ICAO ENVIRONMENT

ACT-SAF #24 SERIES

Alcohol-to-Jet: Unlocking a key SAF conversion pathway

ICAO ENVIRONMENT

ACT-SAF Series #24 Speakers

ACT SAF

Daniel Bloch

Director, Strategic Partnerships

LANZAJET

David Schwalje

Vice President, Emerging Market Development

AXENS

Sylvain Verdier

Senior Strategy Manager

TOPSOE

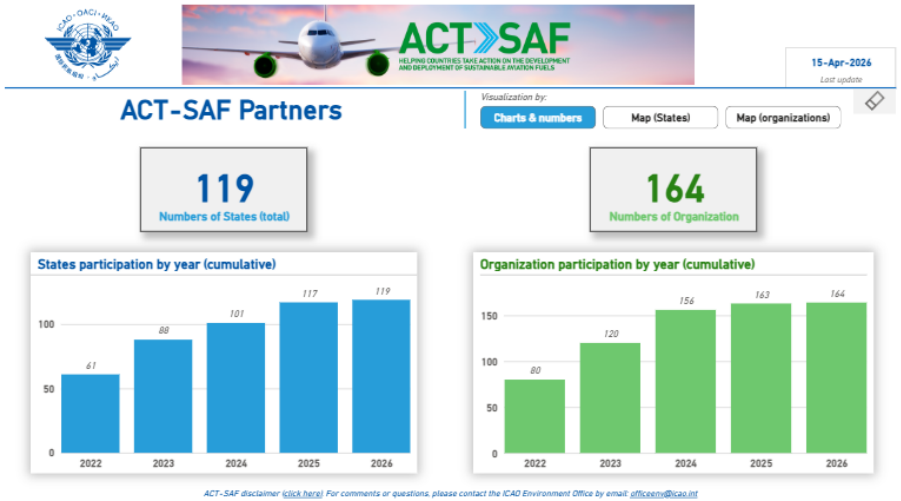
Agenda

- Opening
- Status update on ACT-SAF Programme
- AtJ Technology Providers
  - LanzaJet
  - Axens
  - Topsoe
- Q&A
- Closing

Status update of ACT-SAF Programme

Structure of ACT-SAF Programme

Over 280 ACT-SAF partners



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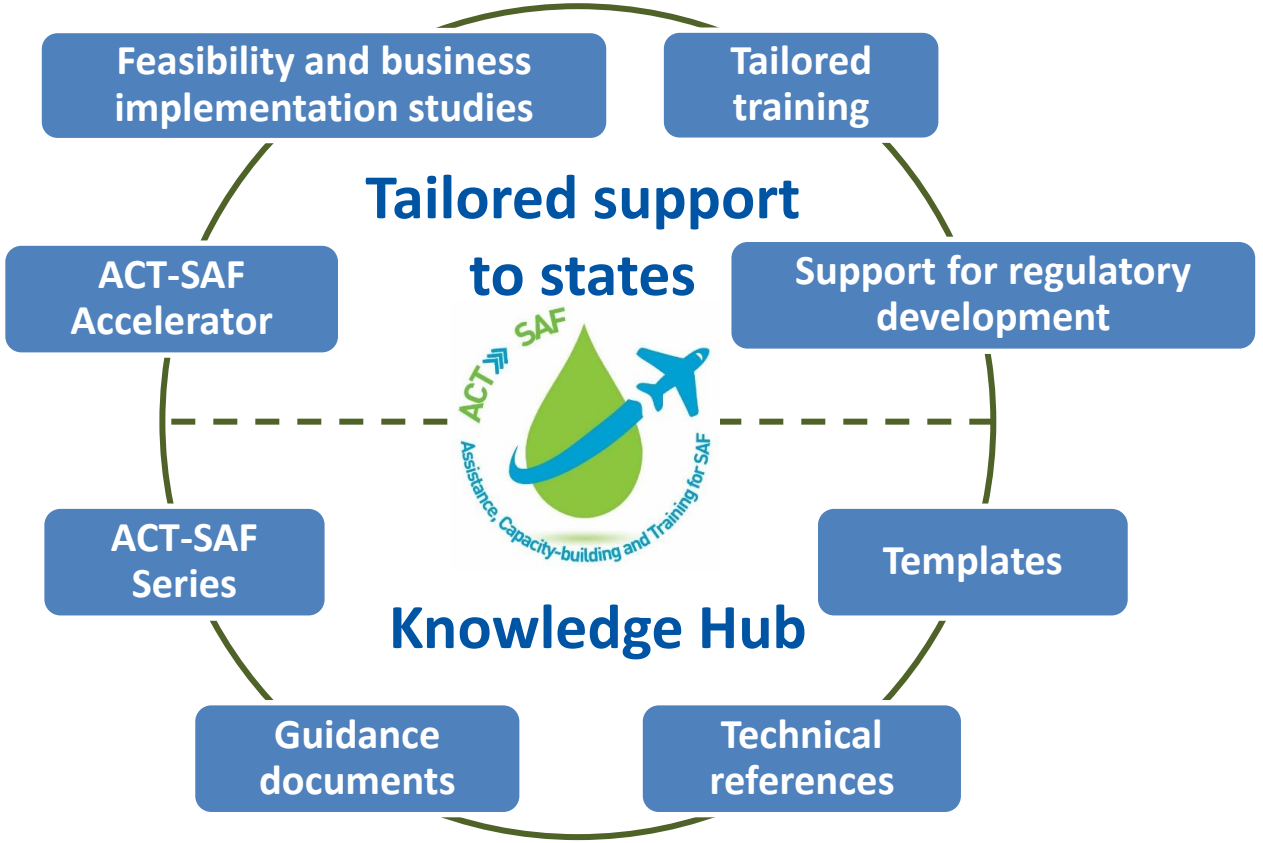
Two streams, eight elements

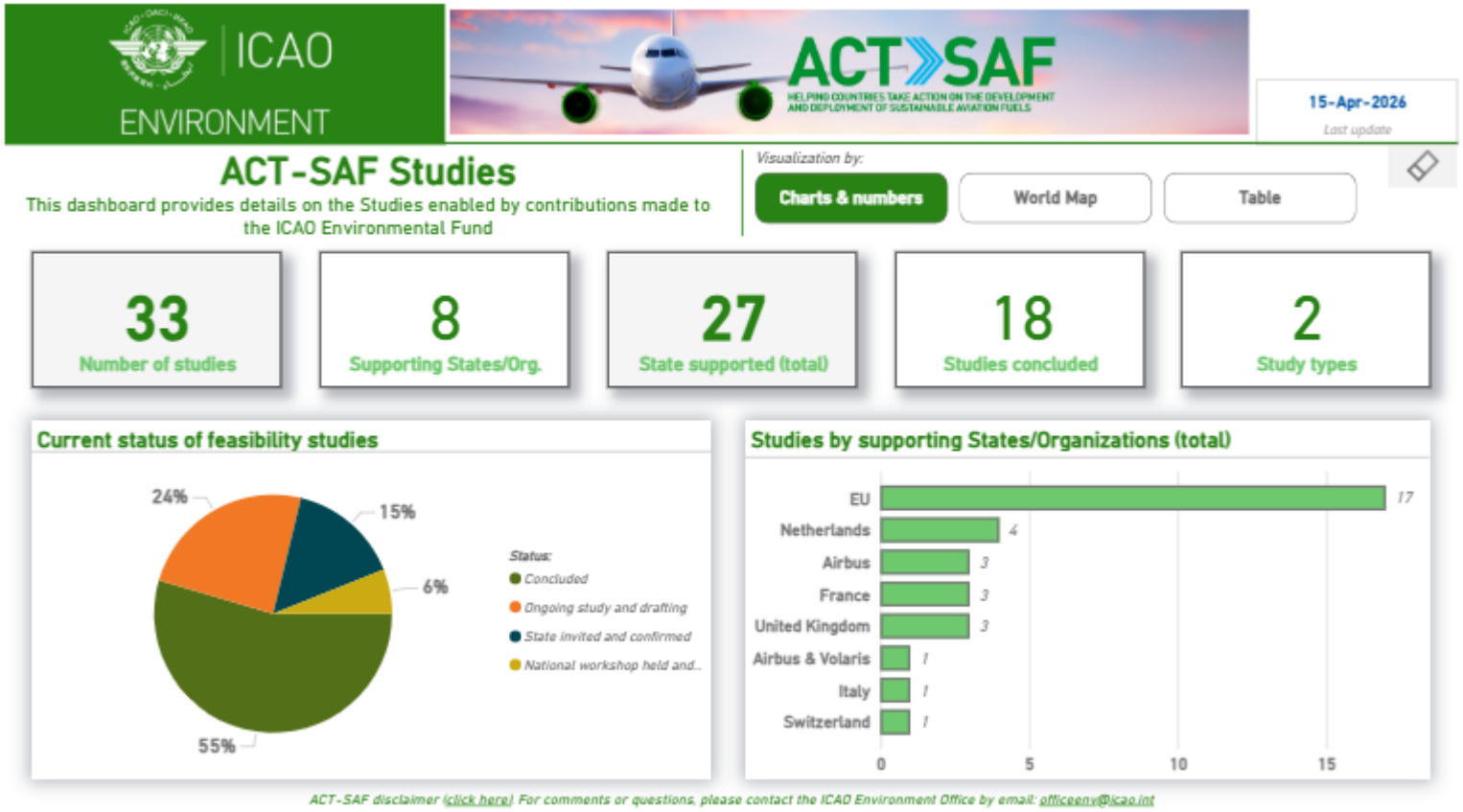


Overview of ACT-SAF studies and funding

33 ACT-SAF studies

(18 concluded / 15 ongoing)

- 8 supporting states/organizations (**France, Italy, Netherlands, Switzerland, United Kingdom, EU, Airbus and Volaris**)
- 1 co-funded study **(Angola/Italy)**
- Recent contributions **Republic of Korea** and **Spain** will enable additional studies
- **Austria and Côte d'Ivoire** contributed towards other activities

