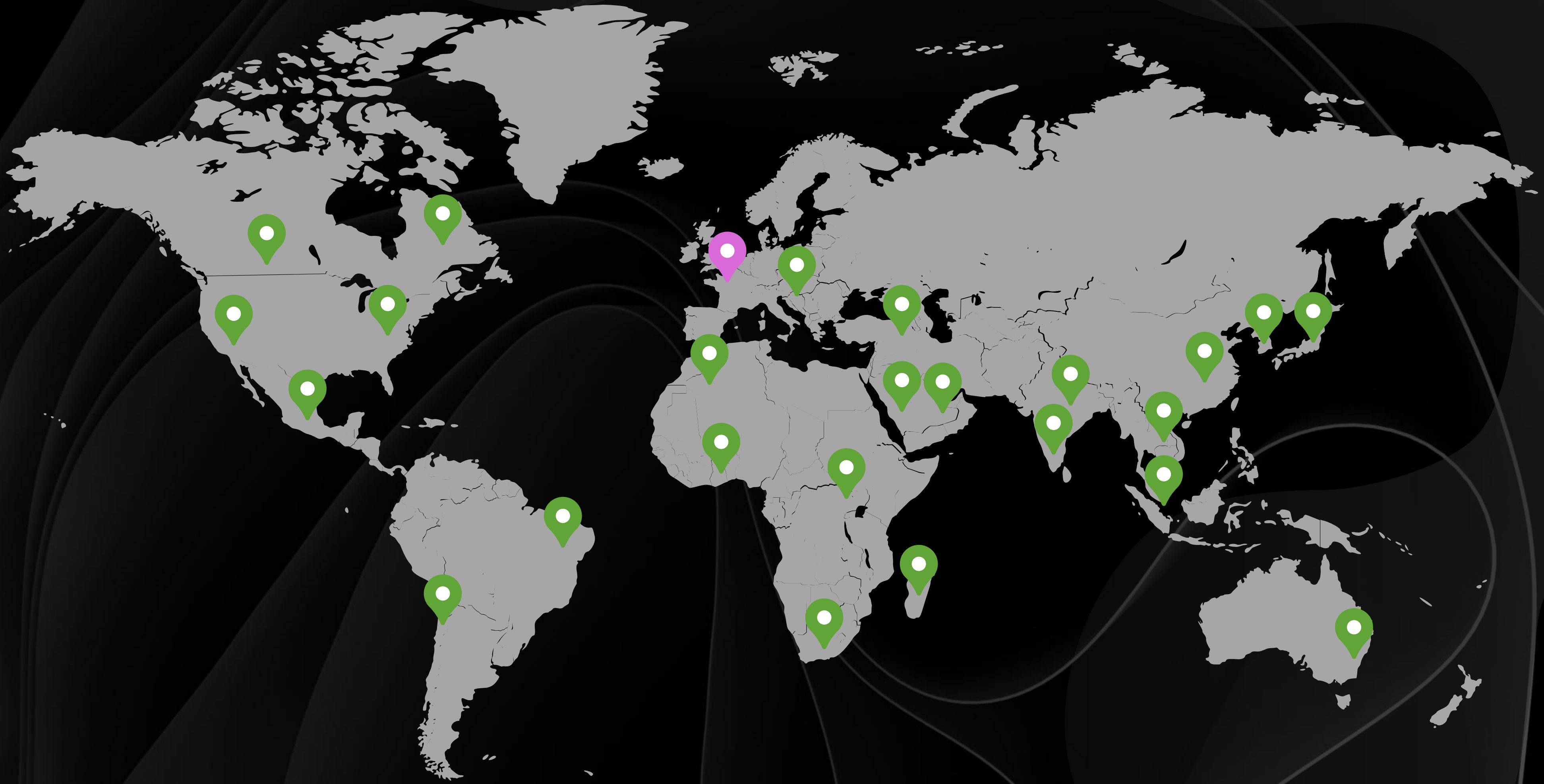


How does it play out for an airline?

