ICAO ENVIRONMENT

ACT-SAF #5 SERIES

SAF conversion pathways

Produced and presented with support of:
Neste, GEVO, Sasol, Topsoe and SAF+ Consortium.

1. Opening

Bruno Silva, Fuels Officer, ICAO.

Objective

ACT-SAF #5 SERIES

Provide participants with in-depth technical knowledge on four main SAF conversion processes

ACT-SAF Series #5 Partners

NESTE gevo® sasol TOPSOE SAF+ CONSORTIUM

Astrid Sonneveld

Technical Development and OEM Partnership Manager, Renewable Aviation

Chris Ryan

Inc, President, COO

Ryan Wolhuter

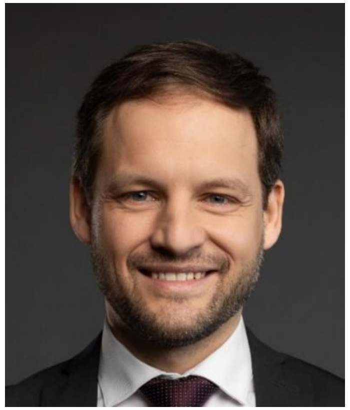
Single Point Licensor

Robert Henkel

Licensing Manager
Topsoe Licensing

Alexandru Iordan

Co-founder &
EVP of Technology



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1. Opening
2. Introduction of partners
3. ICAO update on ACT-SAF programme and process to CAAF/3
4. Presentation of **HEFA** by Neste
5. Presentation of **Alcohol-to-jet** by GEVO
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7. Presentation of **Power-to-liquid** by SAF+ Consortium
8. Q&As and open discussion
9. Closing remarks

ACT-SAF updates

ACT-SAF platform provides the most recent information:

- List of Partners constantly updated
- ACT-SAF series material available online

ACT-SAF Series

Coordination with ACT-SAF partners identified that many States need conceptual training on SAF.

To address that, ICAO is developing the **ACT-SAF Series of training sessions**, to be held on a monthly basis. This will allow delivering comprehensive training to ACT-SAF Partners on an array of important SAF-relatec topics, ranging from sustainability, to policy, economics/financing certification and logistics.

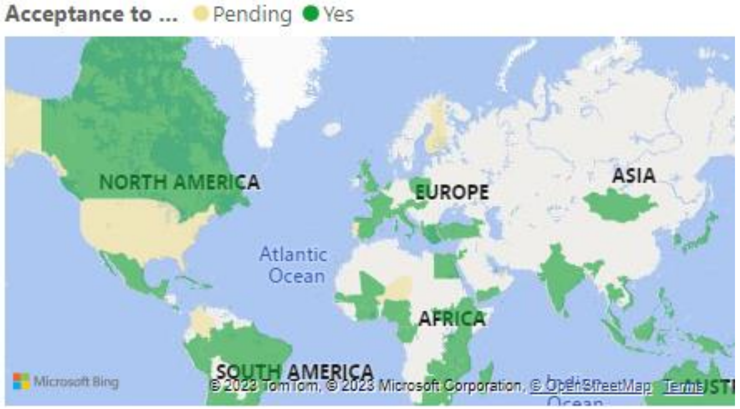
The ACT-SAF Series will empower the ACT-SAF Partners with training material designed with the support o Supporting States and Organisations from the air transport, fuels and finance sectors, as well as academics anc actors with niche expertise such as SAF reporting under CORSIA.

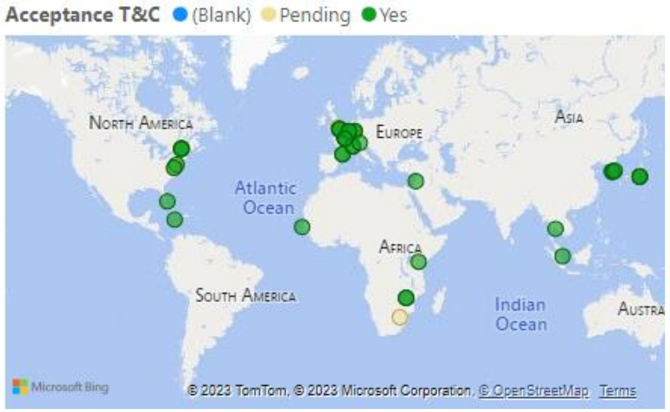
Want to participate on the ACT-SAF Series? Join ACT-SAF now (click here to access the ACT-SAF Terms and Conditions). Participation is open to all States and Organizations interested in further action on SAF.

ACT-SAF Series	Date	Topics	Contributor(s)	Abstract	Video and Presentation
#1	25 November 2022	An introduction to SAF	ICAO	• Introduction to ACT-SAF • Basics of SAF	Introduction to Sustainable Aviation Fuels Download Presentation
#2	25 January 2023	SAF sustainability and reporting under CORSIA	ISCC RSB Verifavia	• process for sustainability certification of SAF • Reporting and verificaiton of SAF Claims under CORSIA	SAF sustainability certification and reporting under CORSIA Download Presentation
#3	23 February 2023	SAF technology and certification	Airbus US FAA Safran	• specifications for aviation turbine fuels • process for approval for new production pathways	SAF production technologies and certification Download Presentation
#4	23 March 2023	SAF policies	Brazil, European Commission,	• Practical experiences from States	

ICAO ACT-SAF Platform

Here you will find more information on our ACT-SAF Participants*





Latest news on ACT-SAF

Date	Latest news	Link
6/1/2023	4 States join ACT-SAF (Ghana, Greece, Mali, Zambia)	
5/24/2023	European Commission announces 4 million euros to support SAF development under ACT-SAF	🔗
5/23/2023	Inter-American Development Bank joins ACT-SAF	
3/29/2023	IBAC joins ACT-SAF	🔗
3/17/2023	Airbus Signs the ACT-SAF Terms and Conditions	🔗

https://www.icao.int/environmental-protection/Pages/act-saf.aspx

ACT-SAF updates

ACT-SAF

Key request - conceptual training on SAF

ACT-SAF Series (preliminary list of sessions)
#1 Introduction to SAF
#2 SAF sustainability and reporting under CORSIA
#3 SAF production technology and certification
#4 SAF policies
#5 SAF conversion processes
#6 SAF market outlook
#7 SAF logistics
#8 SAF economics and financing
#9 SAF Feasibility Assessment

Today's Session

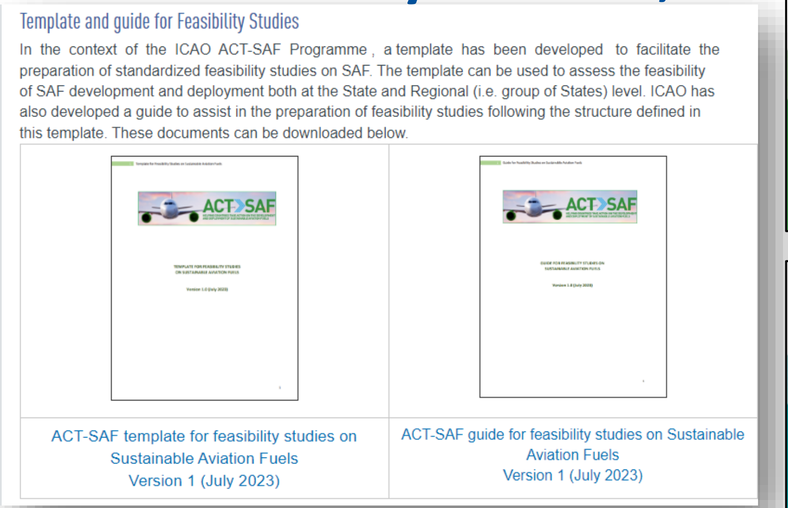
- Future sessions on specific aspects
- Subject to review – **feedback welcome**

https://www.icao.int/environmental-protection/Pages/ACT-SAF-Series.aspx

ACT-SAF updates – Feasibility Studies

ICAO ENVIRONMENT

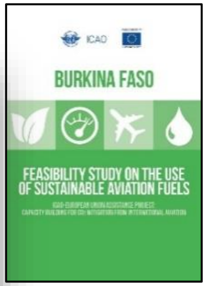
- As part of ACT-SAF, ICAO published a **template for SAF Feasibility Studies,** available on the ICAO website
  - Allow comparability between results
  - Harmonized structure
  - Facilitate outreach of results

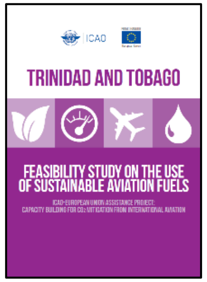

Template and guide for Feasibility Studies

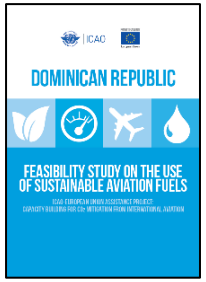
In the context of the ICAO ACT-SAF Programme , a template has been developed to facilitate the preparation of standardized feasibility studies on SAF. The template can be used to assess the feasibility of SAF development and deployment both at the State and Regional (i.e. group of States) level. ICAO has also developed a guide to assist in the preparation of feasibility studies following the structure defined in this template. These documents can be downloaded below.

ACT-SAF template for feasibility studies on Sustainable Aviation Fuels Version 1 (July 2023)	ACT-SAF guide for feasibility studies on Sustainable Aviation Fuels Version 1 (July 2023)

- Many feasibility studies will be developed in ACT-SAF
  - Three new feasibility studies under existing ICAO-EU project (Zimbabwe, Côte d'Ivoire and Cabo Verde) <u>using the ICAO template</u>
  - Financial resources provided by ACT-SAF partners will allow **MANY** additional feasibility studies:
    - ICAO working with the European Union in ten partner States (Cameroon, Egypt, Equatorial Guinea, Ethiopia, India, Gabon, Mauritania, Mozambique, Senegal, and South Africa)
    - Other projects being structured
  - Studies also being pursued by ACT-SAF partners







ACT-SAF partners are invited to contribute

Requirement: Expertise with development of clean energy studies *(not necessarily ACT-SAF focal point – any identified expert is welcome)*

Contact ICAO to participate on this effort (officeenv@icao.int)

ACT-SAF updates – Feasibility Studies

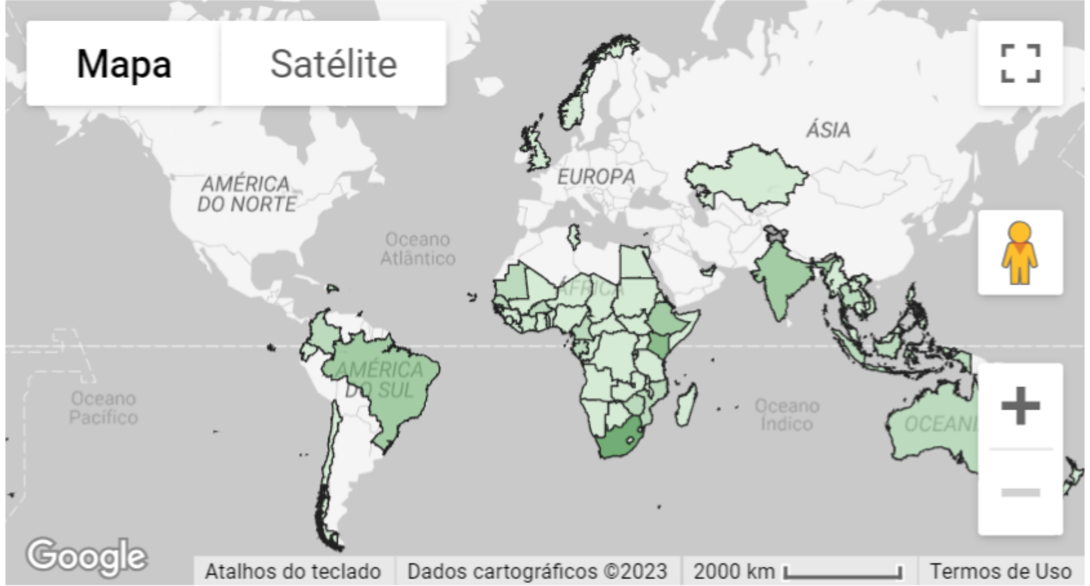
ACT»SAF

- ICAO published a tracker for feasibility studies for aviation cleaner energies

Feasibility Studies
49

	Supported State	Number of initiatives ▾
1.	South Africa	5
2.	Kenya	4
3.	Brazil	3
4.	Ethiopia	3