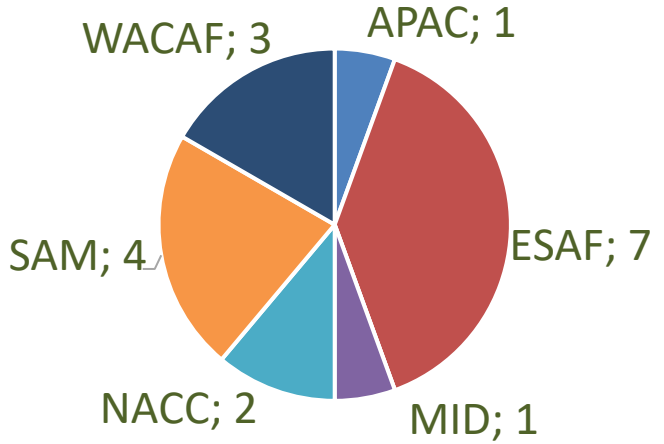


https://www.icao.int/ACT-SAF

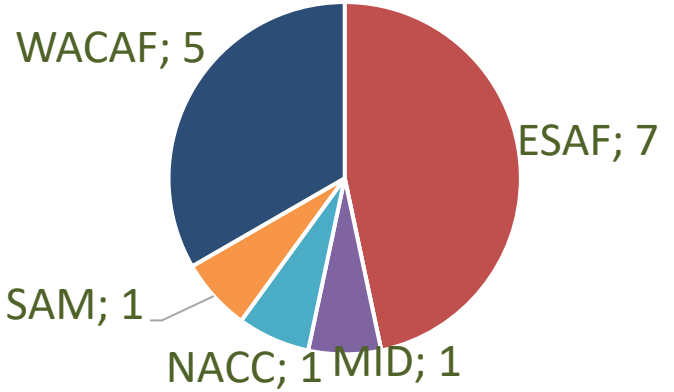
Details of all 33 ICAO ACT-SAF studies

	Feasibility studies	Business implementation studies
Completed	**16** Argentina, Burkina Faso, Chile, Côte d'Ivoire, Dominican Republic, Ethiopia, Ghana, India, Jordan, Kenya, Panama, Peru, Rwanda, Trinidad & Tobago, Uganda, Zimbabwe	**2** Kenya, Rwanda
Under development	**10** Angola, Cameroon, Egypt, Equatorial Guinea, Madagascar, Mauritania, Mexico, Mozambique, Namibia, Senegal	**5** Chile, Côte d'Ivoire, Ethiopia, South Africa, Zimbabwe

Completed: 18



Under development: 15



Recent developments

Launched: Namibia feasibility study / Chile business implementation study

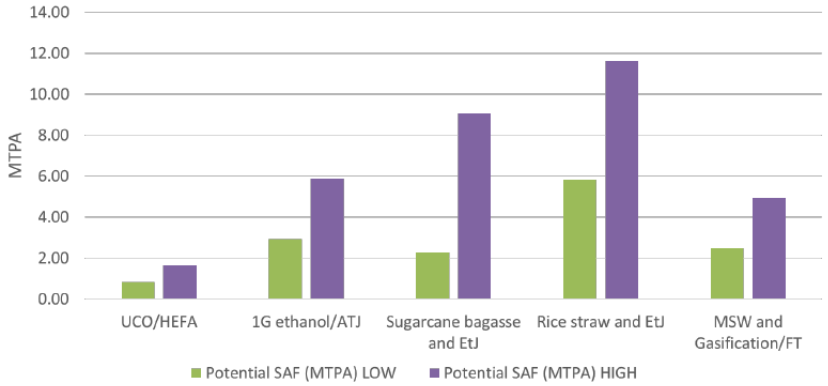
31 March – 1 April 2026

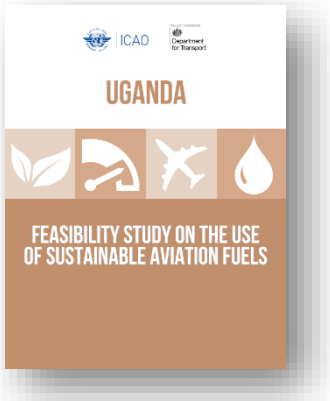
7 April 2026

Delivered: Argentina feasibility study

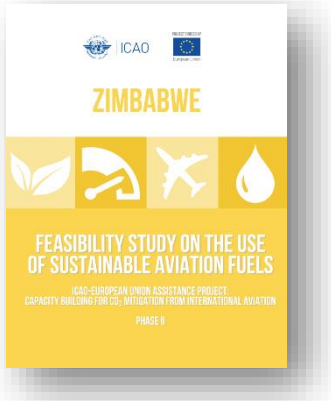
9 April 2026

AtJ in ACT-SAF studies

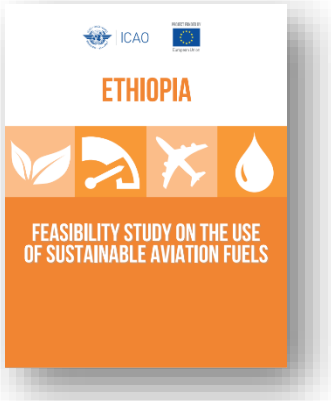




- Key feedstocks suit AtJ: sugarcane, maize, cassava
- Mixed agricultural waste, incl. banana
- MSW



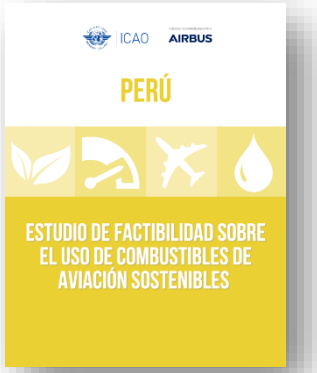
- Significant volumes and expansion potential for sugarcane bagasse
- Business implementation study



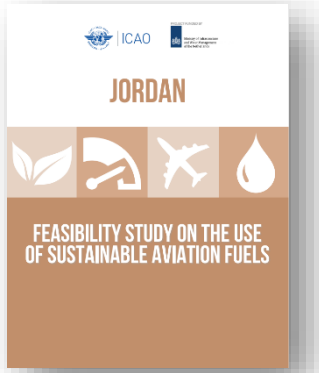
- Two key feedstocks are B. carinata (HEFA) and sugarcane molasses
- Business implementation study

AtJ in ACT-SAF studies

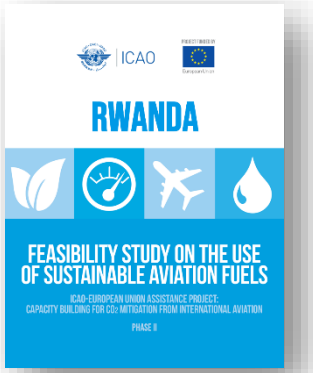
- Many potential feedstocks such as cashew apples, sugarcane (bagasse), maize, elephant grass, sorghum, MSW
- Key option: cassava residues
- Business implementation study



- #1 (sorghum) and #2 (agricultural residues) theoretical feedstocks suitable for AtJ
- Main feedstock in conservative scenario is still agricultural residues



- Up to 64% of feedstock suitable for AtJ
- Mainly MSW, plus fruit residues



- Diverse agricultural residues, chiefly maize stover
- Business implementation study

AtJ in ACT-SAF studies

- Large potential for AtJ, especially unlocking vast and diverse sources of existing agricultural waste
- Further action is needed to increase the maturity of the technology and its implementation globally

LANZAJET

ACT-SAF Webinar

Daniel Bloch – Director, Strategic Partnerships

The world's first commercially proven Alcohol-to-Jet solution

NON-CONFIDENTIAL

INDUSTRY LEADERSHIP

LanzaJet is a World Leader in Sustainable Fuels, Securing the Next Generation of Aviation

Our Mission

We were founded on the belief that it is our responsibility to preserve the world and the opportunity for future generations to fully experience it and thrive.

Who We Are

- A **leading next generation fuels technology company** with the world's first and only commercial-scale SAF Alcohol-to-Jet (ATJ) demonstration plant
- A **versatile and scalable platform,** that has now become **the world's first non-oil based,** drop-in aviation fuel
- Funded and supported by **global industrial leaders** across the value chain

LANZAJET

Our Funders and Supporters

AIRBUS, ANA, Breakthrough Energy, British Airways, Mitsui & Co., Groupe ADP, LanzaTech, Microsoft, U.S. Department of Energy, MUFG, Shell, Southwest

Freedom Pines Fuels

Our Proprietary and Commercially Proven ATJ Technology Has Been Scaled-up Over 15 years

ASTM INTERNATIONAL Standards Worldwide

ANA virgin atlantic

National Research Council Canada

2010 – 2015

Lab Bench and Pilot

- Technology validated at Pacific Northwest National Laboratory
- >300 catalysts screened (>400 through Q3 2020)
- Regeneration
- Catalyst life studies (>200 days)

2014 – 2016

Plant Demo

- 4,000 gallons (15,200 liters) Jet, 600 gallons (2,300 liters) Diesel
- Full recycle
- Tubular reactors; Oligomerization
- Regeneration
- Catalyst life studies (>400 days)
- Purification and distillation

2016 – 2020

ASTM Approval and Commercial Flights

- Ethanol based ATJ-SPK, ASTM D7566 (Annex 5)
- Two commercial flights
- Eight further test flights for contrail and emission analysis

2020 – 2025

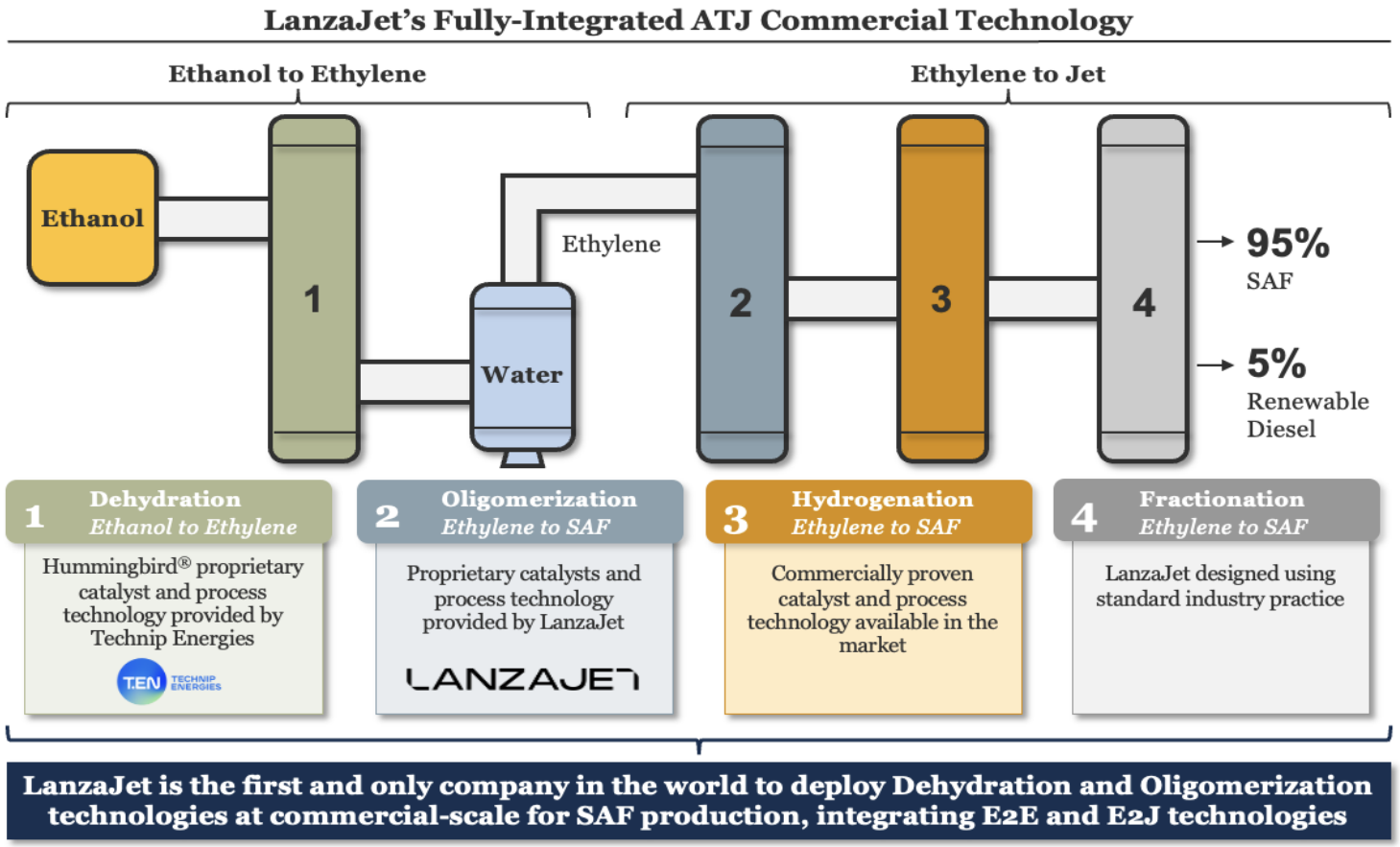
Commercial-scale Demo ATJ Plant

- Freedom Pines Fuels: 10MM GPY (30,000 metric tons)
- Mechanical Completion: Q4 2024
- First Full-Scale Production: Q4 2025