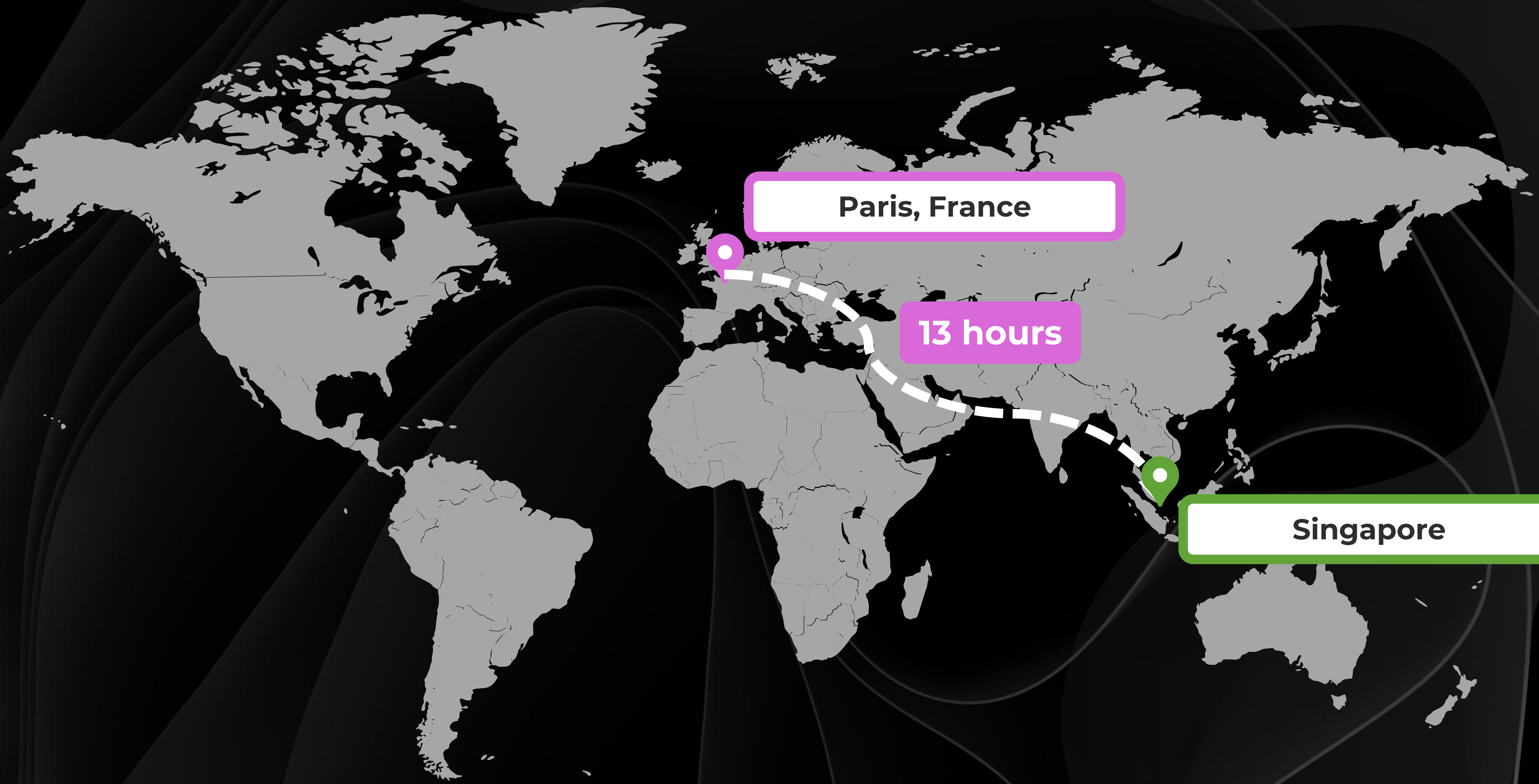
"We aim to incorporate at least 10% of SAF globally by 2030, far exceeding European regulations within this timeframe."