1 - 77 / 77



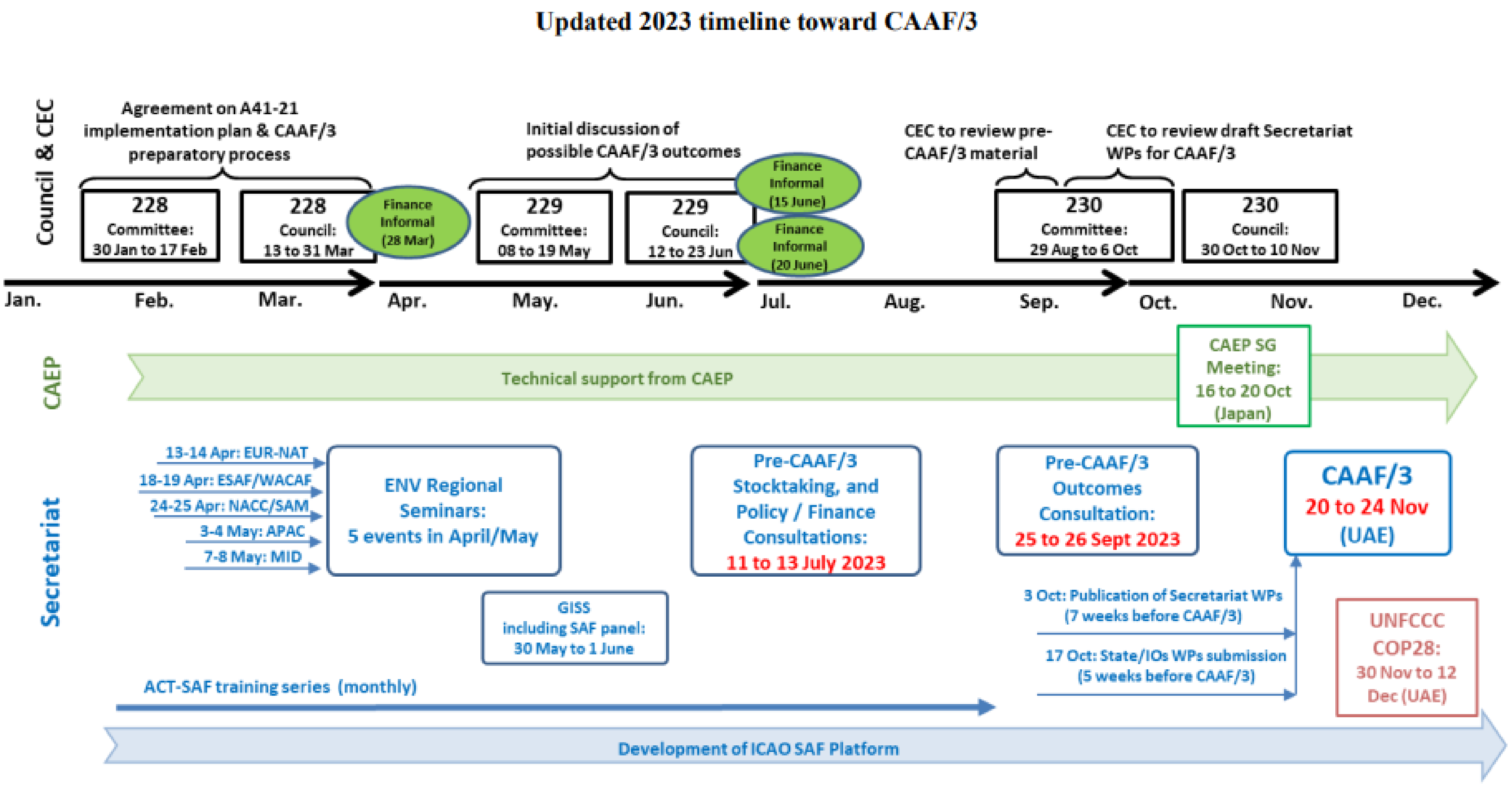
Number of Initiatives 1 5

Supported State/Region	Year	Supporting / Developing Organizations	Title and hyperlink	Details	Status
Australia	2023	Boeing / CSIRO Futures and Towards Net Zero	Sustainable Aviation Fuel Roadmap	CSIRO Futures and the Toward Net Zero Mission are collaborating with Boeing to develop a roadmap for cost-effective production of SAF. CSIRO is developing a range of tools and systems for optimising biomass production as well as fuel processing technologies.	under development
Australia	2013	Qantas, Shell / Sinclair Knight Merz (SKM), AltAir, the Australian Research Council (ARC) Centre of Excellence in Plant Cell Walls at the University of Adelaide and SkyNRG	A feasibility study of Australian feedstock and production capacity to produce sustainable aviation fuel	the project partners focused exclusively on the production of SAF from the HEFA pathway. To augment understanding of the production of SAF from the certified Fischer Tropsch (FT) pathway, Qantas – independent of the main study partners – commissioned Solena to provide industry insights.	concluded
Brazil	2023	GIZ / GIZ	ProQR - Climate Neutral Alternative Fuels	Small decentralised power plants that produce fuel for aviation from renewable electricity not only contribute to climate-neutral aviation, but can already produce economically in many remote locations	Concluded

https://www.icao.int/environmental-protection/Pages/feasibility_studies.aspx

ACT-SAF partners are invited to inform on other studies which are not yet included in the tracker (e-mail to officeenv@icao.int)

Update on the process towards CAAF/3



Update on the process towards CAAF/3

- **LTAG Stocktaking and First pre-CAAF/3 consultation** (July 2023)
  - From 11 to 13 July 2023 as a hybrid event in Montréal, Canada.
  - The 2023 Stocktaking covered all aviation in-sector CO_2 reduction measures, including the latest developments and innovations from technologies, operations, fuels and cleaner energies, with a focus on fuel-related measures in the lead up to CAAF/3.
  - The pre-CAAF/3 consultation focused on policy and finance matters, with involvement of public and private financial institutions and other relevant stakeholders, to consider relevant elements of the ICAO global framework.
- **Second pre-CAAF/3 Outcomes Consultation** (September 2023)
  - From 25 to 26 September 2023 as a hybrid event in Montréal, Canada.
  - Consultation among States with a focus on possible CAAF/3 outcomes, seeking convergence of views on as many issues as possible, and identifying remaining differences of views with a possible way forward to bridge them, in order to pave the way for result-oriented discussions at CAAF/3
- **CAAF/3** (November 2023)
  - The CAAF/3 will be held from 20 to 24 November 2023 in Dubai, United Arab Emirates
  - For reviewing the 2050 ICAO Vision for SAF, including LCAF and other cleaner energy sources for aviation, in order to define an ICAO global framework in line with the No Country Left Behind (NCLB) initiative and taking into account national circumstances and capabilities

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ACT SAF
Assistance, Capacity-building and Training for SAF

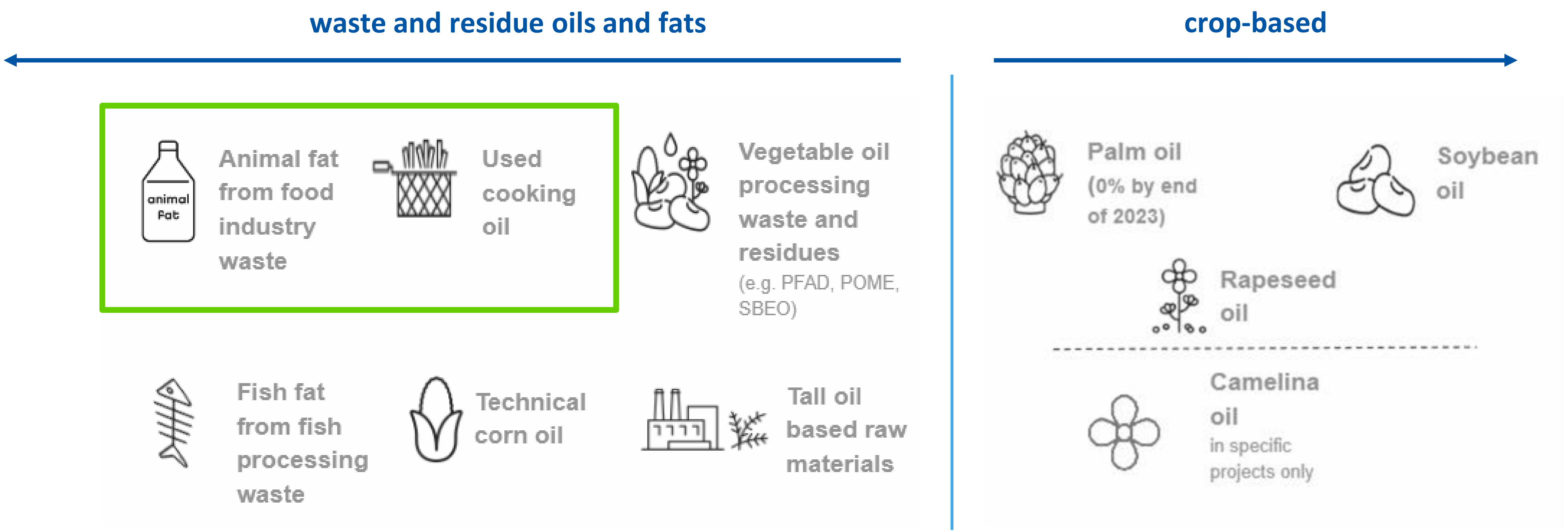
Presentation of HEFA by Neste

About the HEFA conversion pathway

- Approved for commercial use: ASTM D7566 Annex A2, Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)
- Year of Qualification: 2011
- Blending: Required to be blended with petroleum-based jet fuel, up to a 50% maximum level.
- HEFA-SPK is currently the most commercially viable SAF conversion pathways and the one used for producing the majority of SAF available today
- Technology Readiness Level: 9 (proven and commercially deployed)
- NEXBTL™ is a Neste proprietary technology for production of HEFA-SPK, patented 25 years ago after many years of research and development

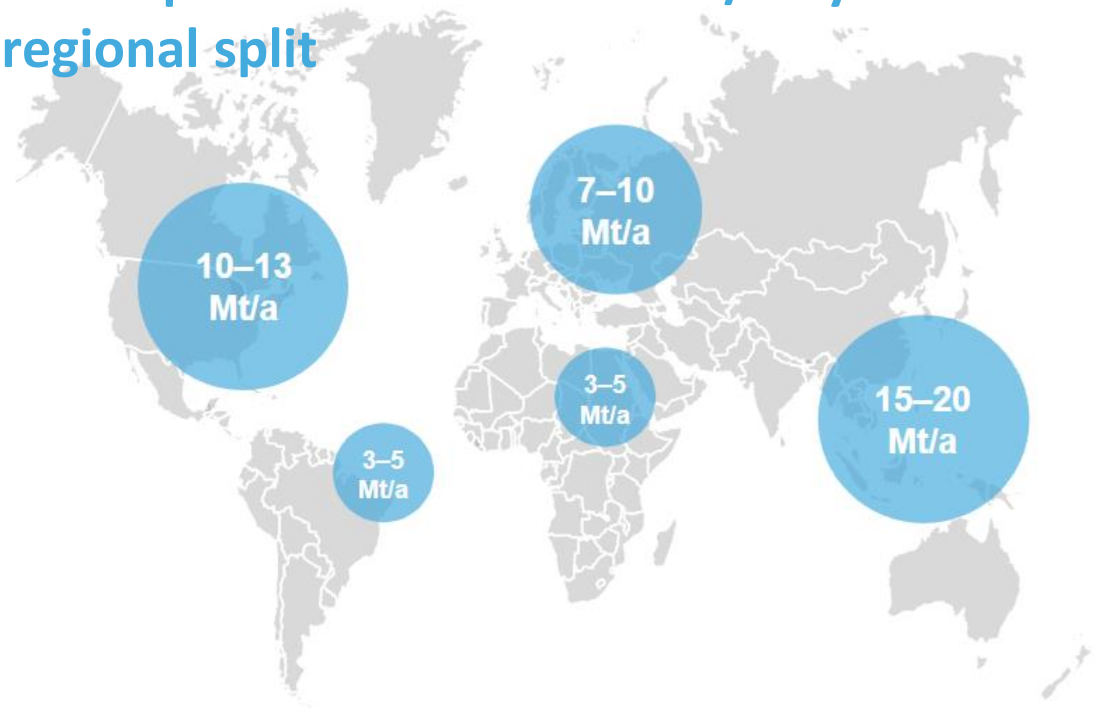
Feedstocks for HEFA

- HEFA can be produced from a wide array of oils and fats which constitute triglycerides or fatty acids. For many HEFA feedstocks, CORSIA default LCA values are available (Table 2).
- Neste HEFA is made from sustainably sourced, 100% waste and residues. Neste currently only uses used cooking oil and animal fat waste for the production of SAF.



Feedstock availability for HEFA-SPK

Availability of waste and residue oils and fats expected to exceed 40Mt/a by 2030[1] – regional split



Neste view on feedstock sources for HEFA production with substantial growth potential beyond waste and residues

- Novel vegetable oils[2]
- Algae oil

1) World Economic Forum Clean Skies for Tomorrow (2020). 2) Novel vegetable oils from novel and regenerative agricultural concepts such as intermediate cropping and silvopasture.

HEFA-SPK process description

- **Pretreatment**: Impurities are removed from the feedstock before refining
- **Hydrodeoxygenation**: Biogenic fats and oils contain oxygen and other less desirable molecules. In a catalytic process, oxygen atoms are removed with hydrogen atoms. This conversion process creates a pure hydrocarbon *(n-paraffin)* with high energy density.

- **Hydrocracking and hydroisomerization**: Pure hydrocarbons are cracked and isomerized to create a HEFA-SPK synthetic jet fuel component with the desired properties.

Neste SAF production

2019
100 kton SAF
total global production capacity

→

2024
1.5 Mton SAF
total global capability through investments in Rotterdam (NL) and Singapore

→

2026
2.2 Mton SAF
total global capability through further investments in Rotterdam (NL)

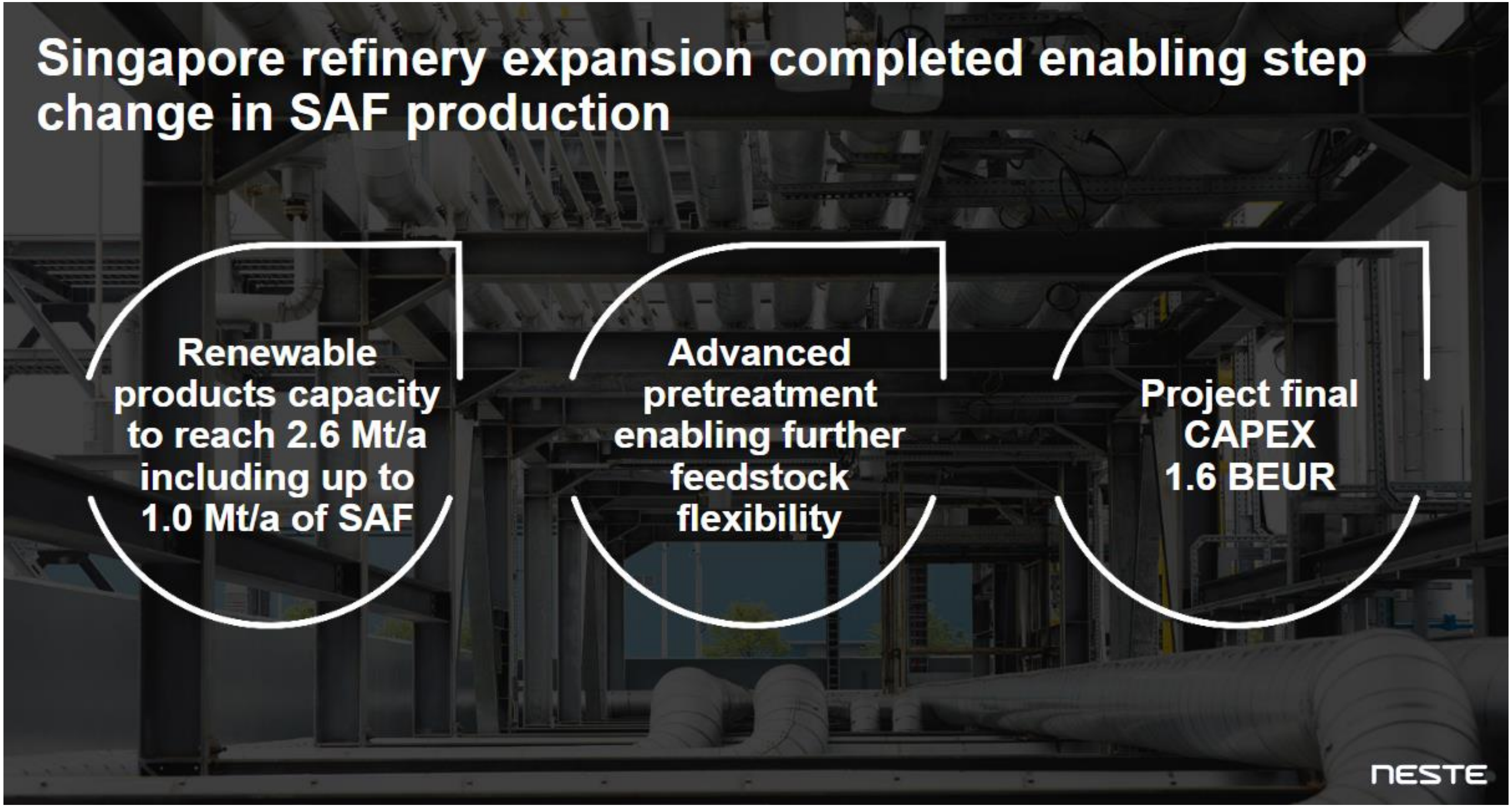
→

Beyond
continuing growth with both HEFA and other SAF conversion pathways

Zooming in on SAF production at Neste Singapore refinery

- Refinery operations since 2010, with annual production capacity of 1.3 million tons of renewable and circular solutions
- Located in Tuas, west of Singapore.
- Refinery expansion project to add SAF capability, production scheduled to start during Q3 2023

HEFA


Singapore refinery expansion completed enabling step change in SAF production
Renewable products capacity to reach 2.6 Mt/a including up to 1.0 Mt/a of SAF
Advanced pretreatment enabling further feedstock flexibility
Project final CAPEX 1.6 BEUR
NESTE

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ACT SAF
Assistance, Capacity-building and Training for SAF

Presentation of ATJ by GEVO

Intro

- Chris Ryan, Gevo Inc, President, COO, 35 years in industry
  - PhD Organic Chemistry
  - Led Process Development, Biotechnology, Business Development, Operations and R&D areas.
  - Formerly Co-founder, CTO, COO of NatureWorks LLC, pioneer in biobased plastics.
  - 35 Years in Industry: 14 Years with Gevo, 17 years Cargill, 4 years Specialty Chemicals
  - Variety of Markets including fuels, consumer packaging, fabrics/fiber, durable plastics.
  - involving biobased chemicals, biofuels, RNG, petrochemicals,
  - Feedstock experience: starches, energy grasses, wood waste, molasses, ag waste, livestock manure

NatureWorks' production plant is headquartered in Blair, Nebraska.