LANZAJET

LanzaJet's Technology: A fully integrated solution for SAF from Ethanol

The commercial technology can use any source of ethanol and turn it into SAF, achieving maximum carbon yield to hydrocarbons with high selectivity




CIRCUIT BREAKER
DC VOLTS AC AMPS AC VOLTS
COMP COOLING
ANTI-ICE
OFF
ON
AUTO

Freedom Pines Fuels Local Community Impact is Representative of Global Potential

Rural Economic Development Driver

- **300+ jobs** during construction
- **30-50 direct full-time jobs** during ongoing operations
- Local economy is expected to see a **$75M boost** in economic growth
- **$8M** in direct salary contributions

Global Partnership and Bipartisan Support

- **400+ executives**, government officials and members of the media from around the world joined our 2024 Plant Opening Event
- Remarks delivered by **Secretary of Agriculture**, Tom Vilsack and **Deputy Secretary of Energy**, David Turk, **Mayor of Soperton** and **Treutlen County Commissioner, Lt. Governor of Georgia**

Community Support and Engagement

- Engaged deeply in community – 2024 recipient of **Million Pines City Citizen Impact Award**
- Mayor Koon, "LanzaJet is like family" when referring to our support to community during Hurricane Helene
- Donation of essential equipment upgrades to local Treutlen County Emergency Management Agency
- Supporting STEM education at local high school events

Job Creation

Representatives from Across Government and Around the World

Citizen Award, Local Emergency Support and Youth STEM Engagement

LANZAJET

LanzaJet Can Use Existing Supply of Ethanol While Waste-based Sources Come Online

1st Generation: Current Ethanol Volumes

1G

- Ethanol currently produced from (non-edible) field corn, sugarcane, grains etc.
- 30Bn gallons of existing production of ethanol across the world
- Market demand is falling for road transportation fleet, as electrification grows

2nd Generation: Emerging Waste-Based Ethanol Sources

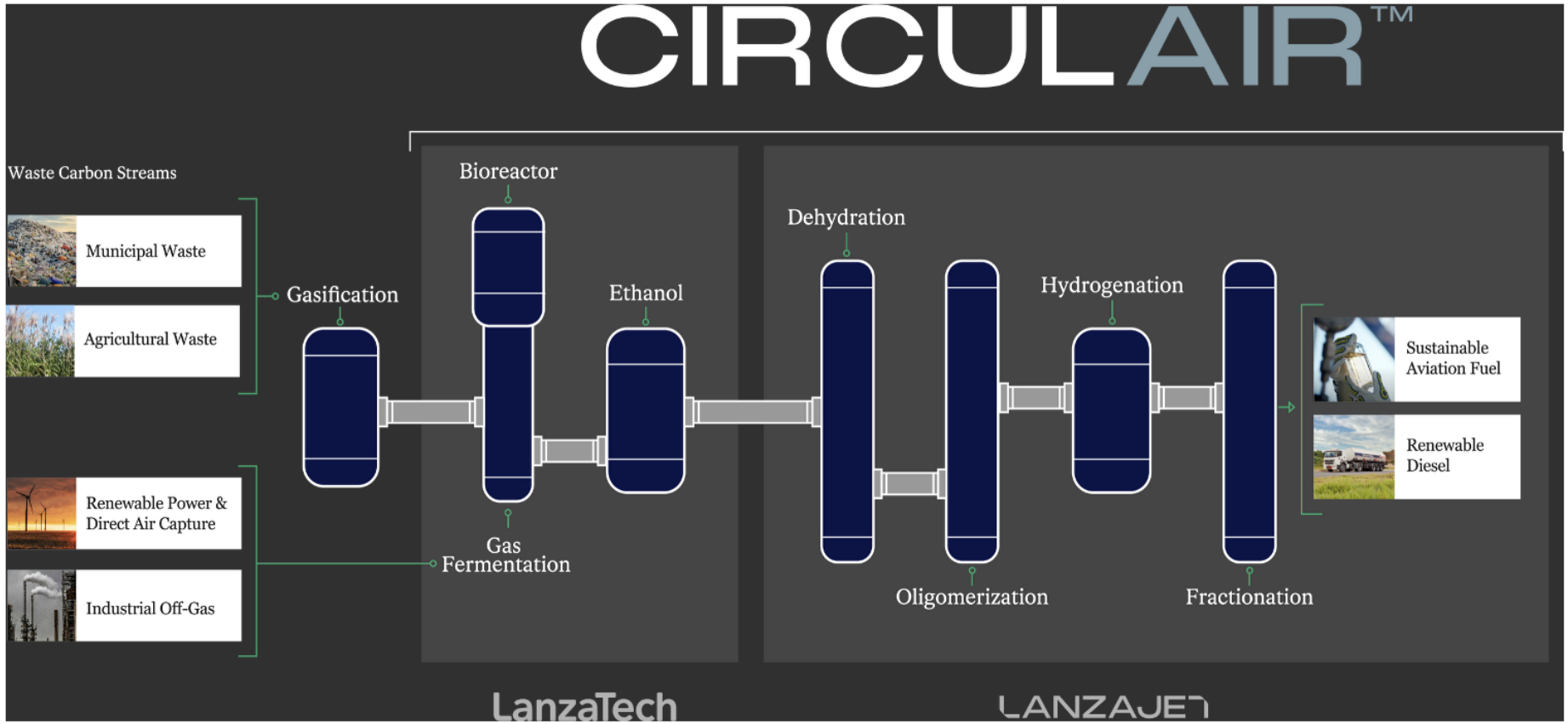
2G

- Industrial / landfill off-gases
- Agricultural / woody waste and residues
- Municipal Solid Waste (MSW)
- Cellulosic ethanol
- Sugarcane bagasse
- CO_2 off-gases
- Direct Air Capture (DAC) – CO_2 + H_2

ATJ can utilize a uniquely diverse array of feedstocks, making it the most flexible, cost effective and scalable solution on the market

Building on first generation ethanol, we'll be able to scale and successfully transition to waste-based sources, including CO_2 off-gases

LanzaJet to Further Expand its Viable Ethanol Feedstock Platform, via Gas Fermentation



Our Ethanol-to-Jet platform is positioned to deliver Power-to-Liquid SAF, via the processing of e-Ethanol

LANZAJET

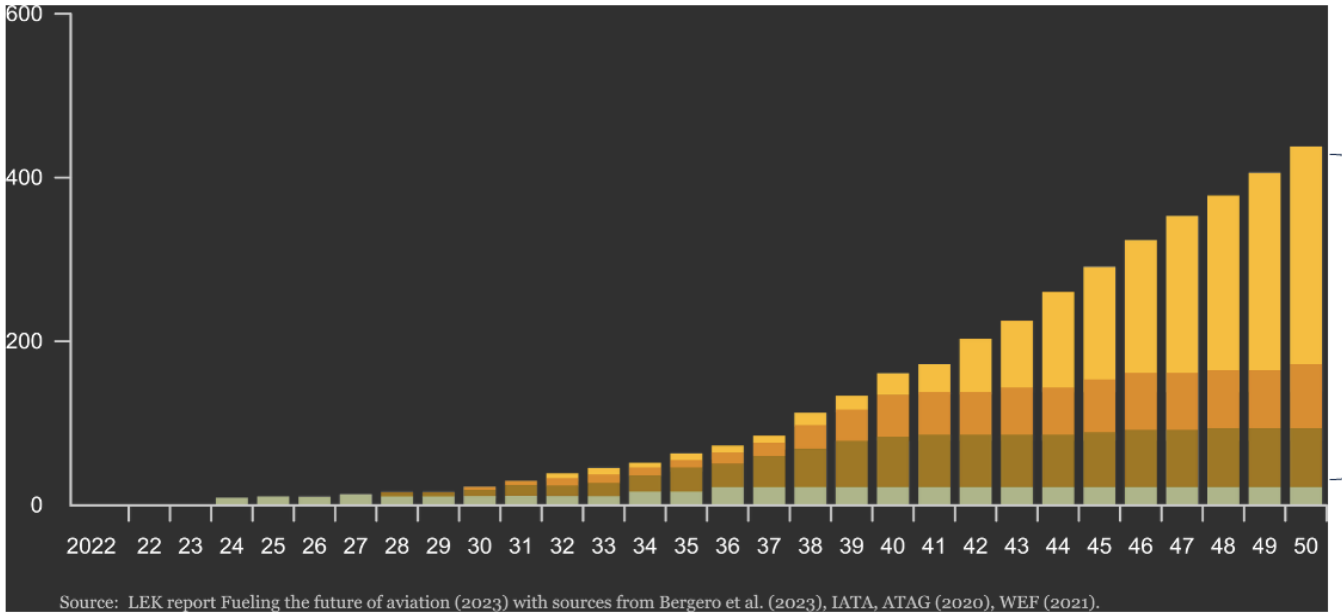
Source: IEA.

ATJ has significant potential for supply growth as other pathways hit capacity limits

SAF PRODUCTION BY TECHNOLOGY PATHWAY (2022-2050)

MILLIONS OF TONNES

LANZAJET ILLUSTRATION



Source: LEK report Fueling the future of aviation (2023) with sources from Bergero et al. (2023), IATA, ATAG (2020), WEF (2021).