AIRFRANCE

AIR FRANCE FLIES TO 85 COUNTRIES

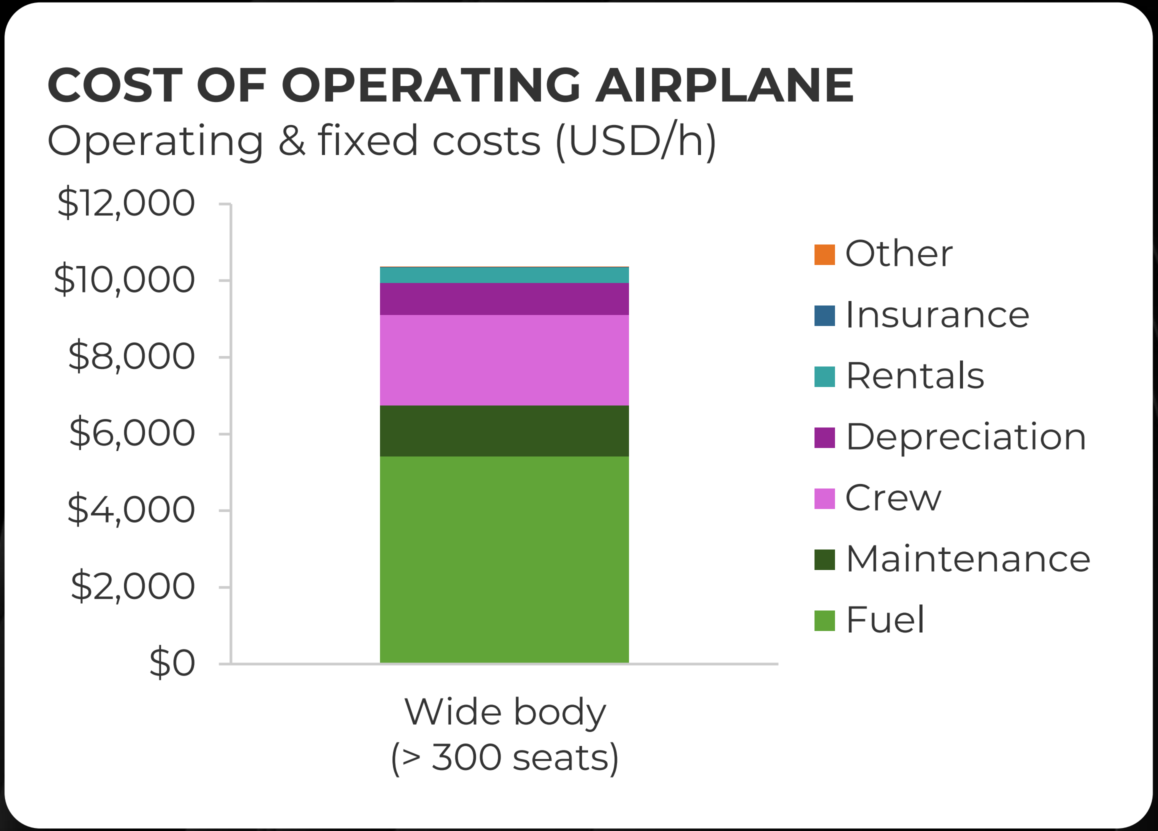


PARIS TO SINGAPORE



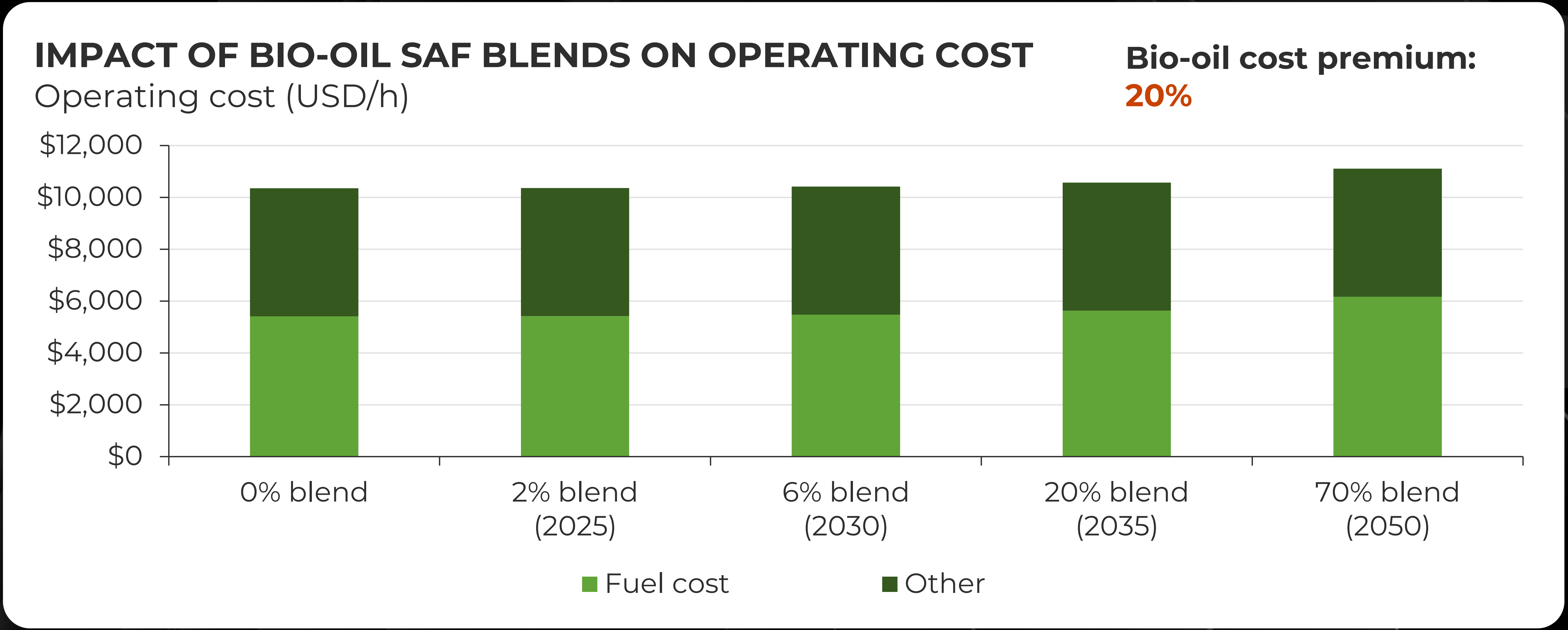
COST OF AVIATION