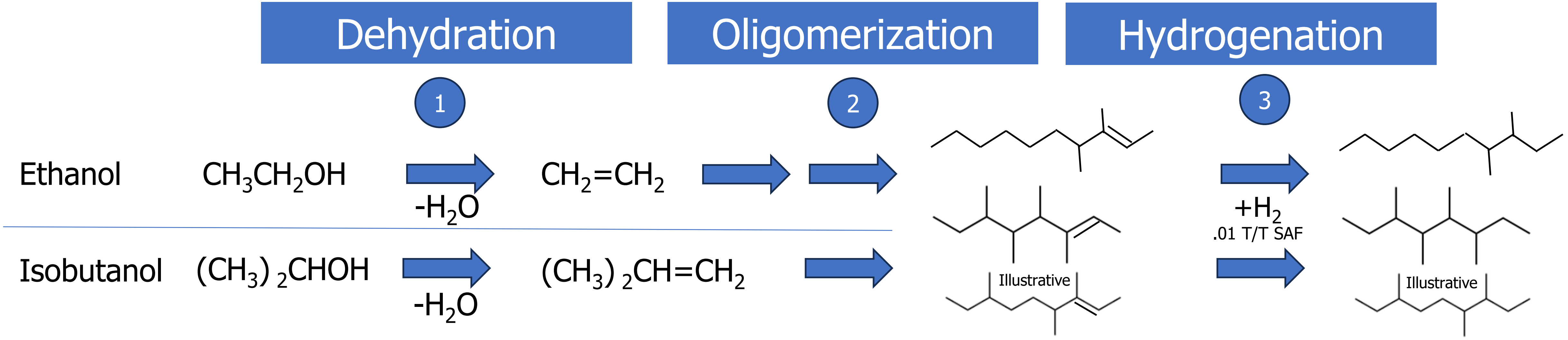
ATJ Pathway

- ASTM certified in 2016 for isobutanol, 2018 for ethanol. Ethanol & Isobutanol are 2 alcohols.
- ATJ Technologies are in commercial use today
- While the alcohol-to-jet process is the heart of the ‘system’, the feedstock, process energy source and business system around the ATJ process is what makes it useful for the aviation industry as a means to decarbonize
- A variety of feedstocks can be used but the choice significantly impacts the scalability, economics, sustainability and carbon footprint. Customers prefer a sustainable business system with max reduction of carbon footprint with a manageable price premium.

Gevo ATJ Use Thus Far

Based on Gevo Supplied ATJ SAF

ATJ Steps



1. Dehydration — Convert alcohol to olefin by removing a molecule of water
2. Oligomerization — Connect small olefins together to give a larger olefin fit for SAF
3. Hydrogenation — Convert olefin to a paraffin fit for SAF use

ATJ Step 1

Dehydration

1

Ethanol	CH_3CH_2OH	→ $-H_2O$	$CH_2{=}CH_2$
Isobutanol	$(CH_3)_2CHOH$	→ $-H_2O$	$(CH_3)_2CH{=}CH_2$

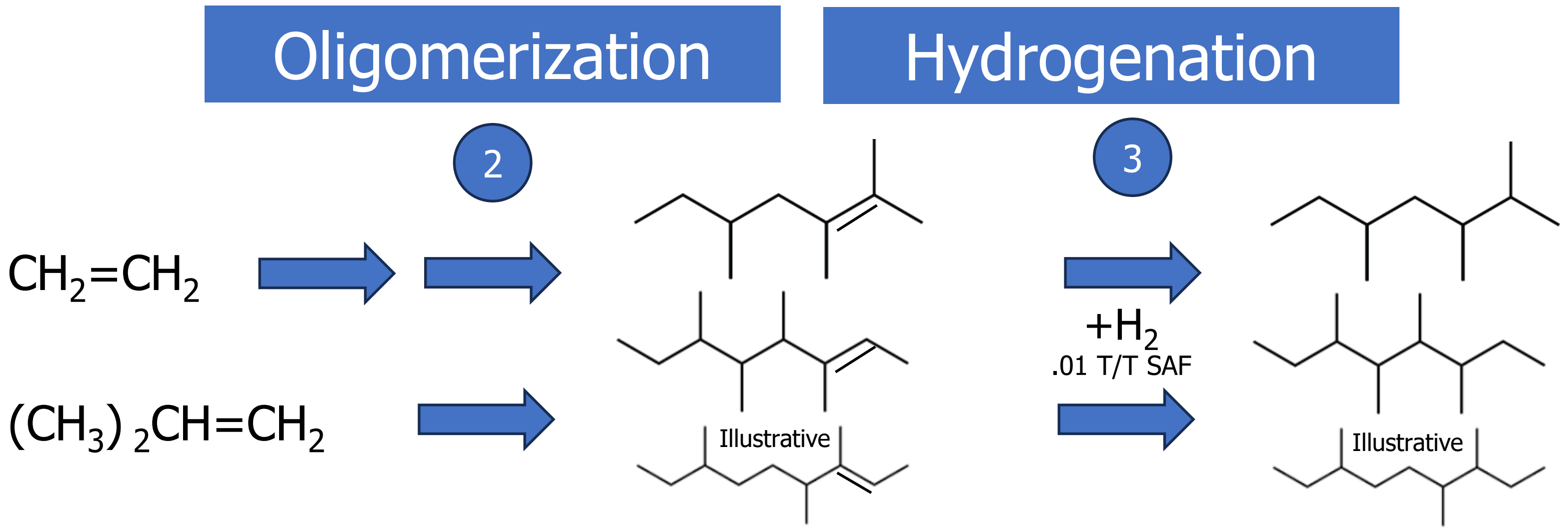
Key Points on this Step

- Commercial processes operating today
- High carbon yields
- Ethanol dehydration takes much more energy and cost than isobutanol dehydration, but producing biobased ethanol is more common today than biobased isobutanol

Example Technology Providers

- Axens
- Lummus-Braskem
- Technip
- KBR-Petron
- UOP

ATJ Steps 2 & 3



Key Points on this Step

- Commercial processes operating today
- High carbon yields
- Very little hydrogen is used (ie not like a 'typical' hydroprocessing process)

Example Technology Providers

- Axens
- UOP
- Lummus

Feedstocks for ATJ

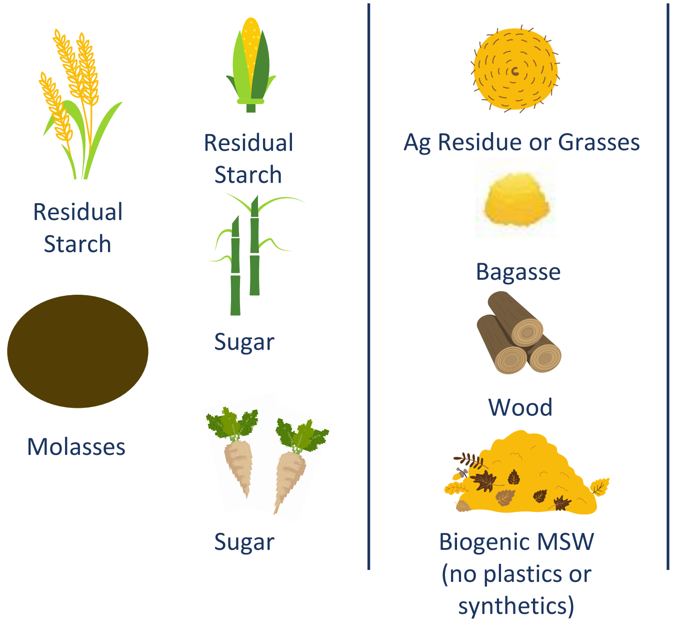
Sourcing the Alcohol for ATJ

- The source can make a huge difference in:
  - Scalability
  - Carbon footprint
  - Sustainability
  - Cost
- Using carbohydrates as the feedstock for alcohol production enables a meaningful solution for SAF
  - Fermentation of plants, organic waste, etc.
- Other feedstocks for alcohol are possible, but won't reach the same scale and impact
  - Waste flue gas
  - Others

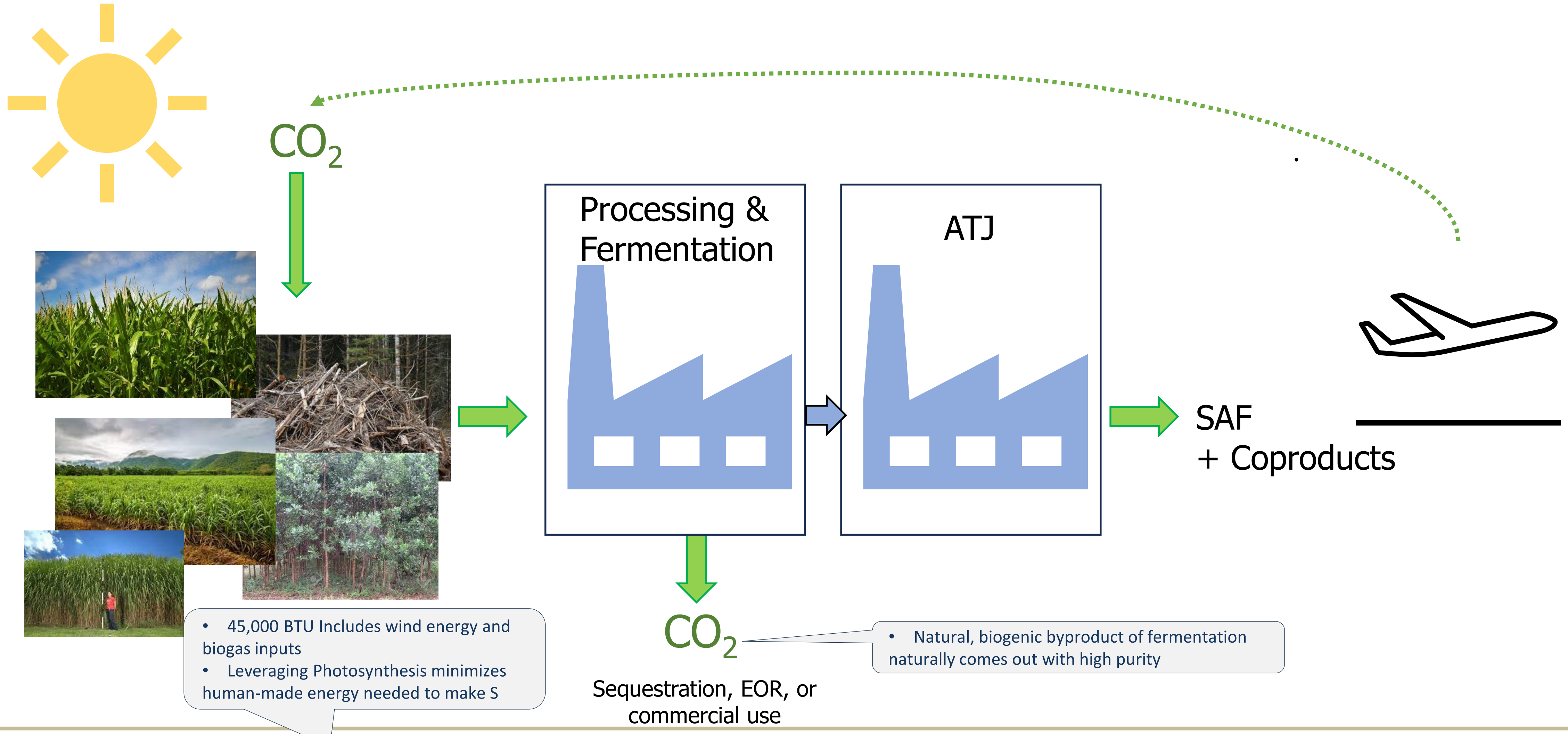
> - Gevo has validated its processes with carbohydrates from a variety of feedstocks including forest trimmings, energy grasses, ag residues, starches, molasses.
> - Selection of feedstock impacts scale, investment hurdle, and selling price of SAF.