Significant portion of forecasted Gasification and PtL volume can be met via LanzaJet's ATJ platform;

Leveraging CirculAir's Gas Fermentation technology

LanzaJet's Ethanol to Jet platformis compatible with nearly all forms of non-oil based feedstocks

LANZAJET

LanzaJet's Global Pipeline of Projects to 2030

LANZAJET

Supporting customers to develop projects

Complementing our Build, Own & Operate strategy, LanzaJet also extends License arrangements with leading Project Developers

NON-CONFIDENTIAL

ACT SAF

Assistance, Capacity-building and Training for SAF

Axens

Alcohol to Jet Perspectives

Axens

Mission Statement

Technology excellence in service of a sustainable transition; our partnering spirit and passion drive innovation into an industrial reality.

Axens In Brief

Company Profile

- Technology and catalyst provider for biofuel, biochemical, oil & gas, and petrochemical industries
- 40+ yrs. experience in biofuel & biotech
- Ownership structure: 100% IFPEN

Business areas

ALTERNATIVES & RENEWABLES | PETROCHEMICALS | GASES | OIL REFINING | WATER

Offices in **15** countries

3,000+ industrial units under license

3,500+ furnaces sold

500+ modular units references

70,000+ tons catalysts & adsorbents sold each year

Axens Offer

- Integrated solutions
- Covers the entire value chain

Axens HORIZON | Axens SOLUTIONS | Heurtey Petrochem SOLUTIONS

Axens & IFPEN Synergies

TRL1 TRL2 TRL3 TRL5 TRL6 TRL7 TRL8 TRL9

INSTRUCTION → EXPLORATION → DEVELOPMENT → INDUSTRIALIZATION including Demo Plant * → First reference sizing and start-up

IFP Energies nouvelles

Applied R&D, pre-screening, concepts testing, scale-up to pilot scale, FTO
IFPEN leadership

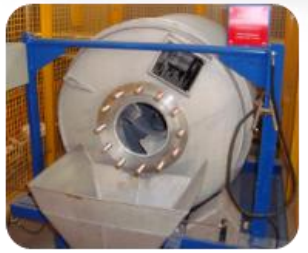
Axens

Scale-up to half-industrial, Industrial trial
Prototyping / Up-scaling / Demo Plant (optional)
Marketing & industrialization

Axens leadership

Chemical Experiments

Process Experiments, Design & modeling



Pilot scale capacities

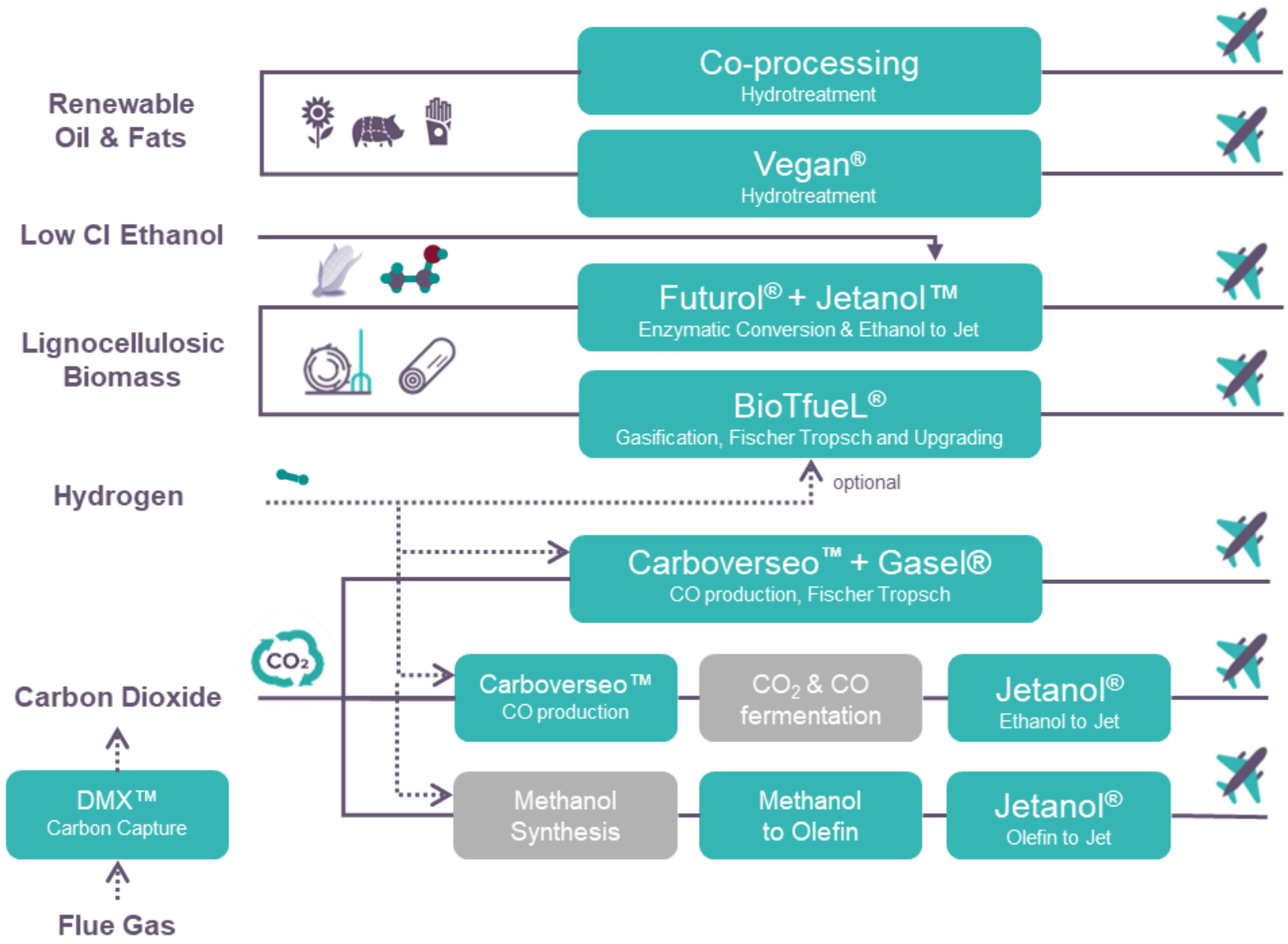
Design & validation

Manufacturing Capacities

Potential Development Partner

Axens Focus on SAF R&D

ACT SAF



CATEGORY (*)	ASTM
SAF	A1 D1655
SAF	HEFA-SPK A2 D7566
SAF	ATJ-SPK A5 D7566
SAF / E-SAF	FT-SPK A1 D7566
E-SAF	FT-SPK A1 D7566
E-SAF	ATJ-SPK A5 D7566
E-SAF	*Coming soon D7566*

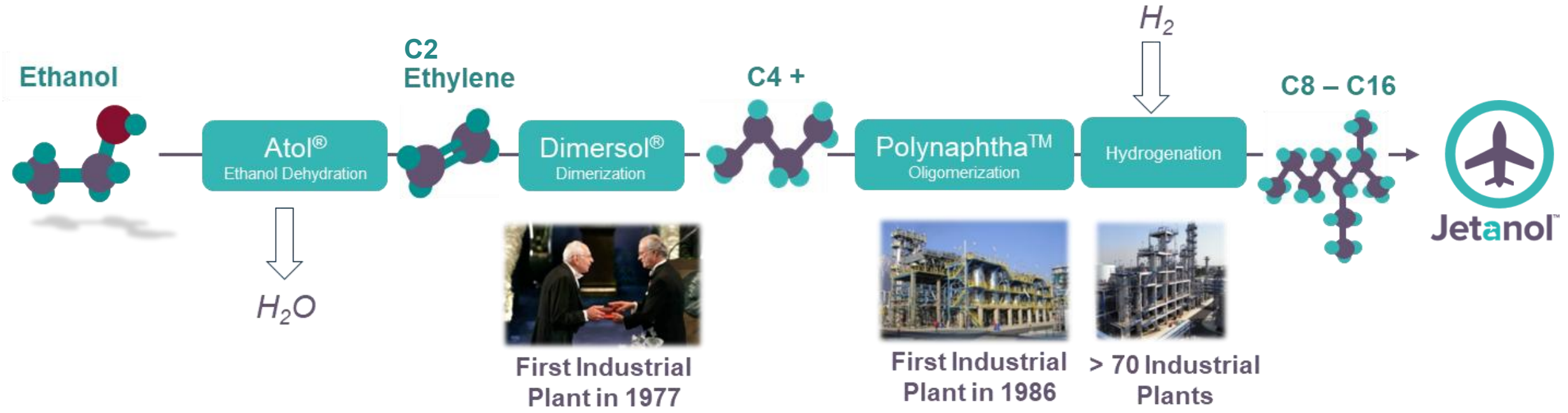
FOCUS ON ATJ

Jetanol™

Ethanol to Jet Chemistry

The Principle:

1. Remove ethanol oxygen by dehydration to water
2. Form hydrocarbons (ethylene)
3. Use existing, proven processes to build carbon chains to jet



Over 100 Oligomerization Industrial References

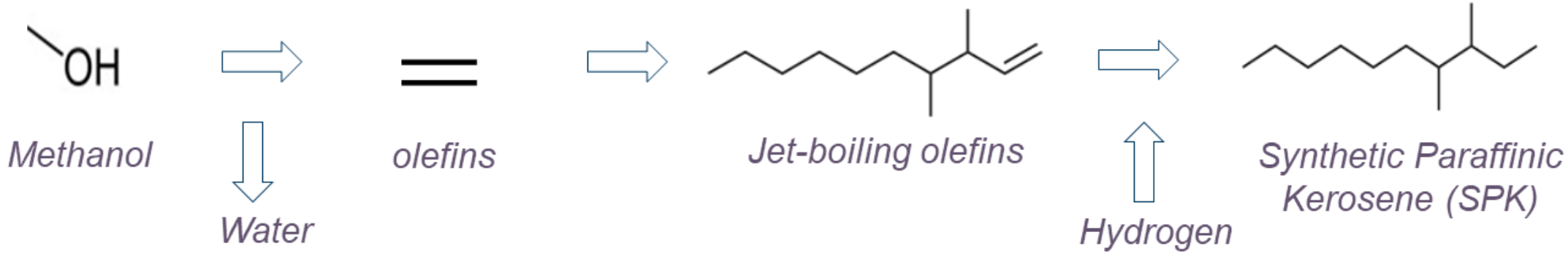
Methanol to Jet Chemistry

ATJ

The Principe:

1. Remove methanol oxygen by dehydration to water
2. Form hydrocarbons
3. Use existing, proven processes to build carbon chains to jet

Dehydration **Oligomerization** **Hydrogenation**



Using the same “chain building” processes as ETJ chemistry

Some History

Jetanol™ journey: The beginning …

- Steps as defined by ASTM…

… were all available technologies in Axens portfolio.