Operating cost of airplanes

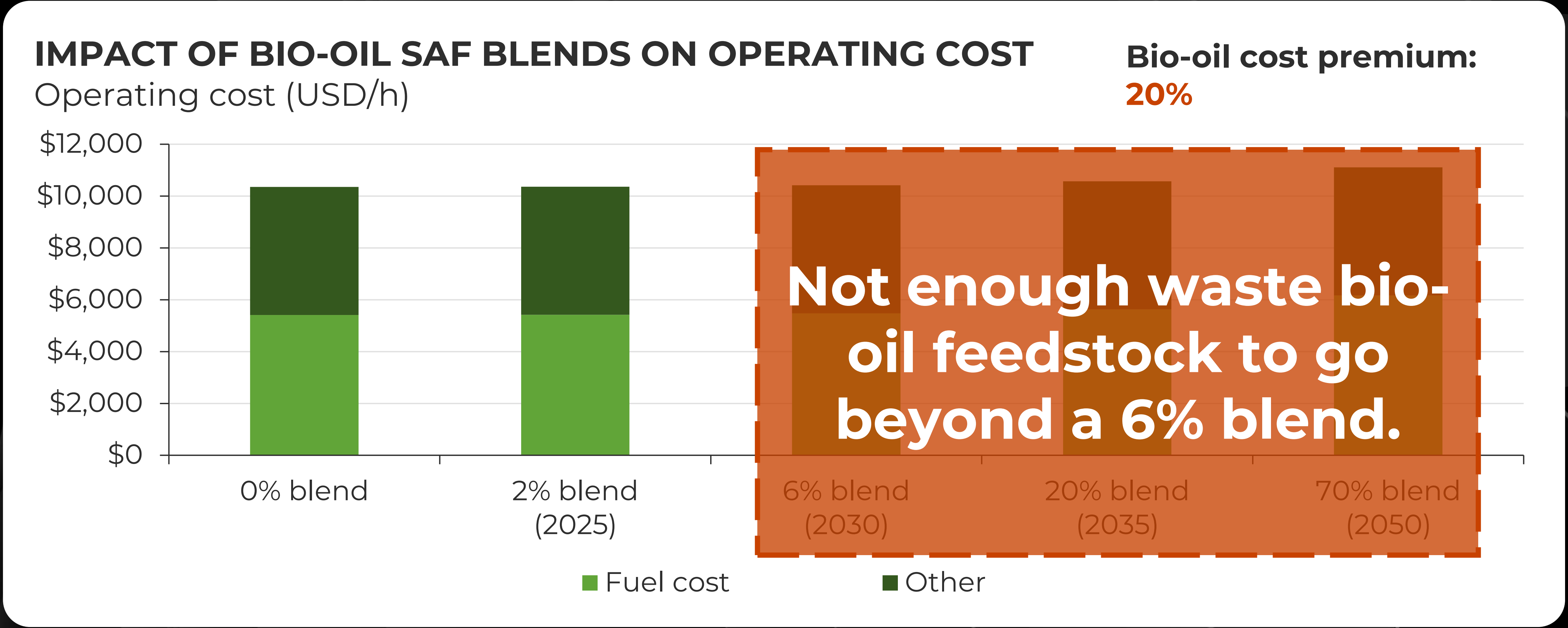


The total operating cost of a 13-h, 300-passenger flight from Paris to Singapore is roughly USD 135,000.