Sourcing the Carbohydrate for the Alcohol

- All Plants contain carbohydrates which are the most abundant natural material
- Plant sequester CO_2 from the air via photosynthesis and convert CO_2 to carbohydrates, which saves a LOT of energy
- The selection of the carbohydrate can significantly impact scalability, capital cost, operating cost, carbon score and sustainability



Alcohol-to-jet



Possible Today:
Example using corn

INPUT 45,000 BTU ENERGY
Incl growing plants

OUTPUT 1 GALLON SAF (~120,000 BTU)
+ VALUABLE COPRODUCTS + CAPTURED CO_2

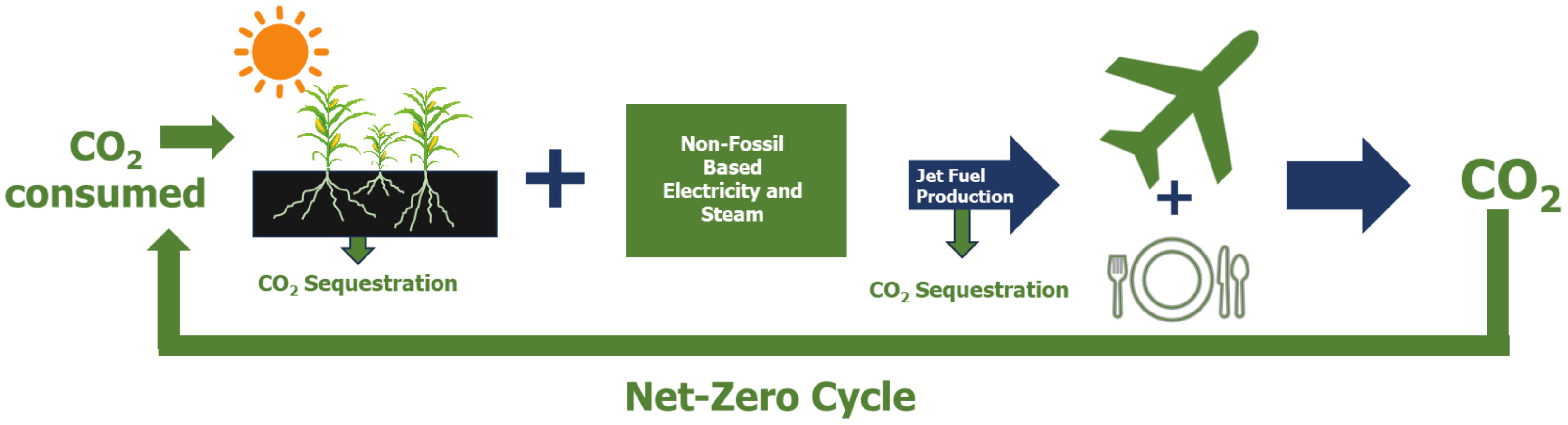
Sources: 1. USDA report: 2015 Energy Balance for the Corn-Ethanol Industry. 2. Gevo Net Zero 1 Mass & Energy Balance.

Providing lower carbon fuels vs more low-carbon fuels

- The lower the carbon score of the SAF, the fewer gallons needed to reach a target carbon reduction
- Plants grown using Climate Smart Ag practices can sequester meaningful amounts of carbon
- Fermentation of the carbohydrates releases biogenic CO2 in a high purity stream that can be sequestered or converted to fuels, chemicals
- Using zero carbon electricity and biogas decarbonizes the production facility

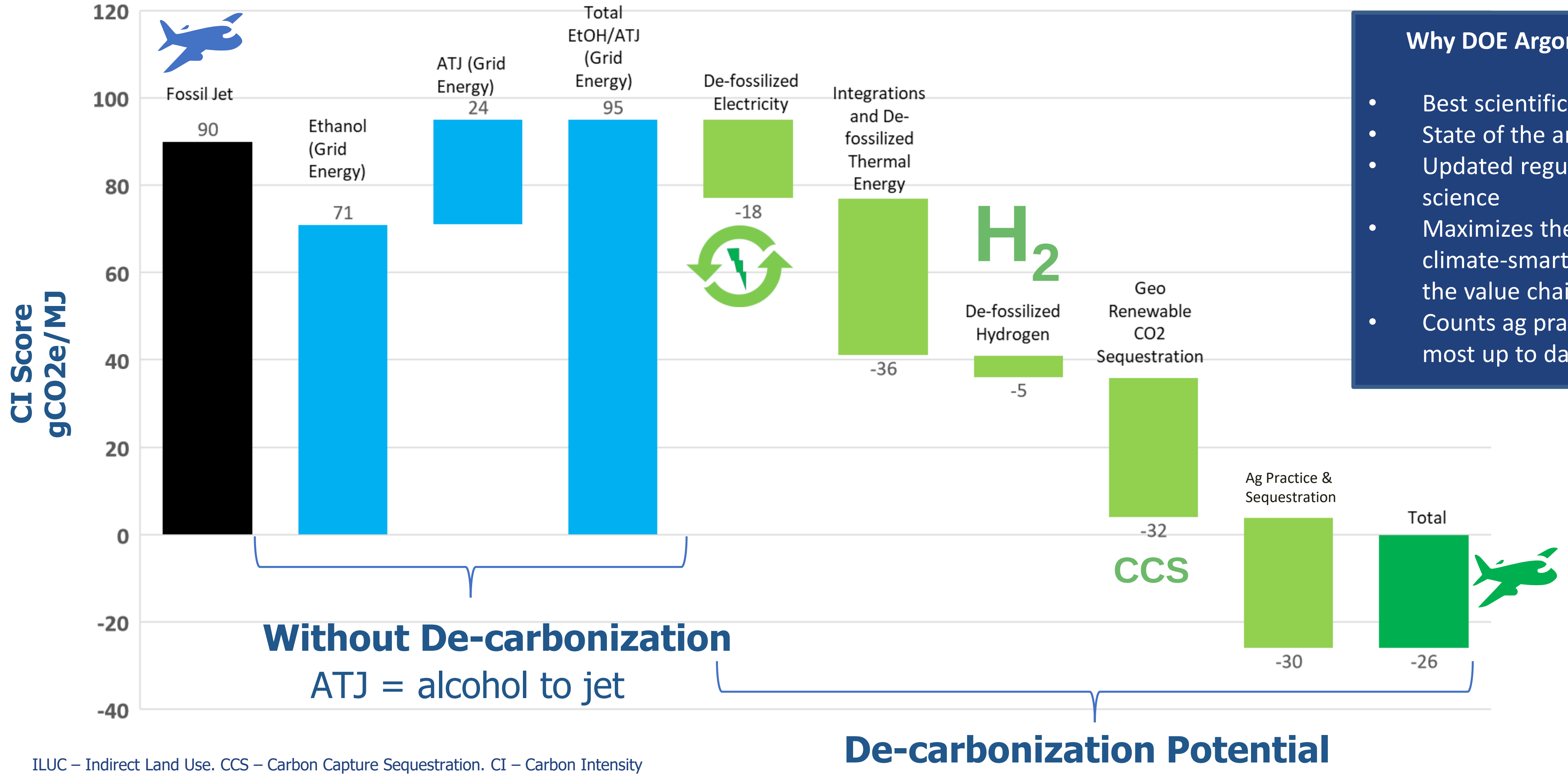
AT GEVO, WE BELIEVE

- **Land should be used first for food**
  - Protein is needed & demand will grow
  - Byproducts from food/feed should be used to make materials and fuels
- **The whole supply chain should be incentivized to improve sustainability**
  - We should capture carbon in soil through advanced farming practices or in forestry
- **Fossil carbon should be eliminated wherever possible**
- **Sustainability attributes must be tracked and verified from the field level**



Reductions in carbon intensity must be measured, tracked and verified

Driving CI down



Why DOE Argonne GREET Model?

- Best scientific model
- State of the art
- Updated regularly to reflect new science
- Maximizes the carbon value from climate-smart ag to be shared along the value chain with farmers
- Counts ag practices, CCS and has most up to date iLUC

ILUC – Indirect Land Use. CCS – Carbon Capture Sequestration. CI – Carbon Intensity

Gevo Net-Zero 1

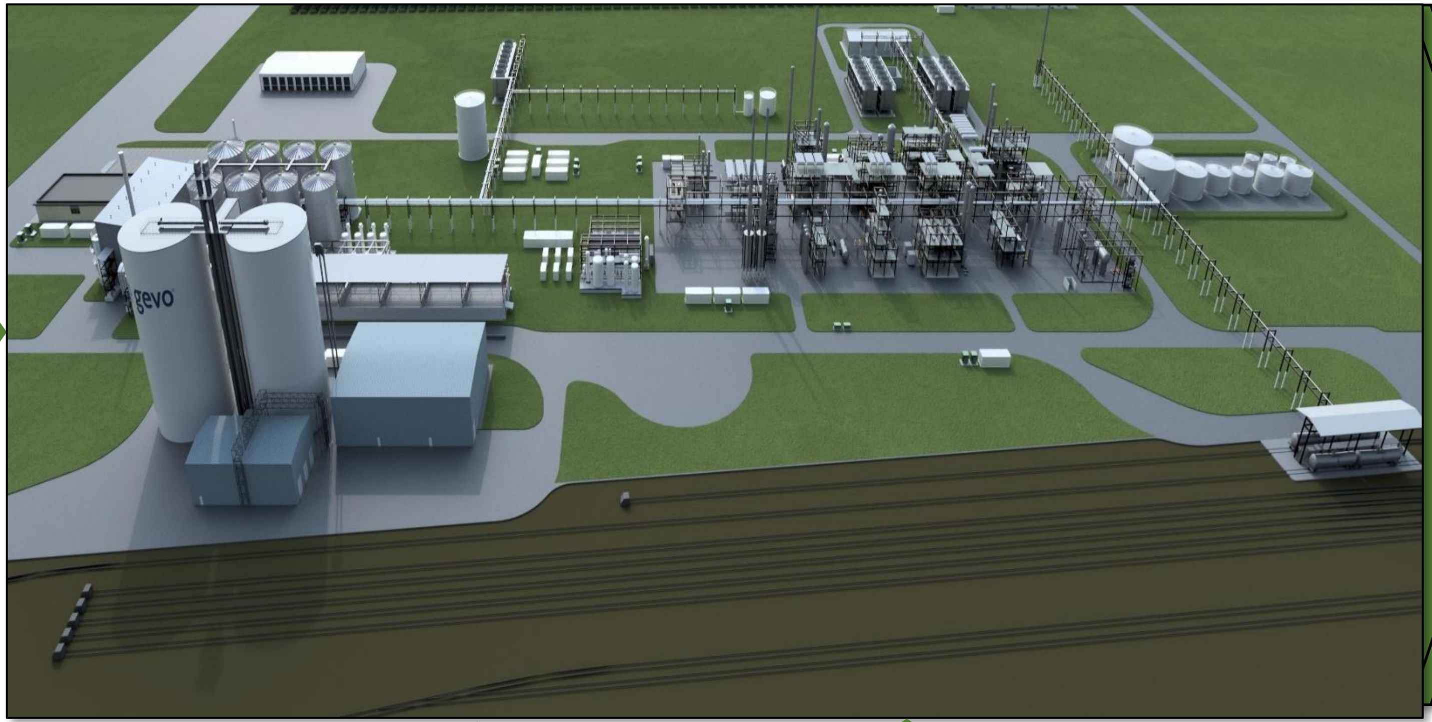
Location: Lake Preston, South Dakota

Targeted start-up 2026[1] **-** Currently in engineering optimization and financing phase

Project unlevered IRR[2] on equity invested is projected to be in upper teens

Climate Smart Corn

VERITY CARBON SOLUTIONS



Low-Carbon Protein, Feed, and Vegetable Oil

Low Carbon Animal Feed and Protein[3]
~695,000 mt/y (wet/as is)
~250,000 mt/y (dry matter)

Low Carbon Corn Oil
~34 million lbs/y

Net-Zero Fuels[4]
4,450 bbl/d Hydrocarbons
65 million gal/y
218,400 mt/y

Biogenic CO_2 Capture and Sequestration
~290,000 mt/y

SUMMIT CARBON SOLUTIONS

H_2

ZERO6 ENERGY

gevo RNG

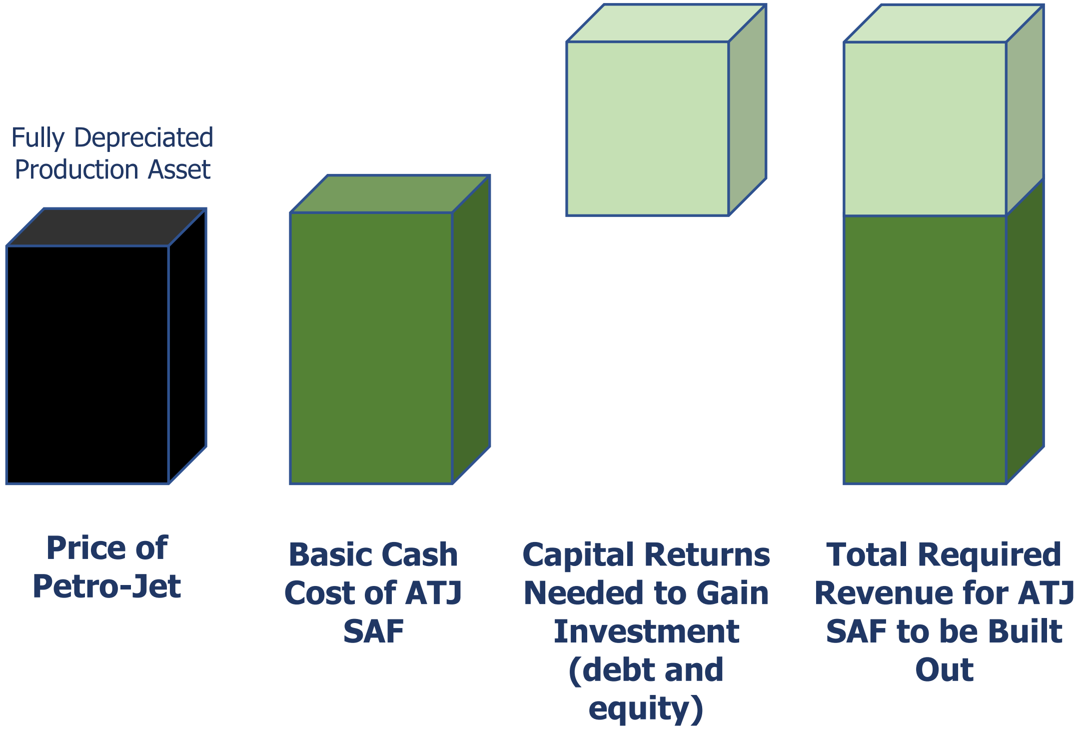
gevo

1. Targeted startup is dependent on a number of factors and assumptions, including the timing of obtaining construction financing for Net-Zero 1.
2. Based upon a number of assumptions, including projected commodity prices, operating costs, revenue projections for SAF and carbon value.
3. Based on 36% dry matter for wet basis, and 88% dry matter for dry basis.
4. Per day metrics based on 350 days of operation per year.

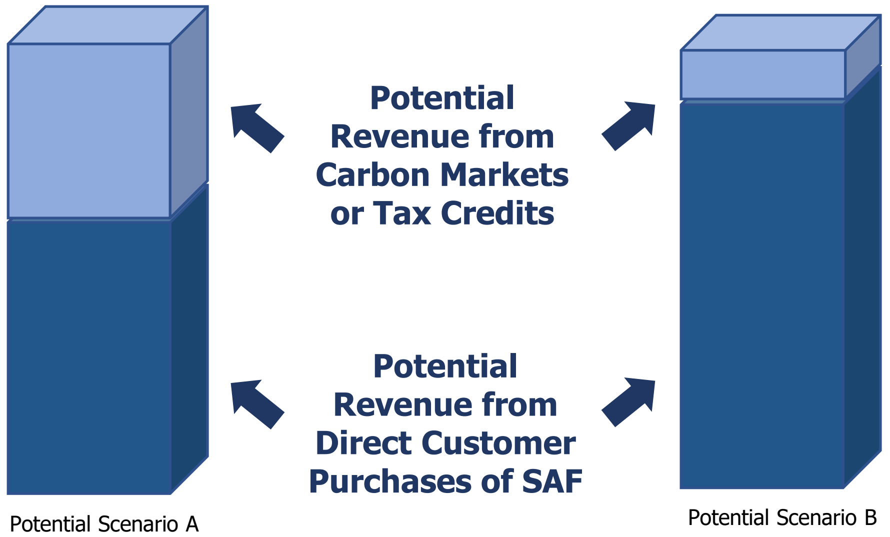
Economics

Cash cost of SAF production isn't too much higher than the price of petroleum jet fuel. However, SAF production involves building new assets which require a financial return attractive enough for investors. That drives the need for carbon value to support building out the infrastructure.