Jetanol™ journey: Existing tech for future challenges…

- Unique Dual catalytic system oligomerization :

Homogeneous Catalysis

Heterogeneous Catalysis

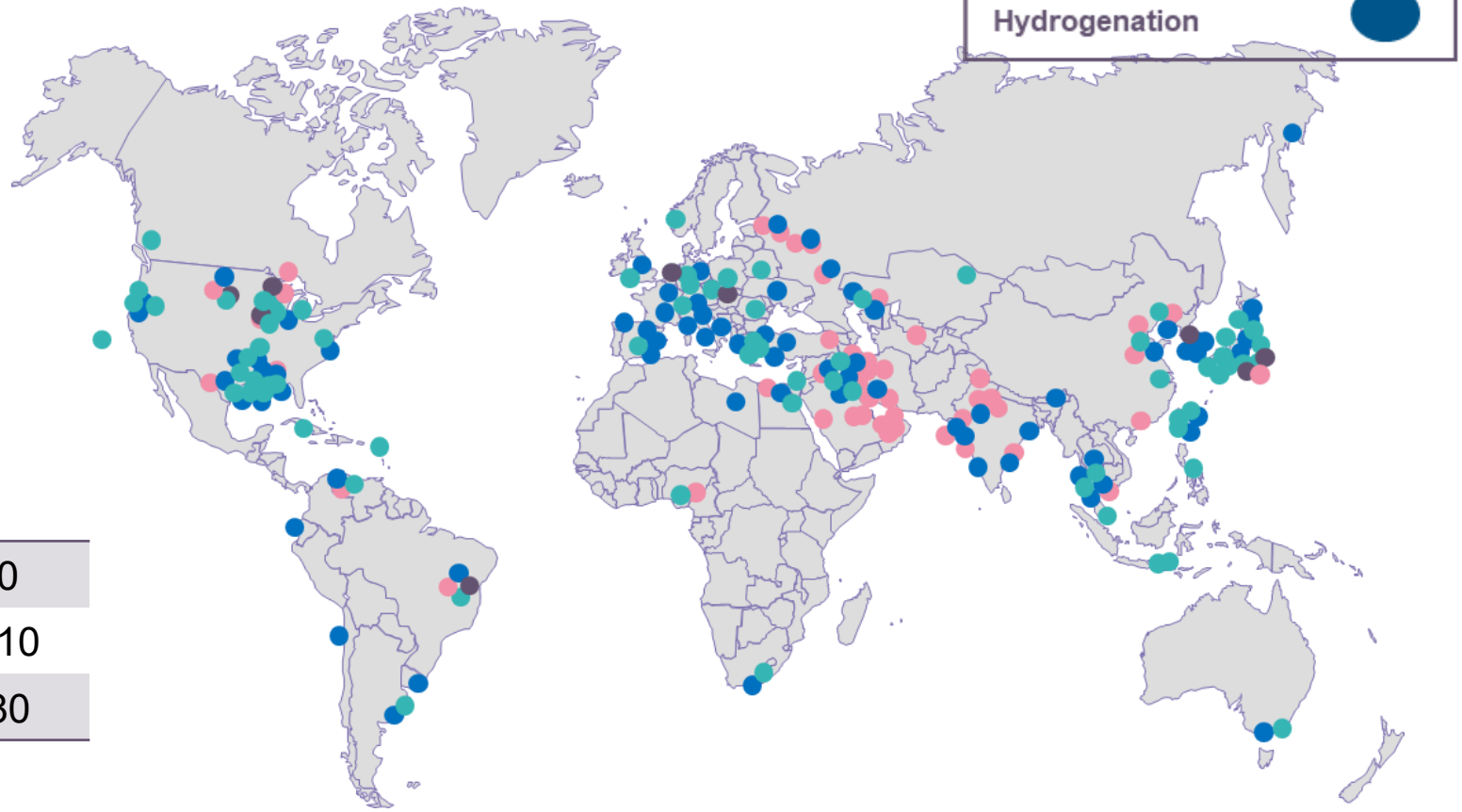
- Key for a controlled ethylene oligomerization & stable operation
- First plant in 1977 (Total Alma, USA)
- > 80 commercial references
- 2005 Nobel Prize in Chemistry

- Highly selective towards Jet
- Maximum Carbon retention
- First plant in 1986 (Idemitsu, Japan)
- > 30 commercial references
- For both fuels and chemicals production

Proven Processes

Jetanol™ Industrial References

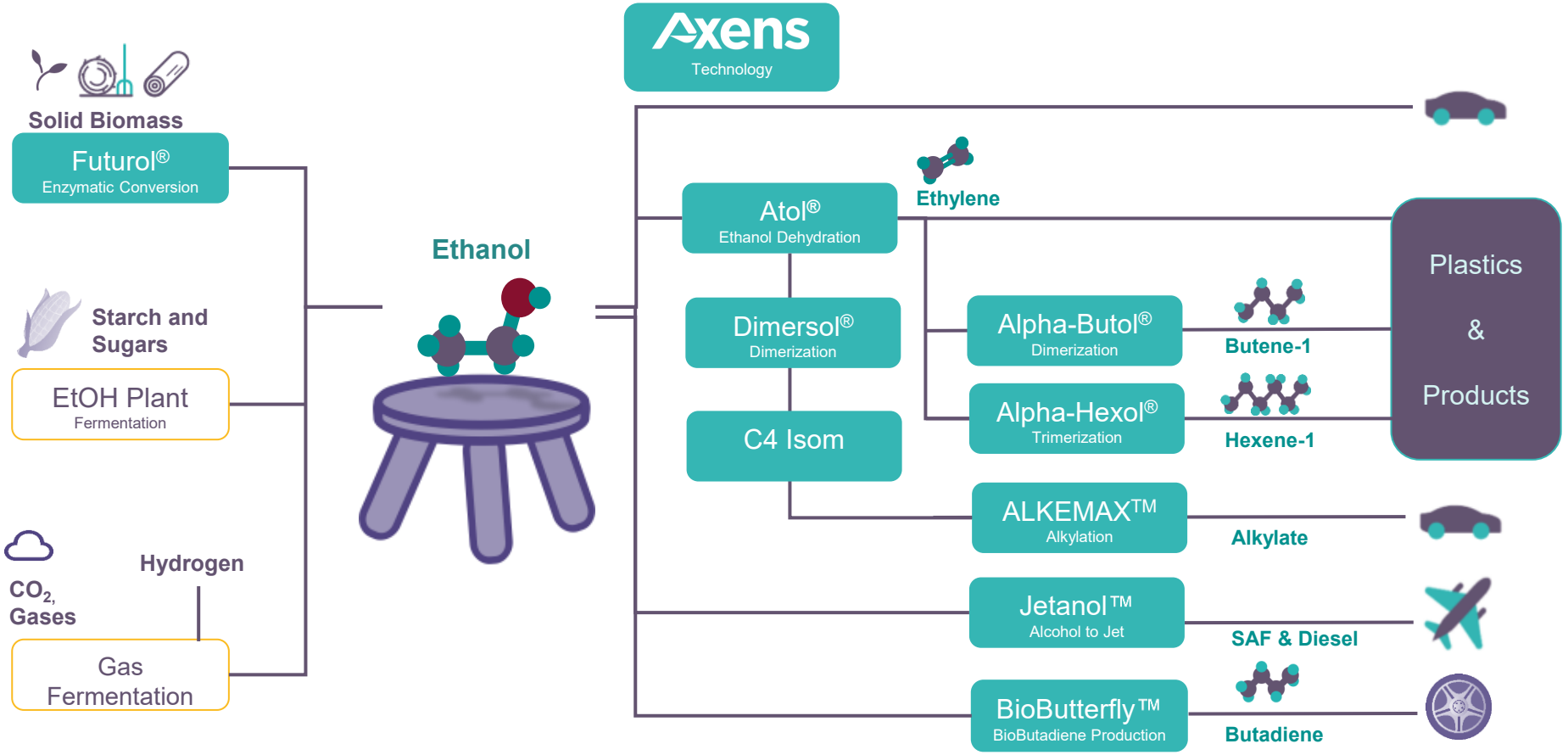
- > 60 years of industrial experience in ETJ chemistry



ETJ Chain Technology References:

Ethylene Dehydration	10
Oligomerization	>110
Hydrogenation	>80

Why Ethanol? A Platform Molecule



So many ways to produce ethanol

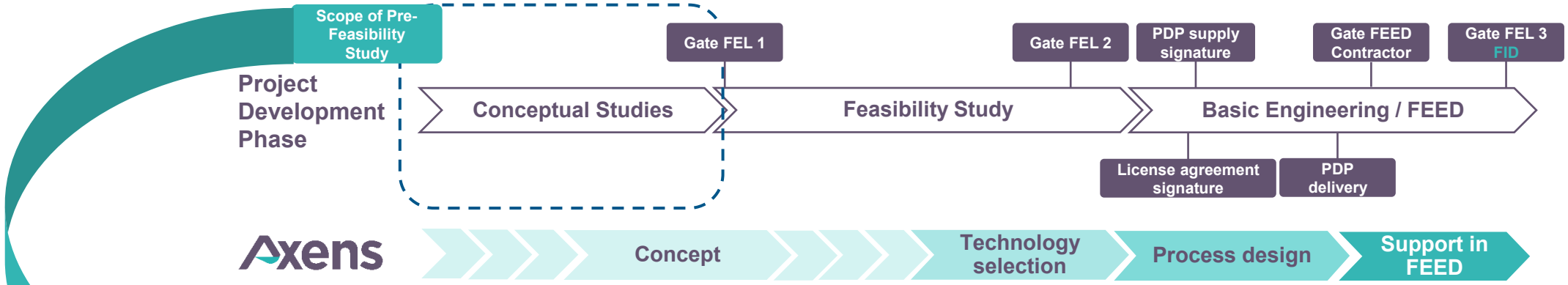
And so many products to make from it

…But "which pathway??"

SAF Pathway	CAPEX	OPEX	Carbon Intensity
HEFA 	**Advantaged:** Ability to repurpose existing refining assets	**Disadvantaged:** Feedstock cost higher than fossil jet and other pathways	• Dependent on feedstock type and requires hydrogen • Limited CO_2 sequestration potential
ETJ 	**Disadvantaged:** New ETJ assets needed	**Advantaged:** Biomass feedstock can be cost-competitive with fossil fuels	• Generally requires decarbonization to meet SAF thresholds • Major CO_2 sequestration potential • Multiple decarbonization levers
Solid Biomass via Gasification + Fischer-Tropsch	**Disadvantaged:** Significant biorefinery new assets needed	**Advantaged:** Cellulosic biomass is low cost relative to other pathways	• Feedstock is carbon-neutral • Major CO_2 sequestration potential • Deeply negative CI fuel is possible
Power-to-Liquids (eFuels) 	**Disadvantaged:** Significant new assets and electrical infrastructure needed	**Disadvantaged Unless….** Low carbon power is generally expensive relative to fossil fuels and significant energy is required to "reverse" combustion	• Feedstock is carbon-neutral • True C-Neutral fuels are possible, provided there is abundant low-carbon, low cost power

ATJ Brings a high CAPEX but low cash-cost pathway compared to HEFA

How can we help?