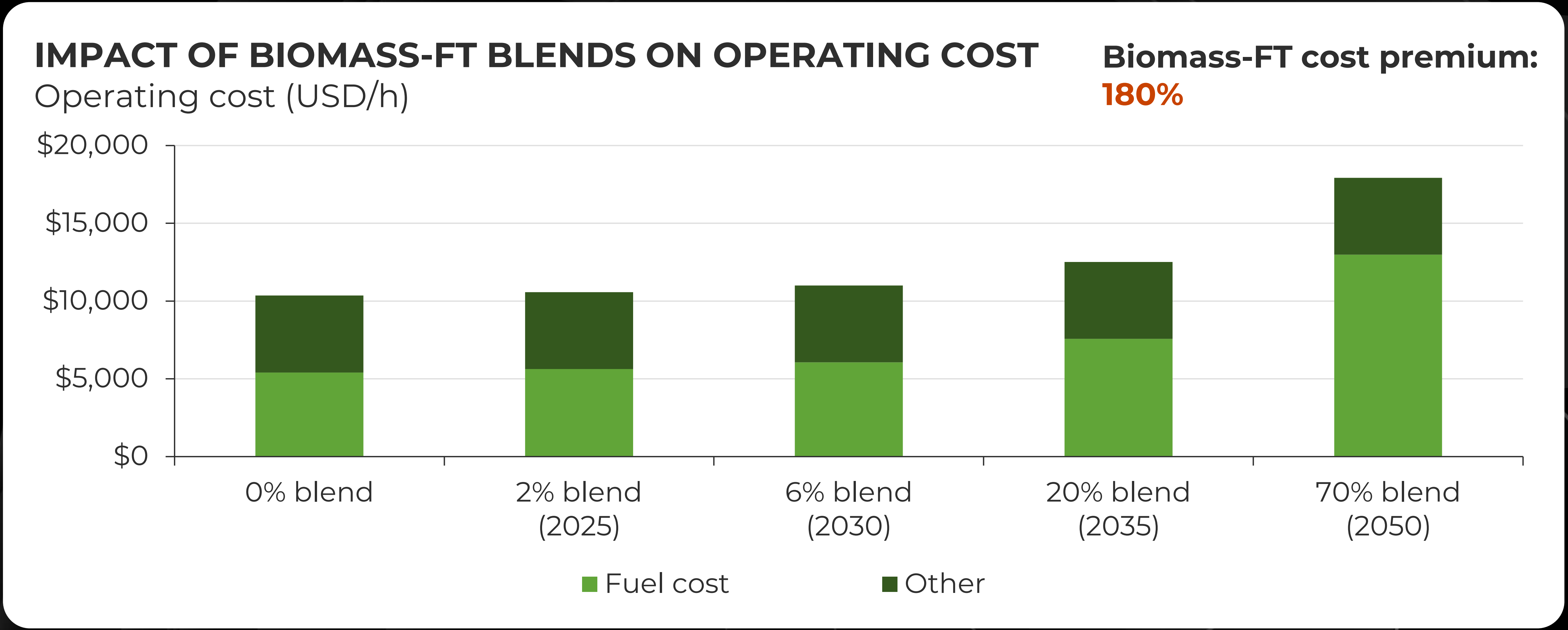
IMPACT OF HEFA IS MINIMAL



IMPACT OF HEFA IS MINIMAL



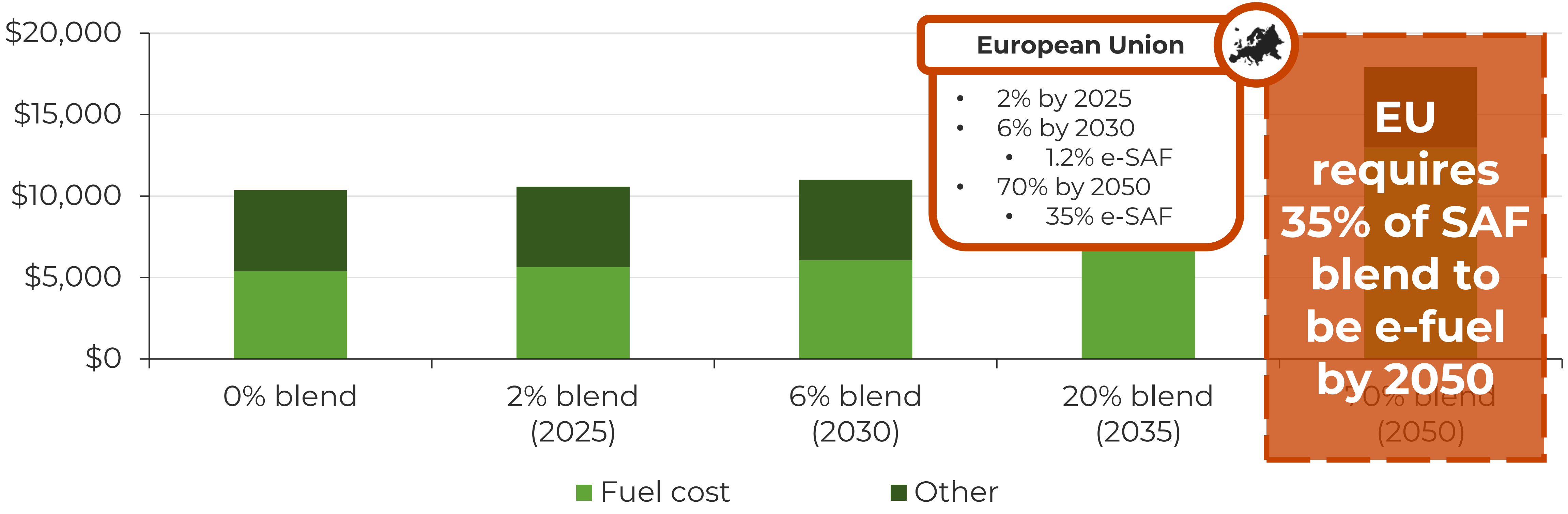
IMPACT OF BIOMASS FT IS NOTICEABLE