Cost [1]



Revenue Sources



Potential Revenue from US Government Programs Could Include a combination of:

- RFS
- Other Federal Credits (IRA)
- State Credits (LCSF, Illinois, etc.)

(1) Based on commodity prices and production costs which can change with changing commodity market conditions

CLIMATE SMART AG: FOOD, FUEL AND CARBON REMOVAL

ICAO ENVIRONMENT

ACT SAF

INCENTIVIZE GROWERS TO IMPROVE PRACTICES

- In the US, roughly 50% of cropland uses low-till or no-till. With 100% implementation, could sequester 2% of total US GHG emissions(2).
- With further advances in soil science and other climate-smart practices, even more is possible.
- We need to reward growers for their contributions to CI reduction while improving soil health.

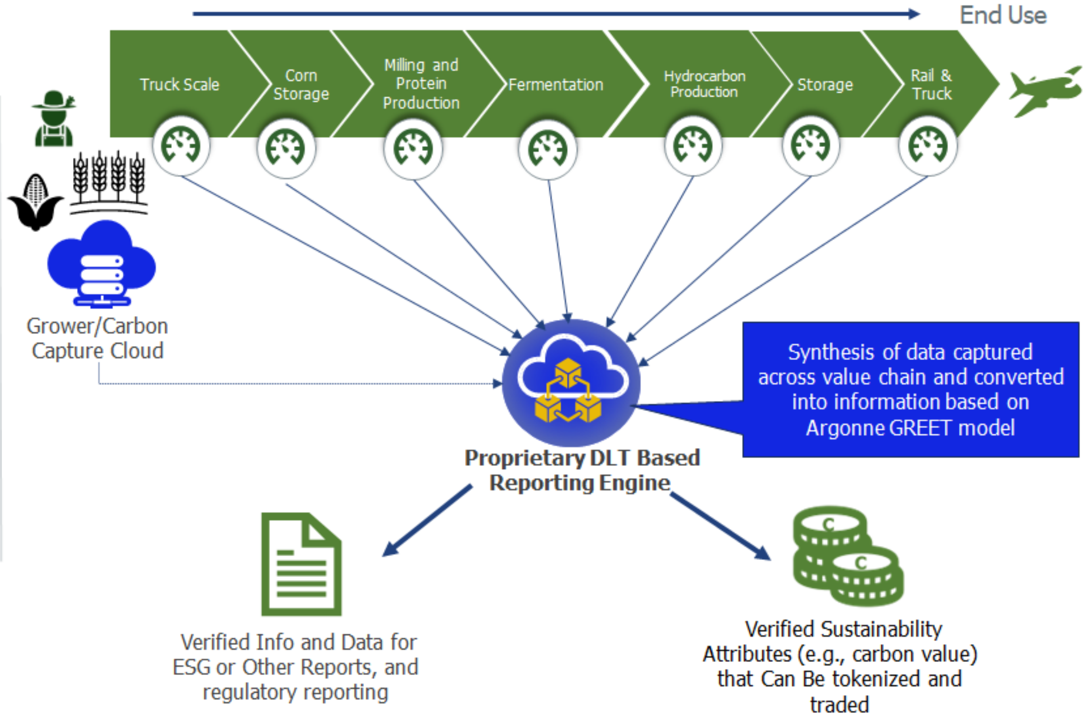
Conventional Till Baseline

Reduced Till leads to a -27 CI reduction in SAF or better (1)

No-Till leads to a -33 CI reduction in SAF or better(1)

Reduced fertilizer, increased soil health and carbon, decreased runoff
Precision AG: apply chemicals only where it is needed

START BY MEASURING, VERIFYING, REPORTING HOW GROWERS ARE DOING



VERITY CARBON SOLUTIONS

(1) For illustration only - Assumes renewable energy is used in manufacturing and calculated using Argonne GREET, including other climate smart ag practices.
(2) Thompson, N. et al. (2021) "Opportunities And Challenges Associated With "Carbon Farming" For U.S. Row-Crop Producers", Purdue University Center for Commercial Agriculture. Accessed on August 12, 2021 at https://ag.purdue.edu/commercialag/home/resource/2021/06/opportunities-and-challenges-associated-with-carbon-farming-for-u-s-row-crop-producers/. Image available on same site, powered by Bing, GeoNames, Microsoft, and TomTom

DRIVING THE RIGHT PRACTICES, PAYS DIVIDENDS

PUT THE DATA IN THE GROWERS HANDS

- Verity smart phone App reports carbon scores and other sustainability attributes

Field Overview	
Entity	Confidential
Farm	Confidential
Grower	Confidential
Field	Field 150
Field ID	#001565
Acres	151.5
Season	2021
Yield (bushel /acre)	210.6
Bushels	31.906 (810t)
CI from emissions	14.3 gCO2e/MJ
CI including SOC	-15 gCO2e/MJ
Total potential CI contribution from feedstock	-0.7gCO2e/MJ
National Corn Average CI	30.1gCO2e/MJ

Data Input Sources	
Granular Software	Fertilizer, Lime, Tillage, Herbicide, Insecticides, Yield, Moisture, Cover Crops
Fertilizer Suppliers	Chemical composition
MyJohnDeere Platform	Diesel, Gasoline
Declarative	Electricity, Nitrogen Management
Laboratories/ Supplier Reports	Manure, Soil sampling, Custom Applications, LPG
Google Earth	GIS Practice verifications, Land Use Change check
Certification	RSB Farm verified

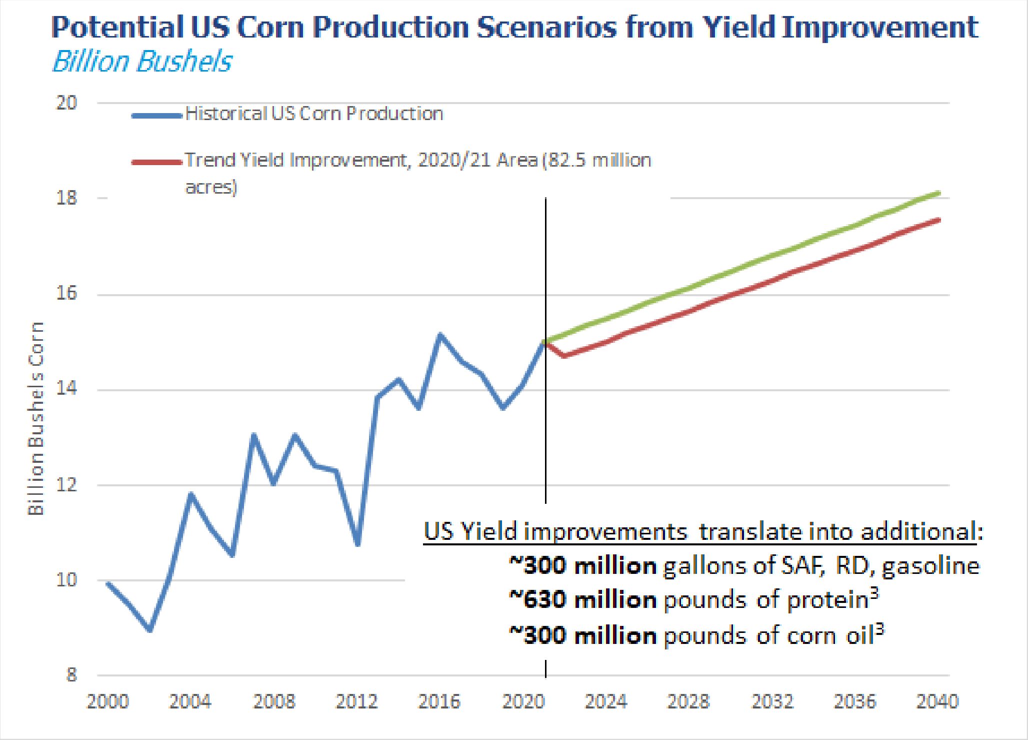
Real field-level results showing potential -31 CI reductions in SAF with precision ag, cover crops and conservation tillage

Now: Developing fully integrated and automated system for biofuels from field to gallon.

*Calculated as potential CI contribution in final SAF, excluding LUC
**Source: Mi. Wang, Argonne National Lab, "Updated Life-cycle Analysis of Biofuels with the GREET Model" Presentation at Task 39 of IEA Bioenergy TCP, April 2, 2020

INCENTIVIZE IMPROVEMENTS

- Potential for more carbon sequestration in the soil
- Reduced fertilizer, increased soil health and carbon, decreased runoff
- Precision AG: apply chemicals only where it is needed



Source: (1) USDA NASS and USDA WASDE. (2) Conversion yields to hydrocarbons assumes expected yields of fermentation alcohols to hydrocarbons. (3) Corn nutrient composition derived from 2015-2019 averages as reported in the 2020/2021 Corn Harvest Quality report from the US Grains Council https://grains.org/wp-content/uploads/2020/12/2020-2021-USGC-Corn-Harvest-Quality-Report.pdf. (4) USDA ERS, Feed Outlook

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ACT SAF
Assistance, Capacity-building and Training for SAF

Presentation of Fischer-Tropsch by Sasol and Topsoe

A history of taking on some of the world’s toughest challenges

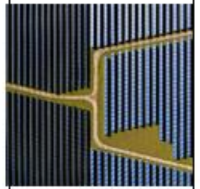
Today and for the future

1940
Dr. Haldor Topsøe founds the company based on his passion for science and determination to make a positive difference in the world

1950s
Topsoe ammonia technology to produce fertilizer helps feed the growing world population

1980s
Topsoe technology removes 18 million tons of sulfur oxides every year

1990s
Topsoe clean air solutions remove hazardous particles, greenhouse gases, and smog from industrial emissions

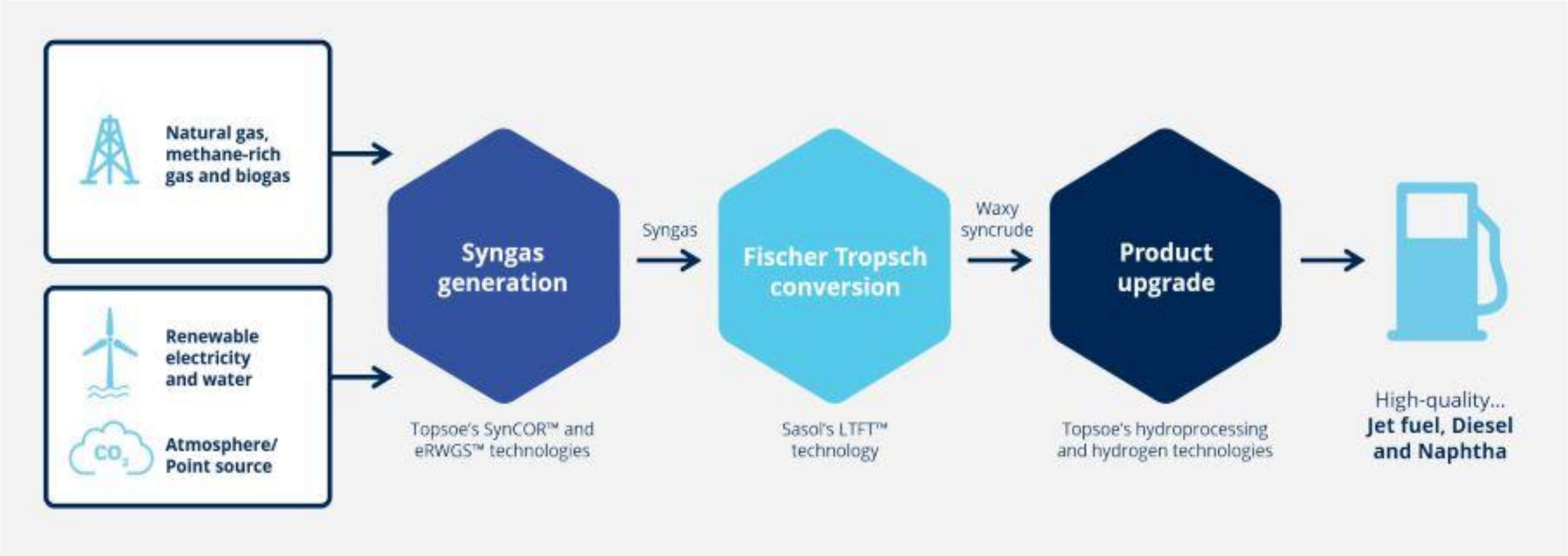


2022
Topsoe solutions support all phases of the clean energy transition

TOPSOE

G2L^{TM} Single Point Licensor

Only licensor offering complete eFuels feed → Product licence



TOPSOE

Development of Topsoe eRWGS™ processes

The result of a constant strive for improvement & perfection

GTL	• Conversion of natural gas to liquid transportation fuels
Two-step RWGS	• Renewable fuels – adaptation of GTL process
eRWGS™	• Technology enabler: eReact – targeting optimal efficiency

TOPSOE

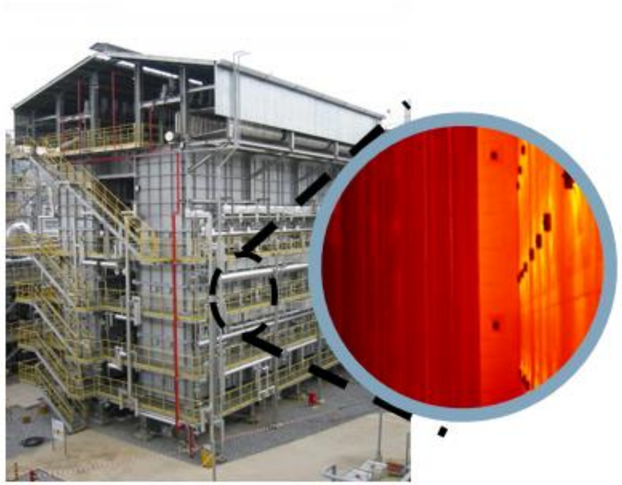
Improvements of RWGS

Transition from “thermal” RWGS to efficient renewable RWGS process

Indirect heating → Direct heating → eRWGS

Indirect heating

- Heating by combustion of H2 and transfer heat to syngas
- Energy loss in flue gas and downstream syngas cooling