- **Conceptual Studies**
  - Pathway comparisons, including:
    - Preliminary Financial models and business case comparisons
    - CAPEX / OPEX comparisons
    - Existing equipment evaluations
    - Product yields
    - Decarbonization potential and CI score estimates
  - Market and feedstock analysis
  - Technical and environmental assessments
  - Next steps and risk assessments .

Objectives

- Identify key criteria for each SAF pathway
- Same quantity of renewable fuels with **maximum SAF**

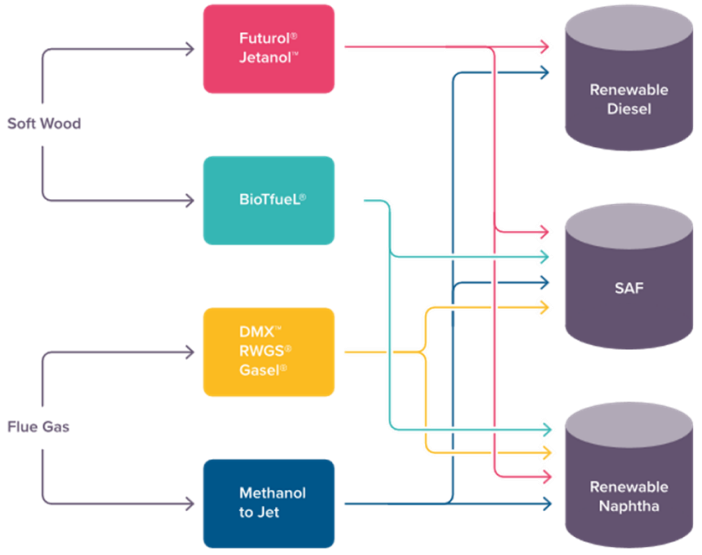
Scope for each Pathway

- Review of feedstock
- Define plant configuration
- Comparison of three pathway:

Feedstock consumption | *Production costs (CAPEX, OPEX, etc)* | *Investment Phasing*

Plot Plan | *Flexibility*

Product Carbon Index | *Product distribution (SAF, naphtha & diesel)*



Axens utilizes our independent “Horizon” team to support early-phase project development

ATJ Take-Aways

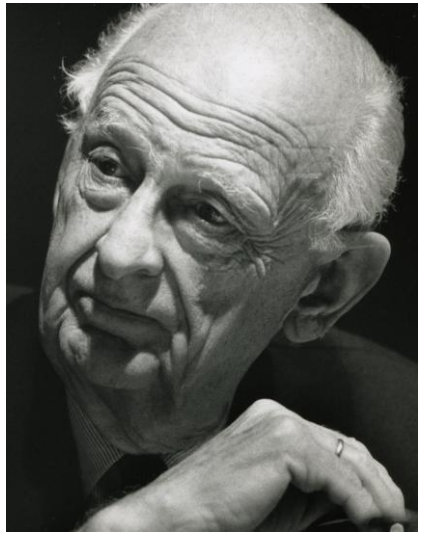
- The Alcohol to Jet Pathway:
  - Utilizes an abundant feedstock that can be produced from starches, sugars, solid waste biomass, and waste gases
  - Utilizes completely proven, industrial-scale processes
  - Is the most SAF-selective pathway
  - Can be cash-cost competitive to Fossil Jet fuel
- Axens:
  - Brings de-risked technology for all major ASTM SAF pathways
  - Is a Proven, Trusted, and Selected ETJ partner worldwide
  - Engages early in project development with our Horizon team to scope projects, select the optimal pathway, and evaluate economic cases utilizing accurate technical information “right from the source.”

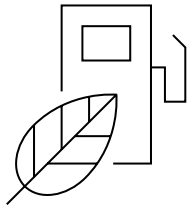
Ethanol to Jet, the next SAF to deploy

TOPSOE AT A GLANCE: OVER 85 YEARS OF INNOVATION AND LEADERSHIP

For more than 85 years, we have been guided by our purpose, **'Perfecting chemistry for a better world'**. We work to deliver solutions that will leave the world in better shape for future generations.

Today, it is our ambition to lead the global transition of hard-to-abate sectors to a net zero future.





Conventional and renewable fuels

H_2

Hydrogen

2,800

Employees

$1B

In revenue
(USD)

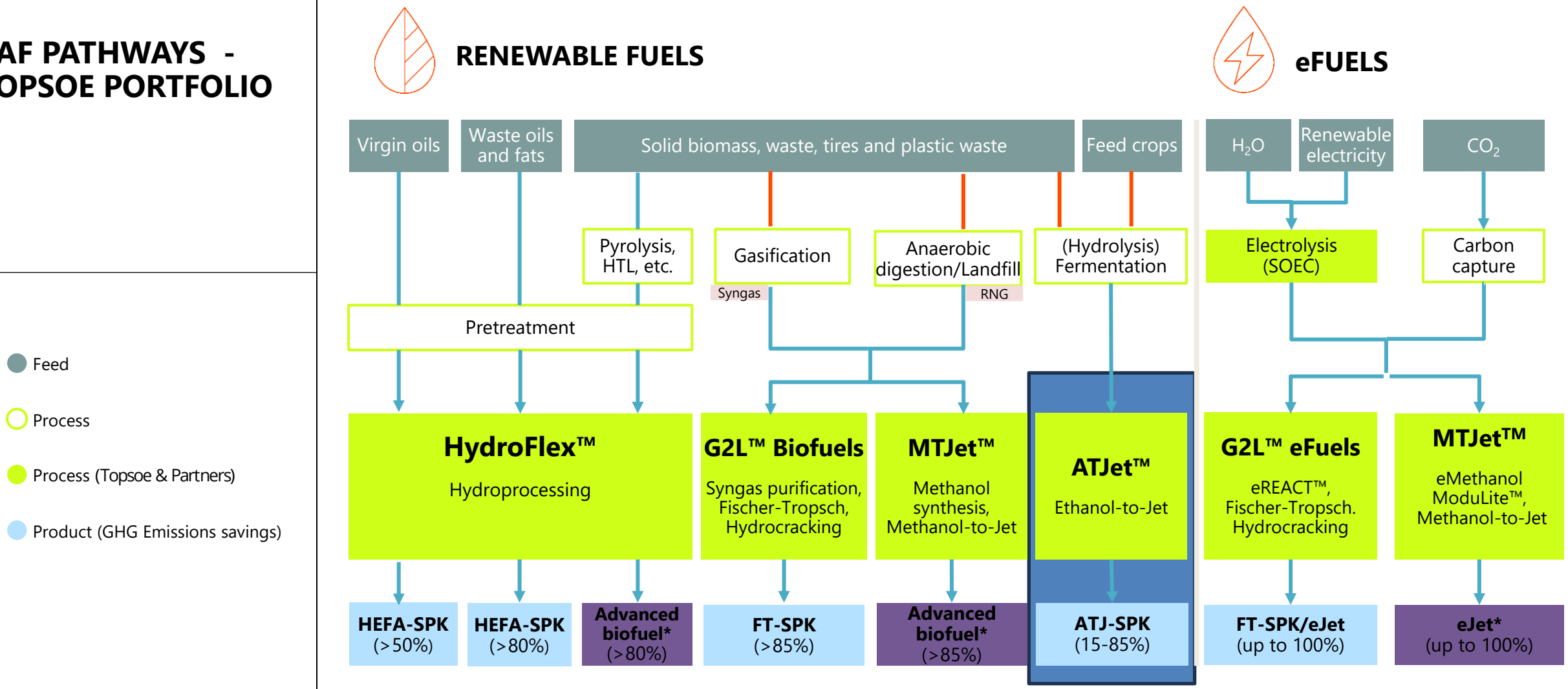
8.6%

Of revenues invested in R&D

+500

Patent families

SAF PATHWAYS - TOPSOE PORTFOLIO



- Feed
- Process
- Process (Topsoe & Partners)
- Product (GHG Emissions savings)

*Not approved ASTM pathways yet

Source: CORSIA, ICCT paper 2021-11, WEF+McKinsey 2020-11

TOPSOE HAS OVER 80 RENEWABLE FUEL PROJECTS GLOBALLY

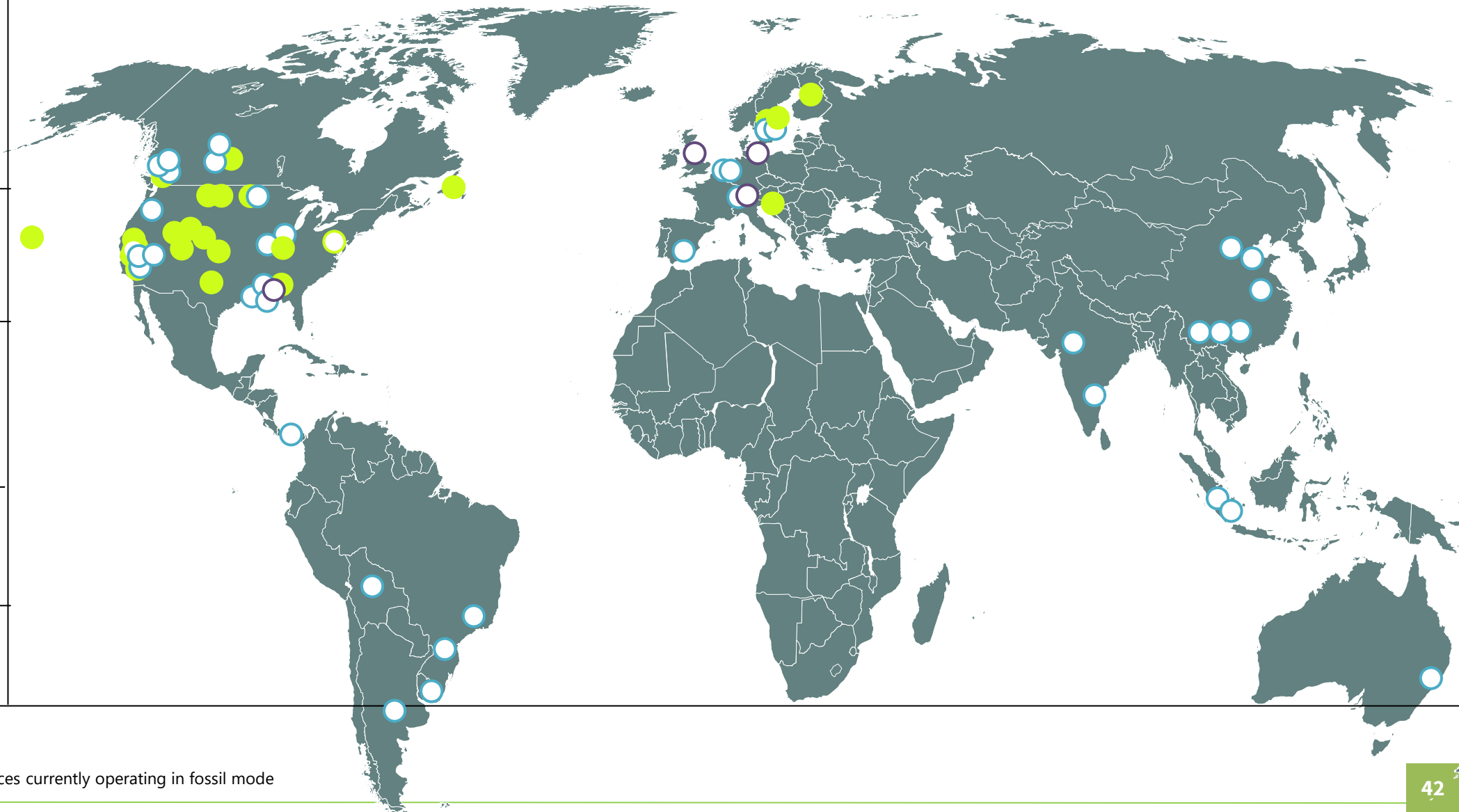
- **HydroFlex™** – Operating (26)
- **G2L™ fuels** – Construction/Engineering (4)
- **HydroFlex™** – Construction/Engineering (52)