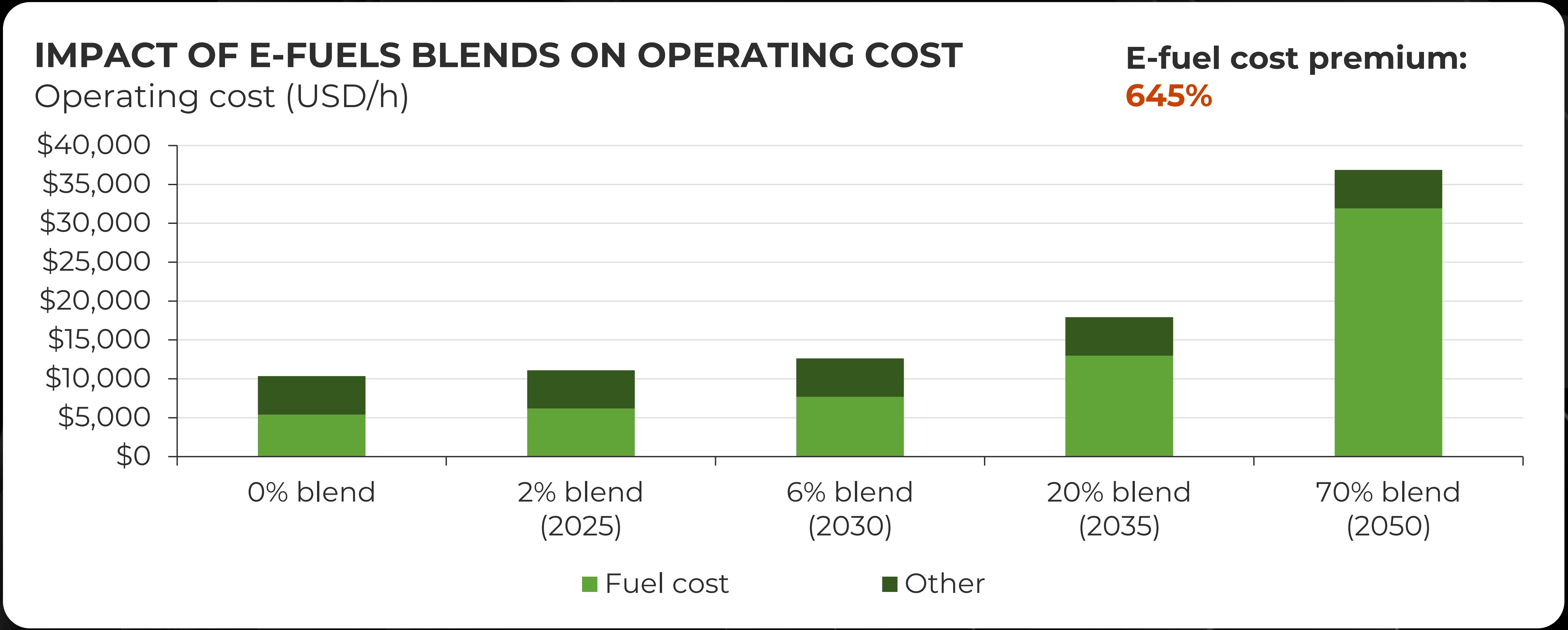
IMPACT OF BIOMASS FT IS NOTICEABLE

IMPACT OF BIOMASS-FT BLENDS ON OPERATING COST
Operating cost (USD/h)