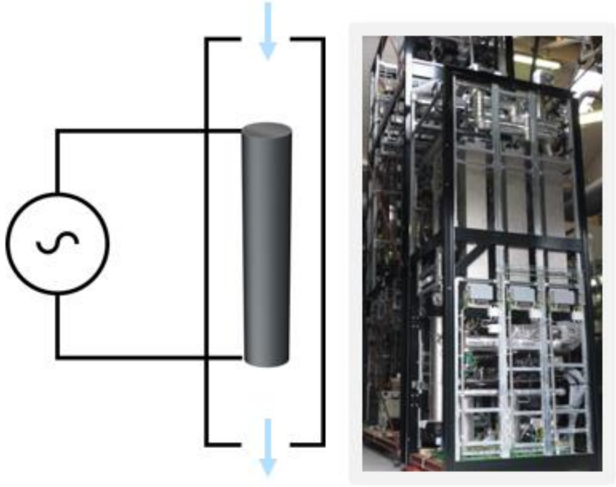


Direct heating

- Heat by combustion of H2 in the syngas
- Energy loss via increased downstream syngas cooling

eRWGS

- Heat from electrical heated catalytic hardware
- Energy loss via syngas cooling



Sasol Limited at a glance

sasol

An international integrated chemicals and energy company, headquartered in South Africa

Pioneer in synthetic fuels production using gas-to-liquids (GTL), coal-to-liquids (CTL) and related technologies with over 70 years' experience

Partner with various organizations to develop, pilot, and implement new technologies

Strong intellectual property portfolio with 2 216 patents held worldwide

ENERGY BUSINESS

LEADING THE ENERGY TRANSITION IN SOUTHERN AFRICA

CHEMICALS BUSINESS

GROWING WITH OUR UNIQUE CHEMISTRY

sasol ecoFT

BUILDING SUSTAINABLE BUSINESSES WITH OUR ADVANTAGED FT TECHNOLOGY

FY22

Turnover
$18.1 billion

Operating profit
$3.4 billion

Enterprise Value
$19.7 billion

Fischer-Tropsch (FT) Chemistry – general overview

sasol

- **FT process converts synthesis gas to liquid hydrocarbons**
  - $nCO + 2nH_2 \rightarrow (-CH_2-)_n + nH_2O$ (Fe, Co) FT Reaction
  - $H_2O + CO \longleftrightarrow CO_2 + H_2$ (Fe) Water Gas Shift Reaction

FT makes more mass of water than of hydrocarbon

- **FT reaction is highly exothermic at ~ 165 kJ/mol CO converted**
- **Product spectrum depends on:**
  - catalyst, temperature, pressure, gas composition
- **Low Temperature Fischer Tropsch (LTFT - Fe/Co catalyst)**
  - 200 - 250 ^oC: high alpha (>0.9) targets distillate and waxes – *less oxygenates*
- **High Temperature Fischer Tropsch (HTFT - Fe catalyst)**
  - 350 ^oC: low alpha (<0.7) targets gasoline and light olefins – *more oxygenates*
- **The higher the temperature the more complex the "soup" of molecules**

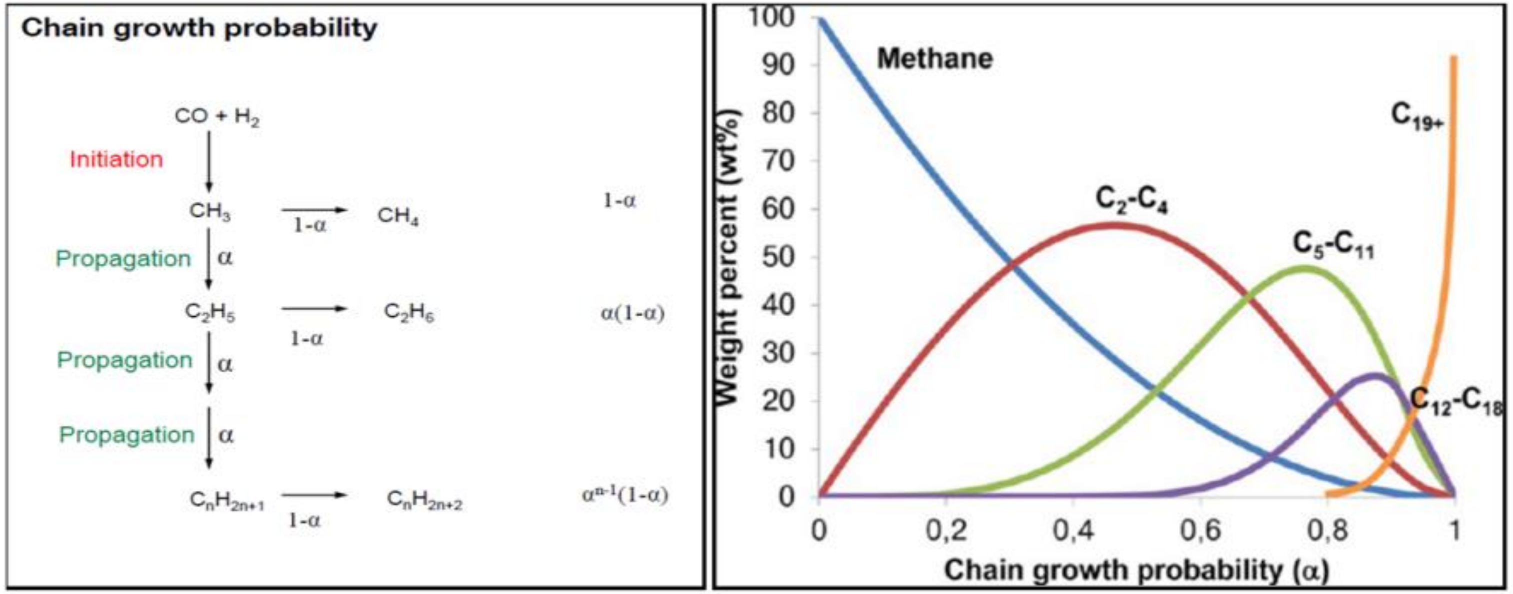
Understanding Fischer Tropsch

- The Fischer-Tropsch reaction is essentially a polymerization reaction and can be characterised by the Anderson Shulz Flory distribution

The key parameter being the alpha (α), this essentially indicates the probability of chain growth.

Typical alpha for Cobalt based LTFT is in the region of 0.85 to 0.95

Higher Alpha is better

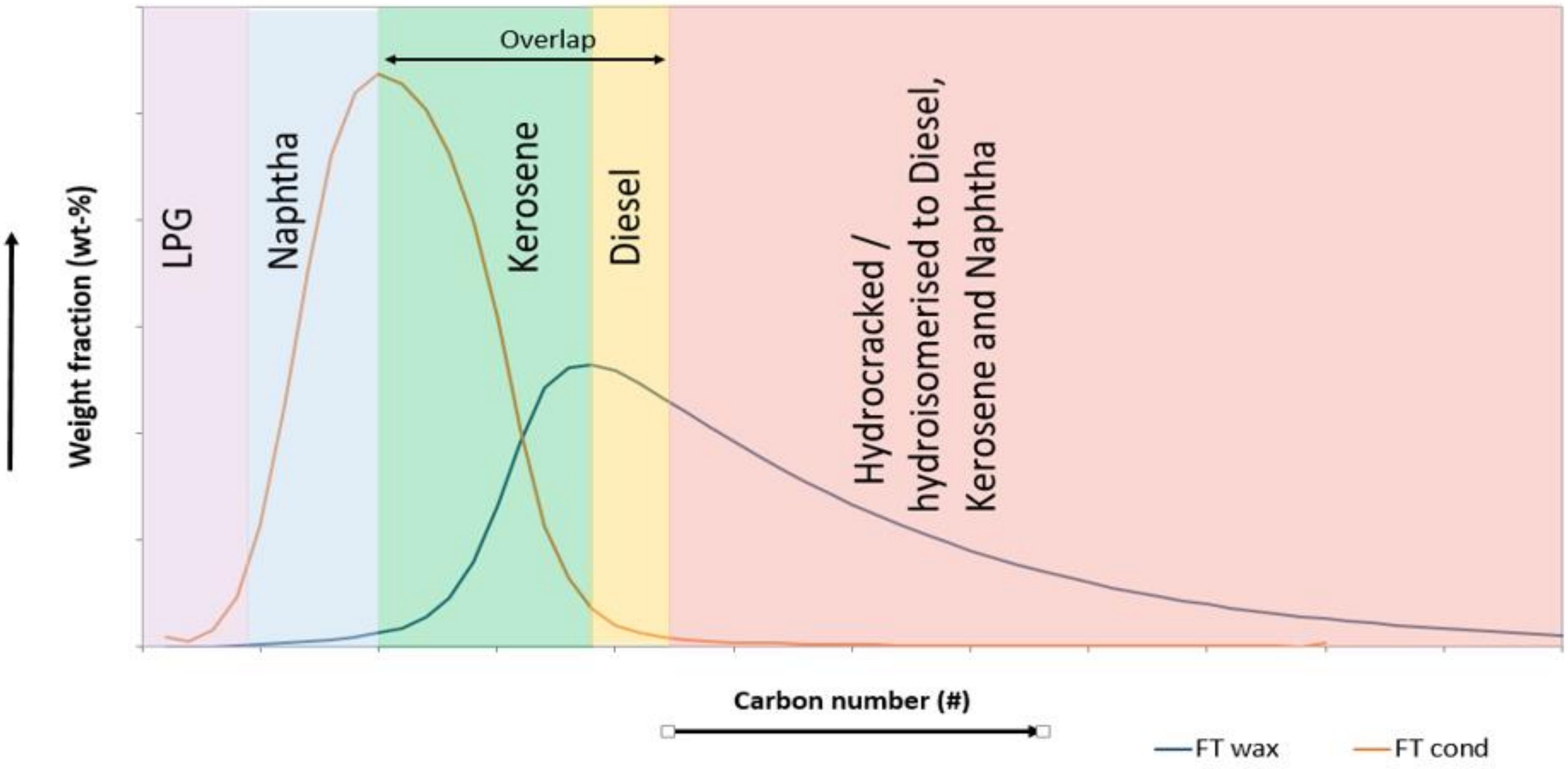


Chen, W.; Lin, T.; Dai, Y.; An, Y.; Yu, F.; Zhong, L.; Li, S.; Sun, Y., Recent advances in the investigation of nanoeffects of Fischer-Tropsch catalysts. *Catalysis Today* **2017**.

Sourced in PhD thesis of Sandy Lama (2018) – University of Potsdam, Functionalization of Porous Carbon Materials with Heteroatoms and Application as Supports in Industrial Heterogeneous Catalysis

Products from the Low Temperature Fischer-Tropsch™ Reactor and equivalent straight run product destination

sasol



Fundamentals of FT reactors

- **FT reaction is highly exothermic**
- **All technologies on offer in the market focus on efficient heat removal. Reactor types utilised include:**
  - **Slurry bed reactors (e.g. Sasol, Axens)**
  - **High tube count, small tube diameter, large diameter reactors (e.g. Shell)**
  - **Short path radial flow reactors (e.g. Johnson Matthey CANS reactor)**
  - **Micro Channel reactors (e.g. Compact GTL, Velocys, Ineratec)**

➔ Typically heat is used to generate steam and this steam needs to be efficiently utilised within the process

Shell Global

Johnson Matthey
Inspiring science, enhancing life

Compact GTL

VELOCYS

INERATEC

sasol

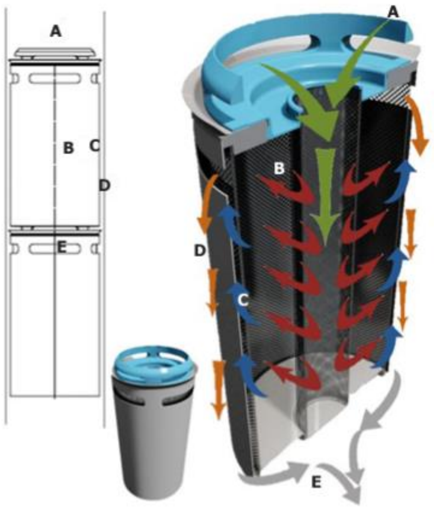
Axens
Powering integrated solutions

References:
Corporate logos sourced from company websites

FT reactors – large scale reactor technologies

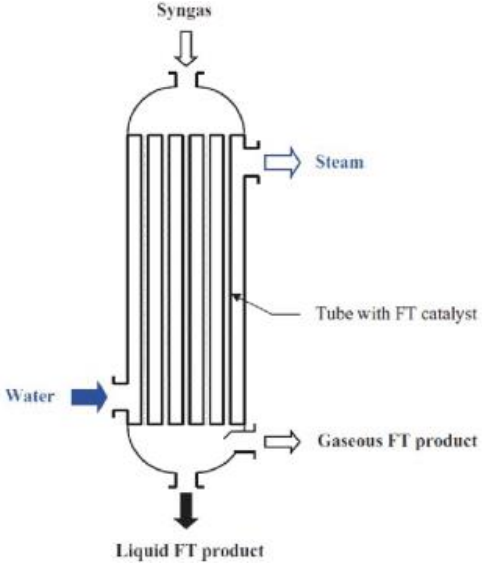
sasol

CANS reactor



Johnson Matthey
Inspiring science, enhancing life

Shell and
Tube reactor



Shell Global

Slurry bed reactor

sasol

Axens
Powering integrated solutions

References
Sasol slurry LTFT reactor : https://www.engineeringnews.co.za/article/progress-in-foundational-business-projects-2014-10-24
Johnson Matthey CANS image : https://technology.matthey.com/article/65/3/395-403/
Shell and Tube reactor image : Temperature control in a multi-tubular fixed bed Fischer-Tropsch reactor using encapsulated phase change materials; Figure 2.10; A. O. Odunsi, ;Published 1 February 2017

Fischer-Tropsch

FT reactors – medium / small scale

VELOCYS

sasol

Microchannel reactors

INERATEC

CompactGTL

References
Velocys Reactor image: Temperature control in a multi-tubular fixed bed Fischer-Tropsch reactor using encapsulated phase change materials; Figure 2.2; A. O. Odunsi, ;Published 1 February 2017

Other FT specific Complexities

- **Exothermic FT reaction – if catalyst gets too hot, catalyst can be damaged. In addition high temperature lowers alpha, leading to undesired selectivity.**
  - Temperature control of the reaction / reactor is critical
- **FT catalysts are typically extremely sensitive to poisons**
  - Incl Sulfur, halides, metals, nitrogenous species
- **FT catalyst manufacture at scale is complex**
- **Wax handling**
  - Typically, lines handling material that can congeal need a form of heat tracing
- **FT waxy product**
  - These long chain molecules must be, hydroprocessed (including cracking and isomerization) to improve cold flow properties. This requires high temperatures and high hydrogen partial pressures but when compared to similar processes for crude derived material, the conditions for FT derived feedstocks are significantly milder
- **FT reaction generates water**
  - This process water is contaminated with oxygenates and hydrocarbons. It needs to be treated before leaving the site
  - Possible reaction water treatment options include
    - Anaerobic digestions
    - Fractionation / effluent biotreatment
    - Incineration