26
Operating plants*

>35%
Of the renewable fuels operating capacity volume

2010
Start-up of first reference

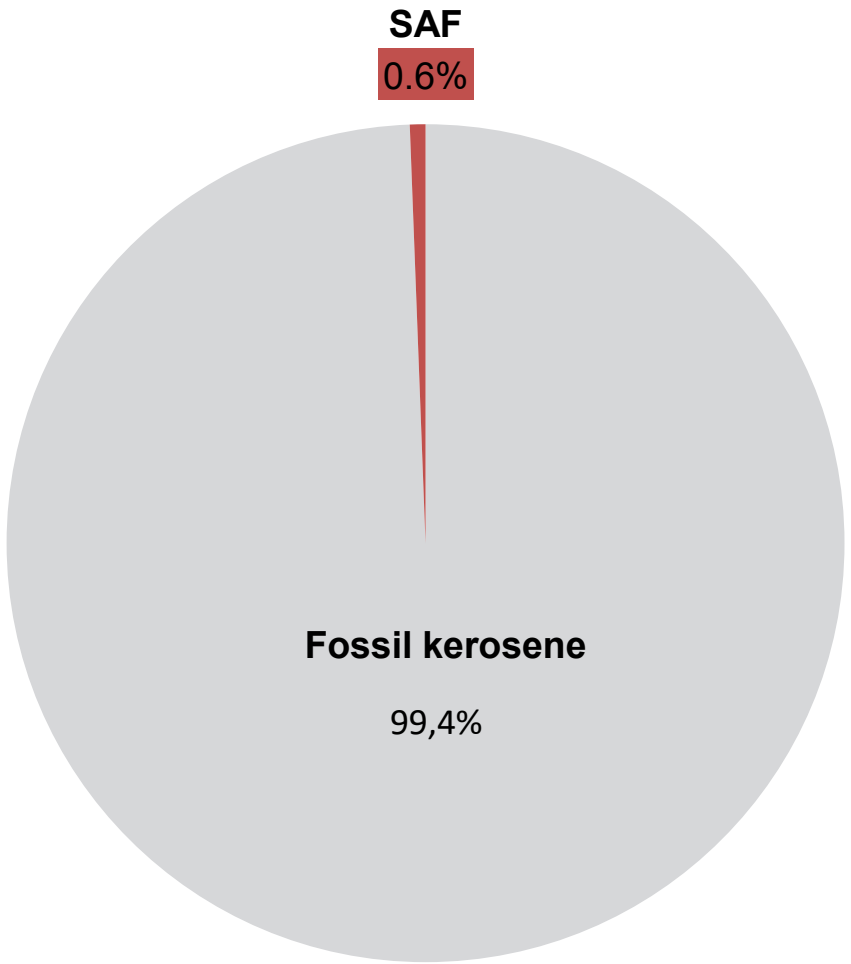
>20
Revamps



*Two references currently operating in fossil mode

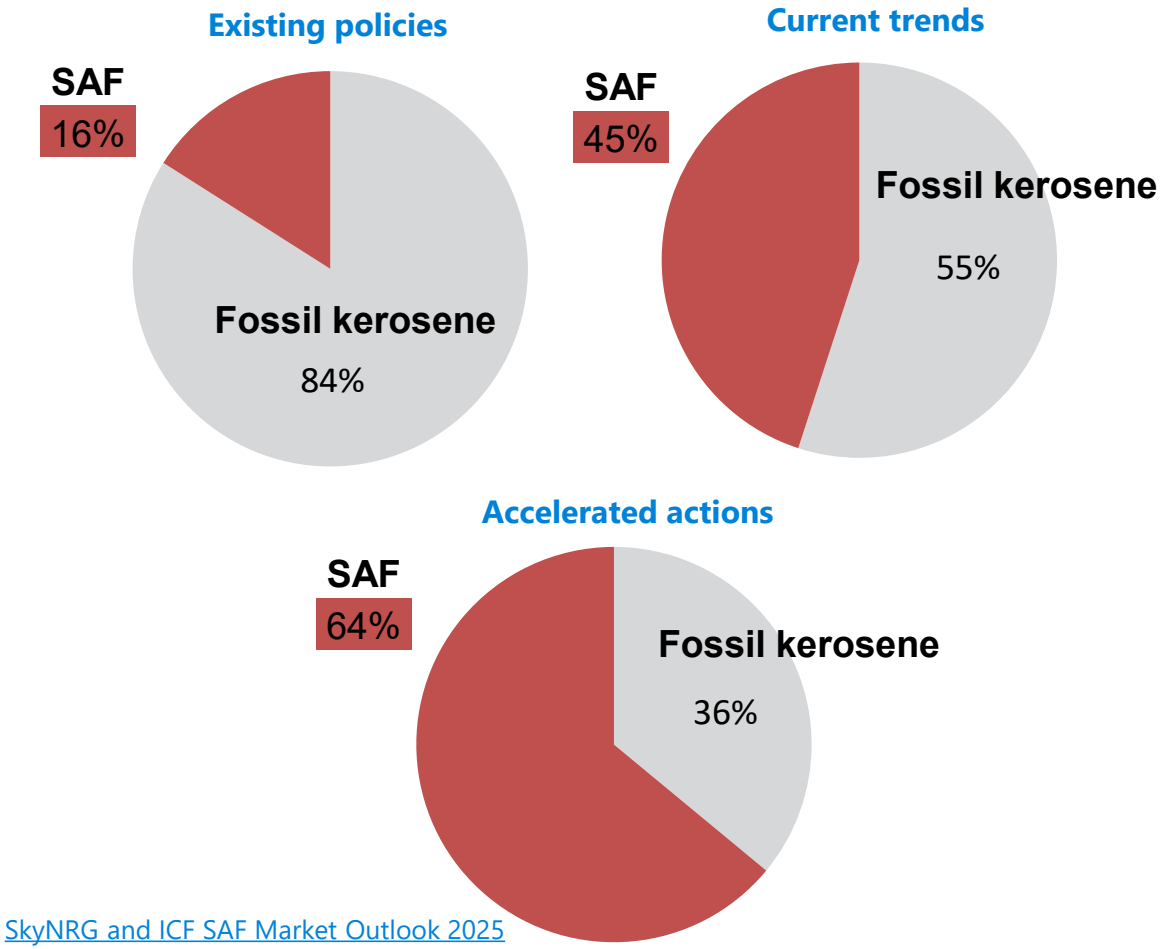
TOTAL JET DEMAND IN 2026 IS 7 MBPD AND IS EXPECTED TO GROW SIGNIFICANTLY

2025



IATA

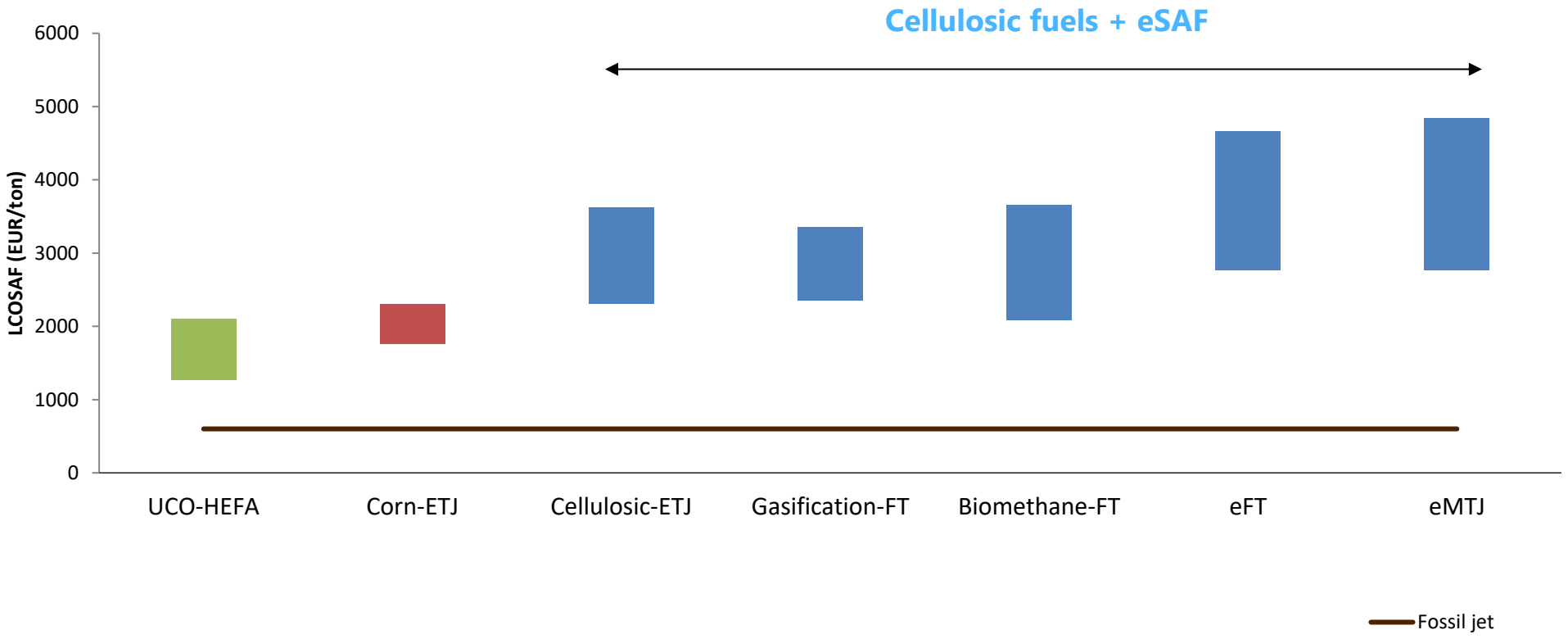
2050



SkyNRG and ICF SAF Market Outlook 2025

THE PRICE OF SAF STRONGLY DEPENDS ON THE PATHWAY AND FEEDSTOCKS

LEVELIZED COST OF SAF (LCOSAF)
EUR/TON SAF



Assumptions: WACC: 10%, Plant lifetime: 25 years, UCO: 900-1600 EUR/ton, corn ethanol: 800-1100 EUR/ton, cellulosic ethanol: 1100-1800 EUR/ton, Forrest residue: 50-150 EUR/MWh, biogas 15-25 EUR/GJ, eMeOH: 900-1450 EUR/ton, electricity: 30-60 EUR/MW, CO2: 60-80 EUR/ton, other OPEX: 4% of TIC
Source: McKinsey, Bain, ICF, Neste, Morgan Stanley, Topsoe analysis