Biomass-FT cost premium: 180%



IMPACT OF E-FUELS IS UNFATHOMABLE



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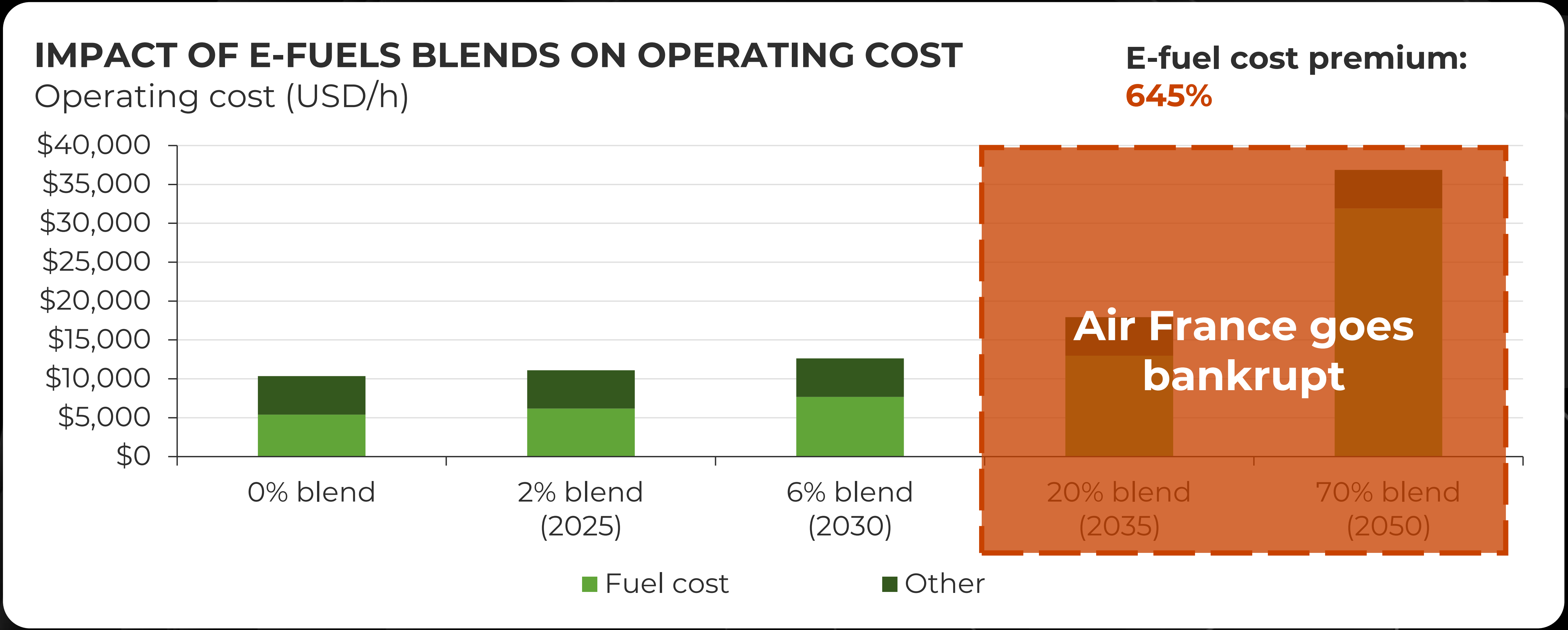