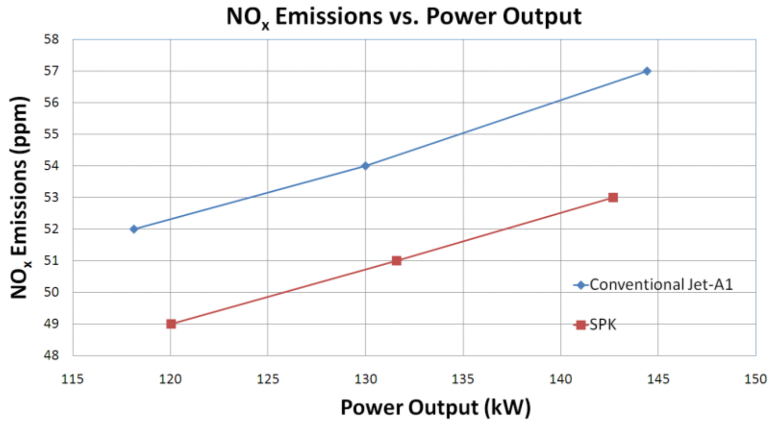
The GTL - LTFT pathway is commercially proven

• Sasolburg, South Africa	- 2500 bbl/day
• Bintulu, Malaysia	~14 700 bbl/day
• Oryx GTL, Ras Laffan Industrial City, Qatar	~33 500 bbl/day
• Pearl GTL, Ras Laffan Industrial City, Qatar	140 000 bbl/day
• Escravos GTL, Nigeria	~34 000 bbl/day
• Sasolburg, South Africa	7 500 bbl/day
• UzGTL, Uzbekhistan	38 000 bbl/day

➔ GTL is commercially viable and commercially proven

The FT pathway is at the core of Sasol's business

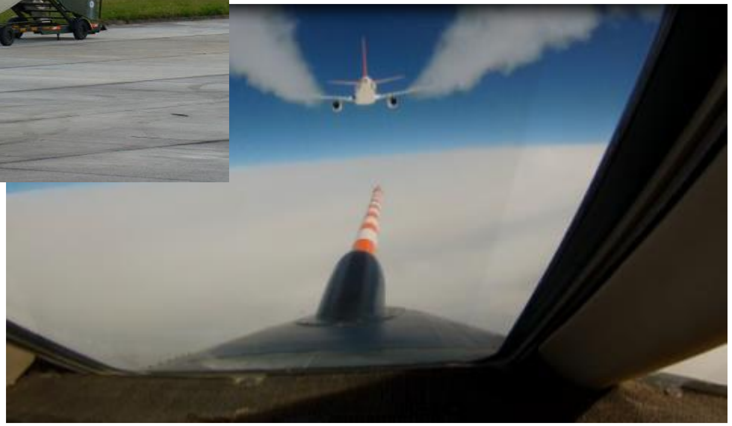
sasol



- Sasol believes the FT route can enable the sustainable fuel space.
- Kerosene range material produced from FT can meet the ASTM D7566 Annex 1 specification for Synthetic Paraffinic Kerosene (SPK)
- Can be blended up to 50% with crude derived Jet-A1
- FT derived Kerosene has lower
  - NO_x emissions
  - SO_x emissions

  and forms less soot on combustion leading to a lower propensity to form contrails

➔ Sasol involved with First fully synthetic jet fuel flight in 2010

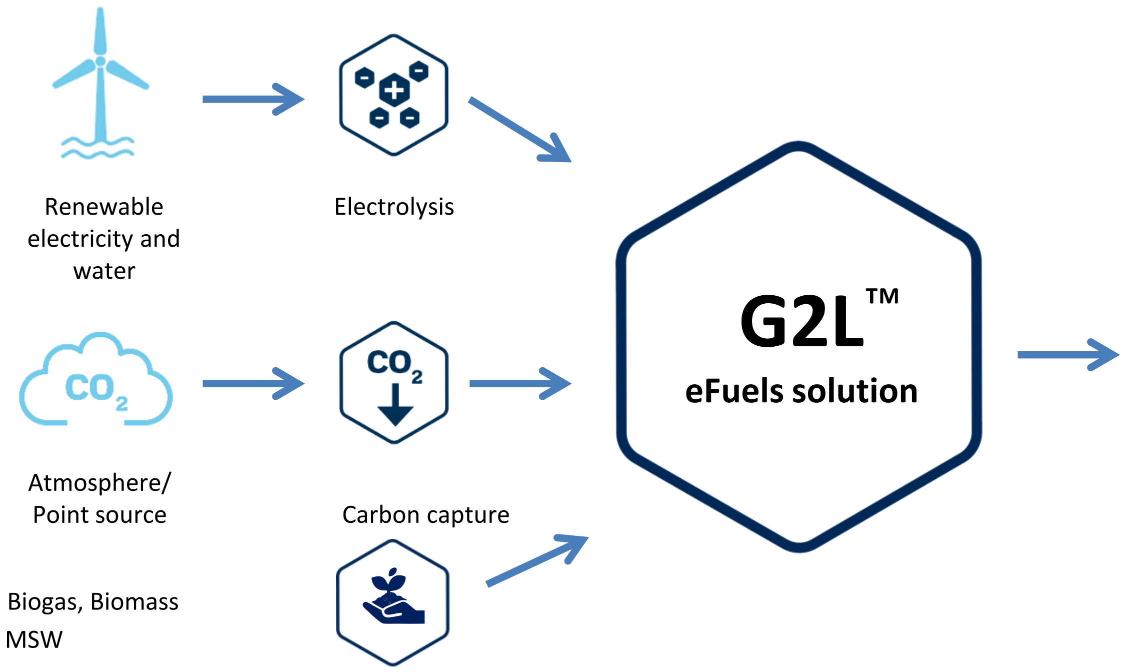


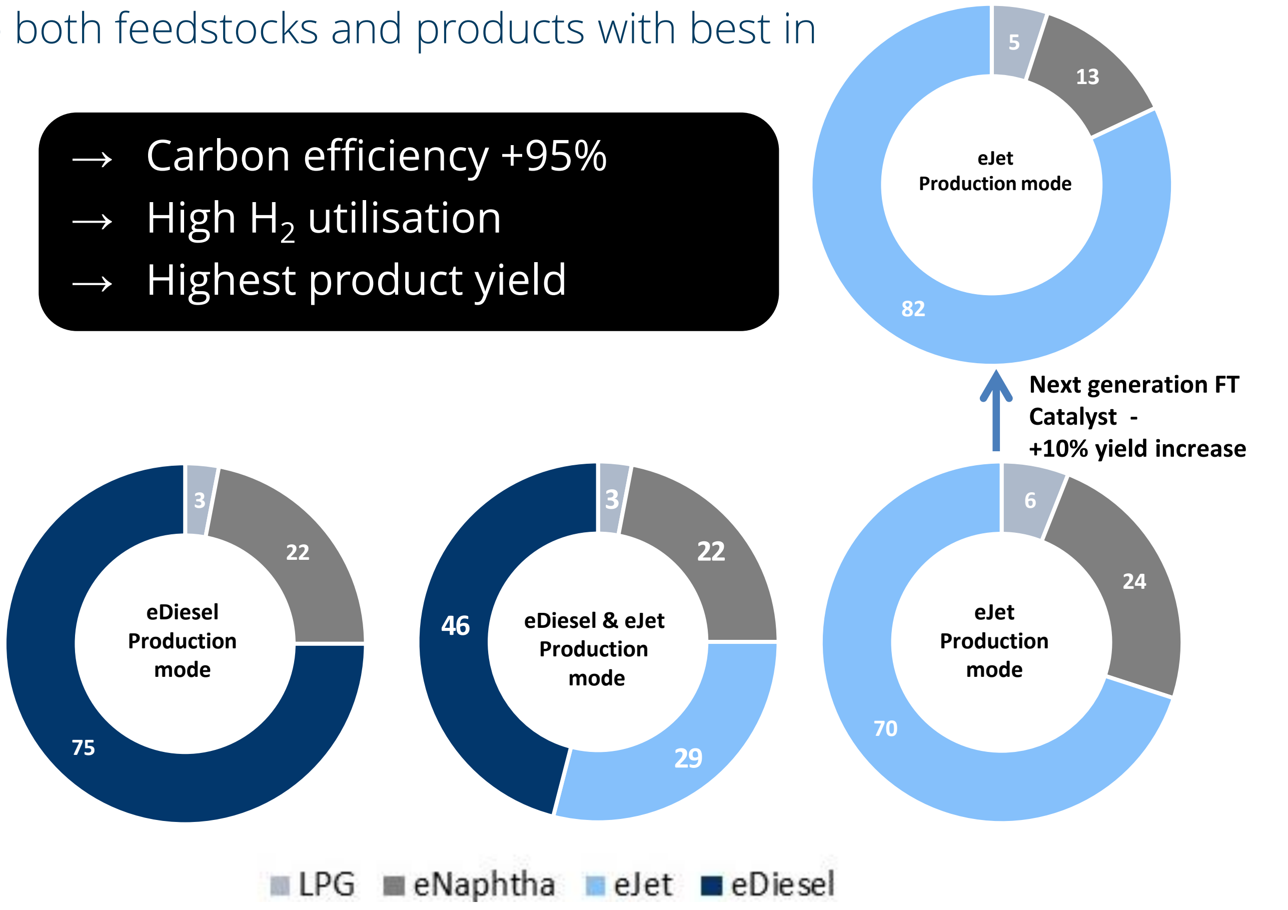
Reference.
Bester N. & Yates A. Sasol Fuels Research. 2009. Assessment of the operational performance of Fischer–Tropsch synthetic–paraffinic kerosene in a T63 gas turbine compared to Conventional jet a-1 fuel, ASME Turbo Expo. GT 2009-60333

sasol

Integrated syngas, FT and PWU processes offer full flexibility to both feedstocks and products with best in class efficiency and yields

- → Carbon efficiency +95%
- → High H_2 utilisation
- → Highest product yield





$SkyfuelH_2$

Sasol ecoFT and Uniper to develop, implement and operate a fully integrated facility for SAF production

(start: April 2028)

Uniper and Sasol jointly develop the project combining the experience of two industries

Sasol

Project development
FT equipment
FT license/catalyst
SAF product quality

Uniper

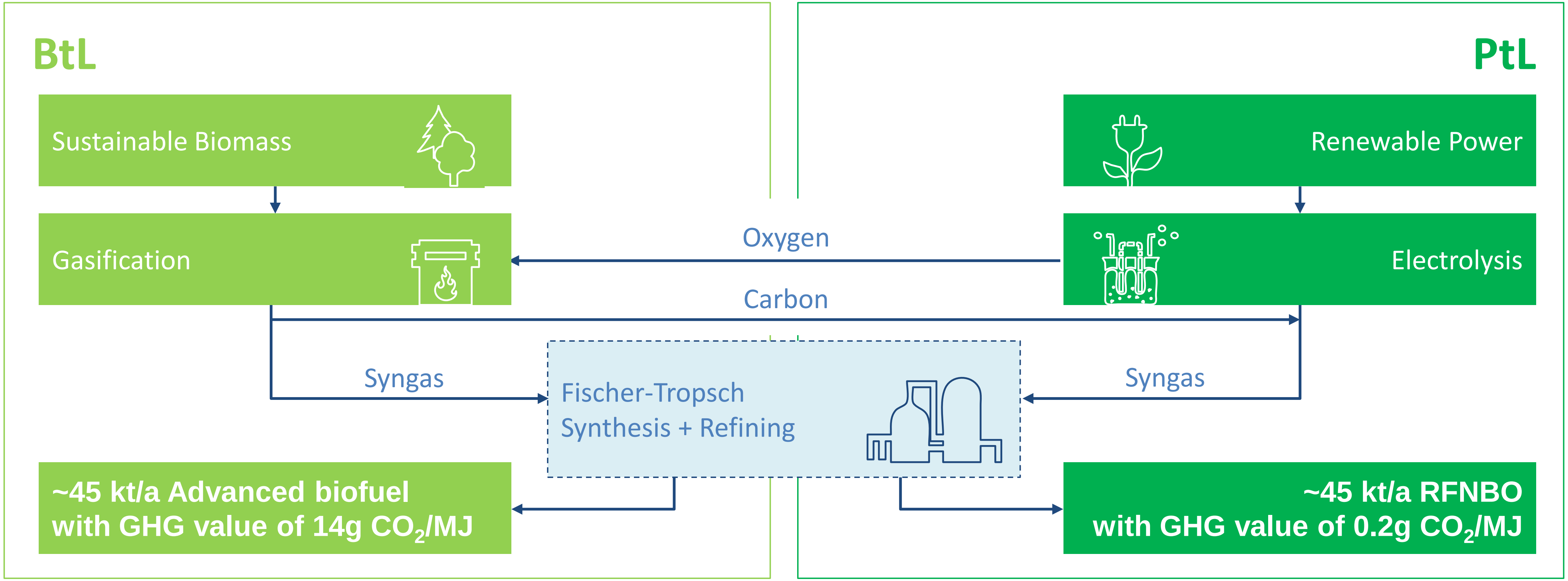
Project development
Power sourcing
Biomass sourcing
Site sourcing

Supporters

Municipality of Solleftea (site)


Launching event on Apr 27th 2022

SkyfuelH2 – „2 in 1“: Creating synergies from BtL and PtL production by exchanging oxygen against carbon