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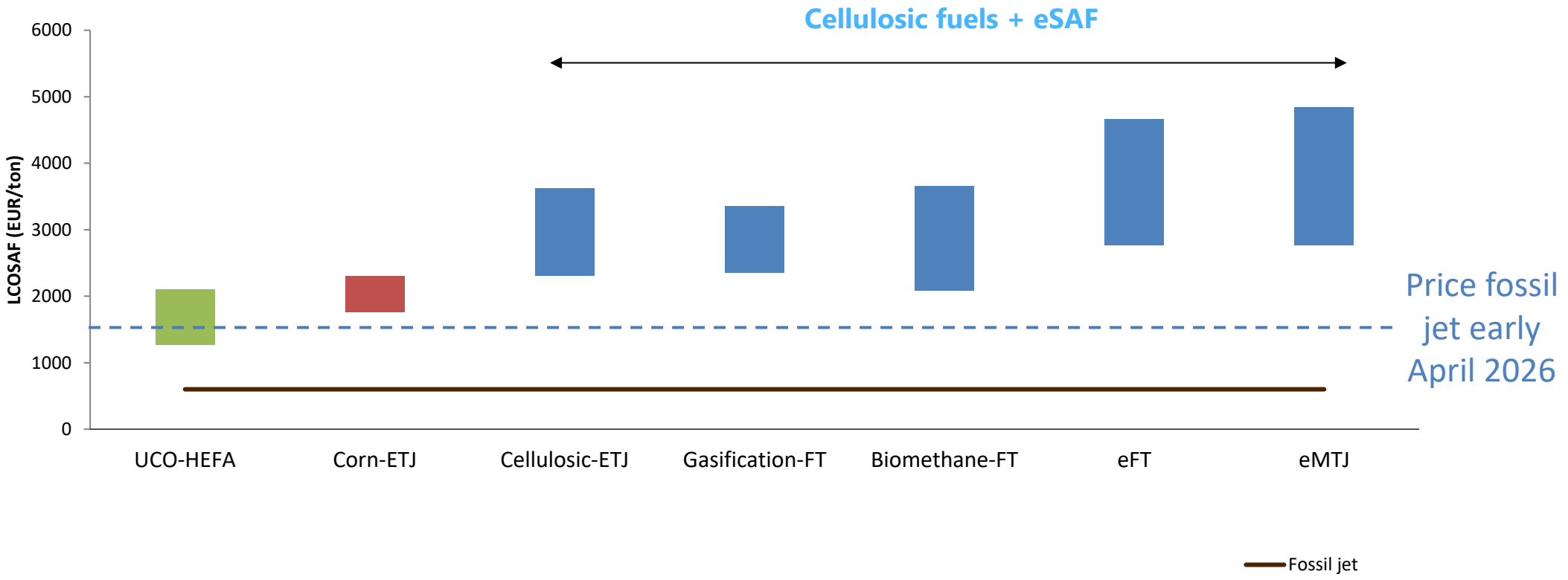

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ETJ WILL BE THE MOST COST-EFFICIENT SOLUTION AFTER HEFA FOR SAF FOR MANY YEARS

- ETJ **adds feedstock** and geographic diversification
- It **reduces** exposure to **FOG price volatility**
- It **leverages existing ethanol** infrastructure and markets
- It is attractive because it balances:
  - Cost
  - Technology maturity
  - Time to FID

Why and when will ETJ deploy?

SAF demand will outpace HEFA feedstock availability in a few years resulting in higher feedstock prices

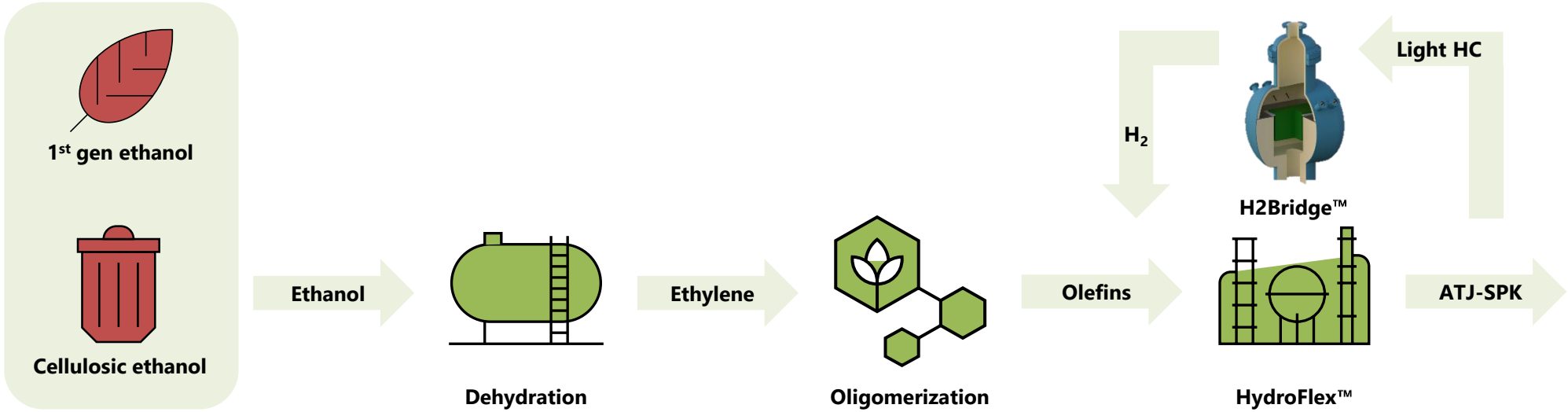
The growing SAF demand will be driven by regulation / incentives

Advanced bio-SAF and eSAF pathways have many years to become cost competitive

Ethanol production will mature with CCS in many places

The price of 2G Ethanol will drop as the capacity and demand increase

TOPSOE ATJET'I TECHNOLOGY OFFERS HIGHER YIELD AT LOWER CAPEX



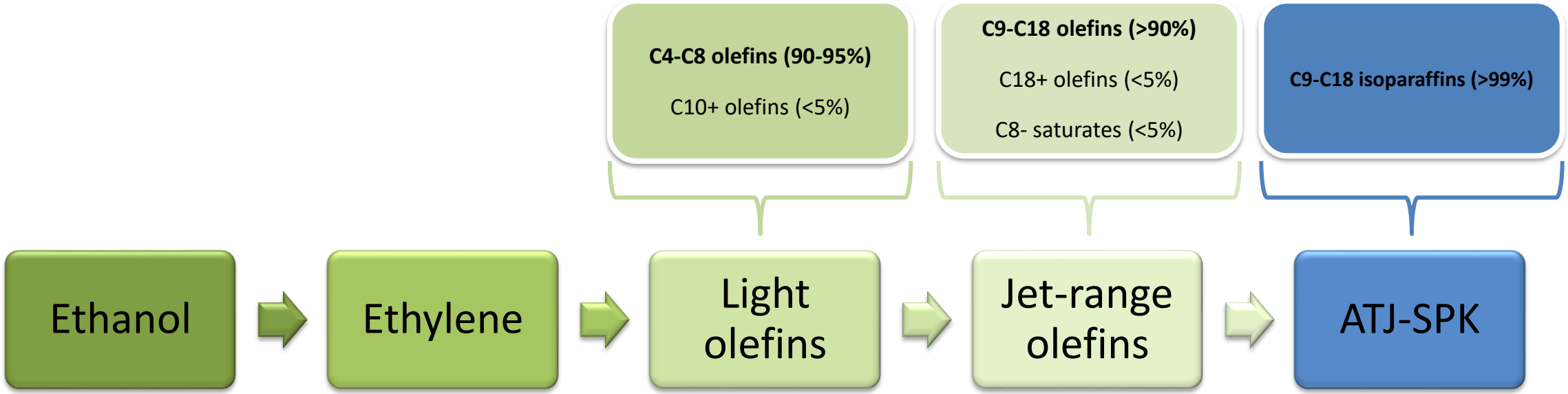
Solution features

- Highly selective oligomerization catalysts and proven hydrogenation catalysts
- High SAF yield to minimize feedstock contribution to the levelized cost of SAF
- Integration (including H_2 production) to minimize carbon intensity and maximize credit generation

Benefits

- Offering simplified design for lowest CAPEX in the market (fixed bed down flow reactors)
- Fast-track program targeting commercial operation no later than 2030
- Relying on Topsoe's strong history in commercializing integrated fixed bed catalyst technology

WHAT IS THE CHEMISTRY OF THE ATJET I PROCESS?



C2 to mostly C4 in fixed bed heterogeneous reactor to minimize operational complexity and maximize plant reliability

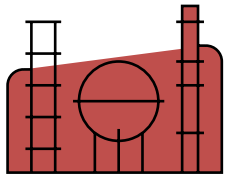
Second step to maximize selectivity and minimize side reactions (light saturation and over-oligomerization)

A FEW WORDS ABOUT OUR ATJ REACTOR CONCEPT

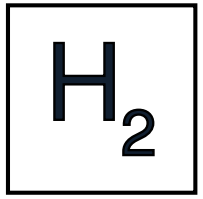
- Reactors are fixed bed with down flow. Very easy to upscale
- Reactor sizes are easy to transport
- Low grade base metal material is sufficient for reactor shell
- Topsoe provides all necessary internals
- All design aspects are well known in the industry and therefore considered low risk

ATJet'I - CAPITALIZE ON THE INDUSTRY'S STRONGEST PROCESS & CATALYST SOLUTION

Chemistry is key.



Process & catalyst options



Will need **hydrogen** but can be produced with lower GHG emissions

- **High SAF yields** by using high selectivity catalyst, tailoring oligomerization distribution and minimizing saturation side-reactions
- **H2 consumption for ETJ** is considerably lower than for the HEFA route to SAF ensuring **lower utility consumption**
- **Duration proven** Oligomerization catalysts ensures **longer cycle length**
- Industrially proven **reactor** technology ensuring **higher robustness**
- Operating parameters ensuring lower material cost leading to **lower TIC**
- Carbon intensity & GHG emission can be further reduced with **H2bridge™ solution.**
- **Feedstocks high flexibility:** All variations of Ethanol feed ranging from denatured streams of 92% EtOH to 1g and 2G Bio ethanol feeds at 98-99.5% EtOH content can be used

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THANK YOU