What can you do?

BUILDING A PERFECT SAF TECHNOLOGY

Bio-oil to SAF	Biomass to SAF	Ethanol to SAF	CO_2 to SAF
– Limited feedstock	+ Abundant feedstock	+ Abundant feedstock	+ Abundant feedstock
+ Sustainable feedstock	+ Sustainable feedstock	+ Sustainable feedstock	+ Sustainable feedstock
+ Scalable technology	– Developing technology	– Developing technology	– Scalable technology
+ Mature developers	– Emerging developers	+ Mature developers	+ Mature developers

BUILDING A PERFECT SAF TECHNOLOGY

Bio-oil to SAF

- – Limited feedstock
- \+ Sustainable feedstock
- \+ Scalable technology
- \+ Mature developers

CEMVITA

Develops a microbial platform to convert CO_2 and water into bio-oil feedstock for HEFA.

LUX TAKE

Bio-oil from CO_2 is a breakthrough, but scalability will remain an issue.

MONTANA RENEWABLES™

Uses non-food camelina oil to produce SAF from HEFA.

LUX TAKE

Innovations in energy crops will resurface as feedstock supply challenges loom.

BUILDING A PERFECT SAF TECHNOLOGY

Biomass to SAF

- \+ Abundant feedstock
- \+ Sustainable feedstock
- – Developing technology
- – Emerging developers

Haffner Energy
Making Hydrogen Super Green

Develops a combined thermolysis and cracking technology for syngas from biomass.

LUX TAKE

Full tar elimination will be crucial for successful deployment.

ALDER RENEWABLES

Develops a pyrolysis oil treatment technology to reduce oxygen content below 10%.

LUX TAKE

Unlocking pyrolysis oil for existing refinery assets will be a breakthrough.

BUILDING A PERFECT SAF TECHNOLOGY

Ethanol to SAF

- + Abundant feedstock
- + Sustainable feedstock
- – Developing technology
- + Mature developers

NOVAPANGAEA TECHNOLOGIES

Develops steam-assisted pyrolysis of biomass into fermentable sugars.

LUX TAKE

Technology validation is key as ETJ is ready to scale.

synata bio

Develops microbial conversion of syngas into ethanol for jet fuel.

LUX TAKE

ETJ must showcase better economics versus MTJ for commercial success.

BUILDING A PERFECT SAF TECHNOLOGY

CO_2 to SAF

- + Abundant feedstock
- + Sustainable feedstock
- – Scalable technology
- + Mature developers

OXCCU

Develops a technology to convert CO_2 and hydrogen directly into SAF via FT.

LUX TAKE

Technology will reduce capex, but high feedstock costs will remain a barrier.

sora fuel

Develops a technology for single-step DAC and syngas generation.

LUX TAKE

Reducing energy demand will lower CO_2 cost, but tech is still at lab scale.

Lux Research

Novel SAF technologies are not yet ready to scale; the space is full of innovation opportunities

KEY TAKEAWAYS

1

The EU's SAF mandate for 2030 will fail.

Lack of feedstock supply for waste oil and immature technologies will cause the EU to delay implementation of the 6% blend level; the e-fuel sub-mandate is likely to be scrapped due to high production costs for CO_2-based SAF.

2

DAC should not be used for SAF.

It will always be cheaper to sequester CO_2 than transform it into fuel. Beware of any projects that rely on DAC as they are likely to fail.

3

Innovate in biobased feedstock & technology.

The only chance to meet the demands of the mandate is through bio-SAF. Focus on unlocking energy crops for HEFA and scaling gasification and pyrolysis to convert cellulosic biomass into SAF.

THANK YOU

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