SkyfuelH2: First-of-its kind, technically mature, cost efficient, sustainable

First-of-its-kind industry scale production of SAF,

located in Northern Sweden based on green H_2 and biomass

Combining established technologies

to minimize technical risk and reducing time to market

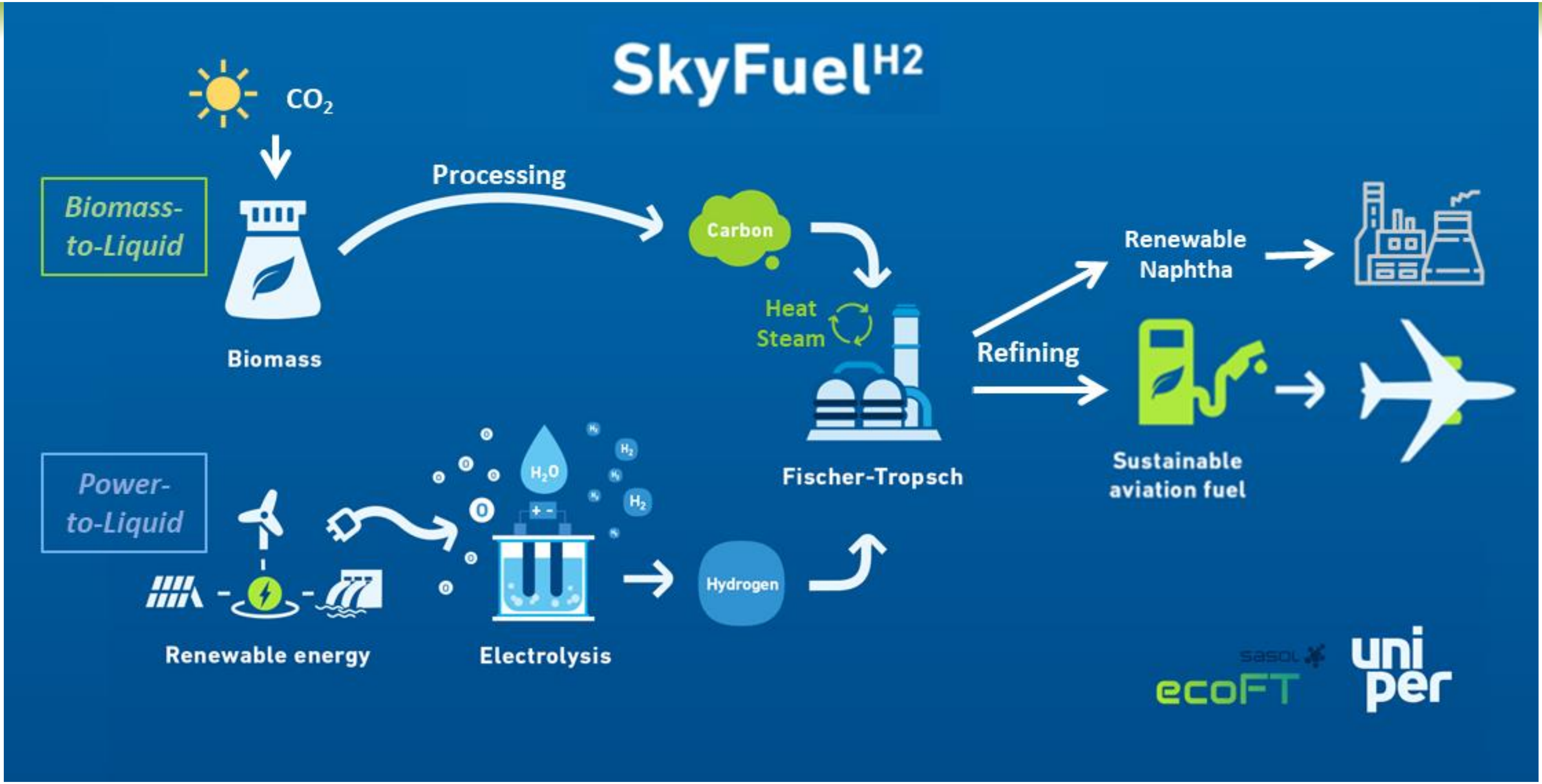
+90% higher SAF yield from biomass
+10% higher energy efficiency

Cost efficiency

through scaling, and a location beneficial regarding renewable electricity prices and availability as well as biomass availability

Sustainable product

Highest **carbon efficiency**, thus high degree of utilization of valuable and sustainable biomass, **>90% CO_2 reduction** vs. fossil kerosene, **100% RED2 compliant** renewable electricity and bio-feedstock (Annex IX a)


SkyFuel H2
CO2
Biomass-to-Liquid
Processing
Biomass
Carbon
Heat
Steam
Renewable Naphtha
Refining
Fischer-Tropsch
Sustainable aviation fuel
Power-to-Liquid
H2O
H2
Hydrogen
Renewable energy
Electrolysis
sasol
ecoFT
uniper

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Presentation of Power-to-Liquid by SAF+ Consortium

SAF+ CONSORTIUM

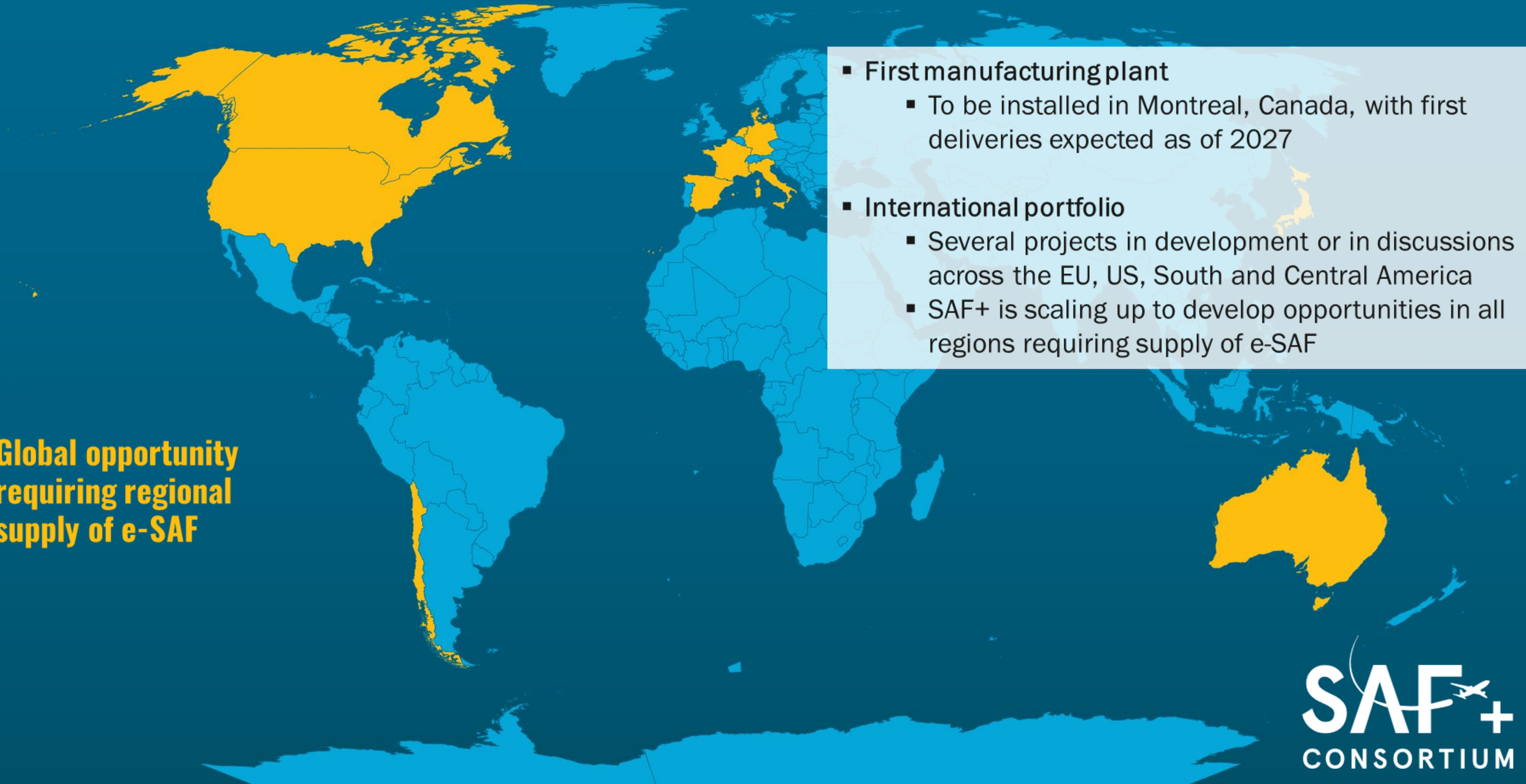
Who are we?

SAF+ is a pioneering sustainable energy company actively developing e-SAF projects internationally

- Global e-SAF off-takes
- Replicable Integrated Plant Design
- Project Implementation acceleration & de-risking

International Project Portfolio Development

Thanks to our signature approach we are accelerating high potential site identification & securing



- First manufacturing plant
  - To be installed in Montreal, Canada, with first deliveries expected as of 2027
- International portfolio
  - Several projects in development or in discussions across the EU, US, South and Central America
  - SAF+ is scaling up to develop opportunities in all regions requiring supply of e-SAF

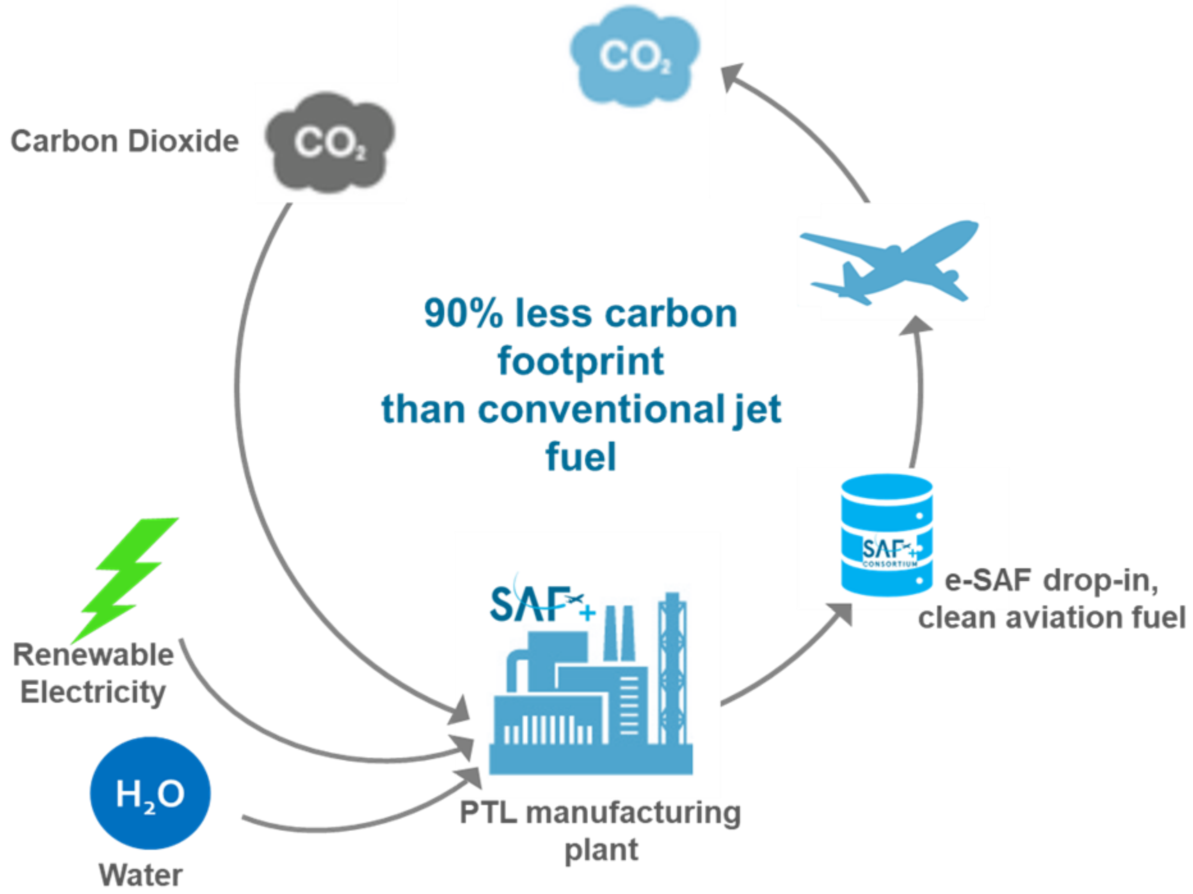
Global opportunity requiring regional supply of e-SAF

SAF+ CONSORTIUM

What is PTL?

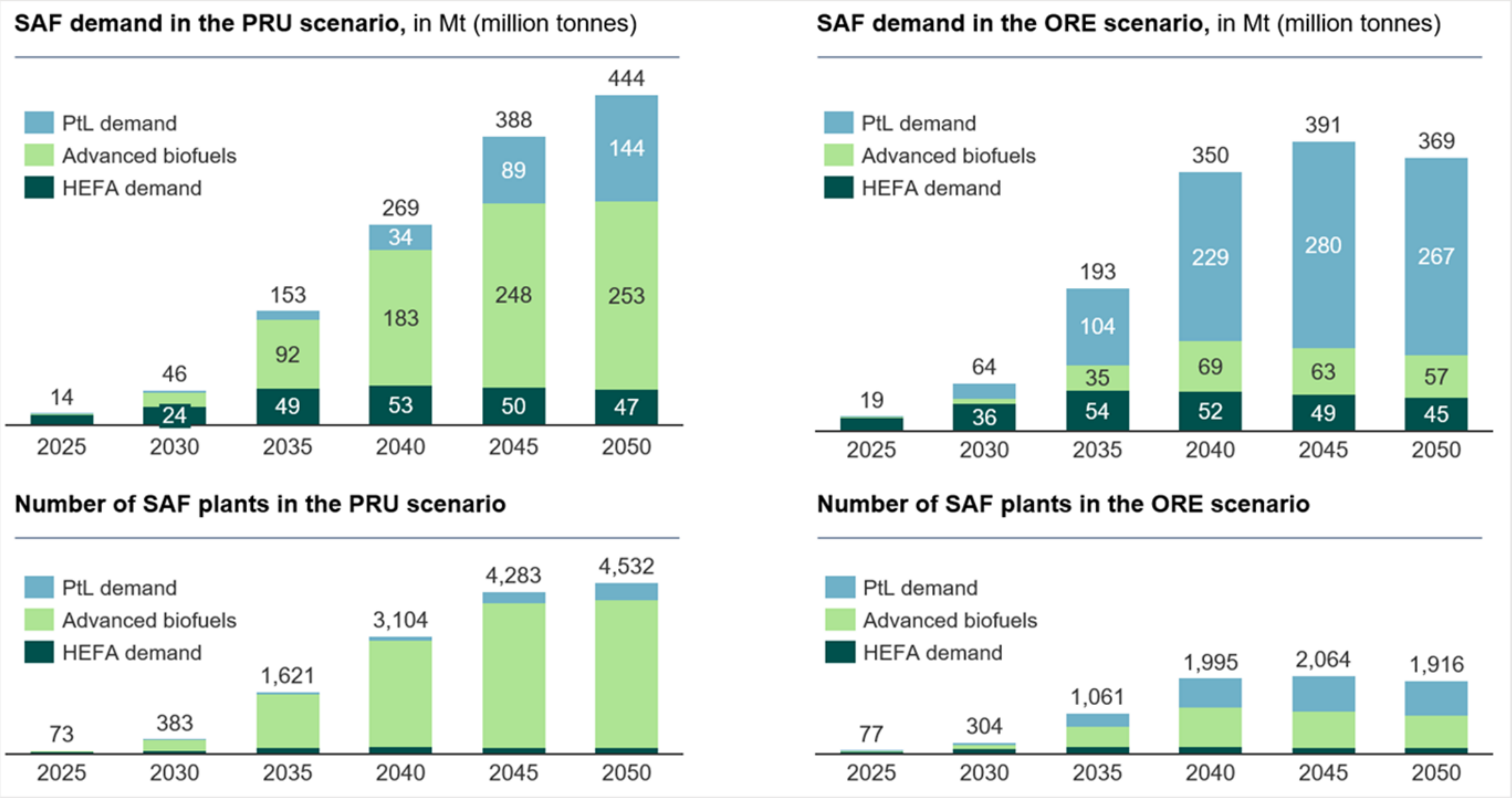
- Power-to-Liquids (PTL) means the manufacturing of synthetic hydrocarbons from carbon dioxide (CO_2) and water, through a process that is fully electrified

- End products are called e-fuels or PTL fuels



Demand Outlook for PTL SAF

Slower green electricity levalized cost decline



Source: World Economic Forum, McKinsey & Company

Faster green electricity levalized cost decline

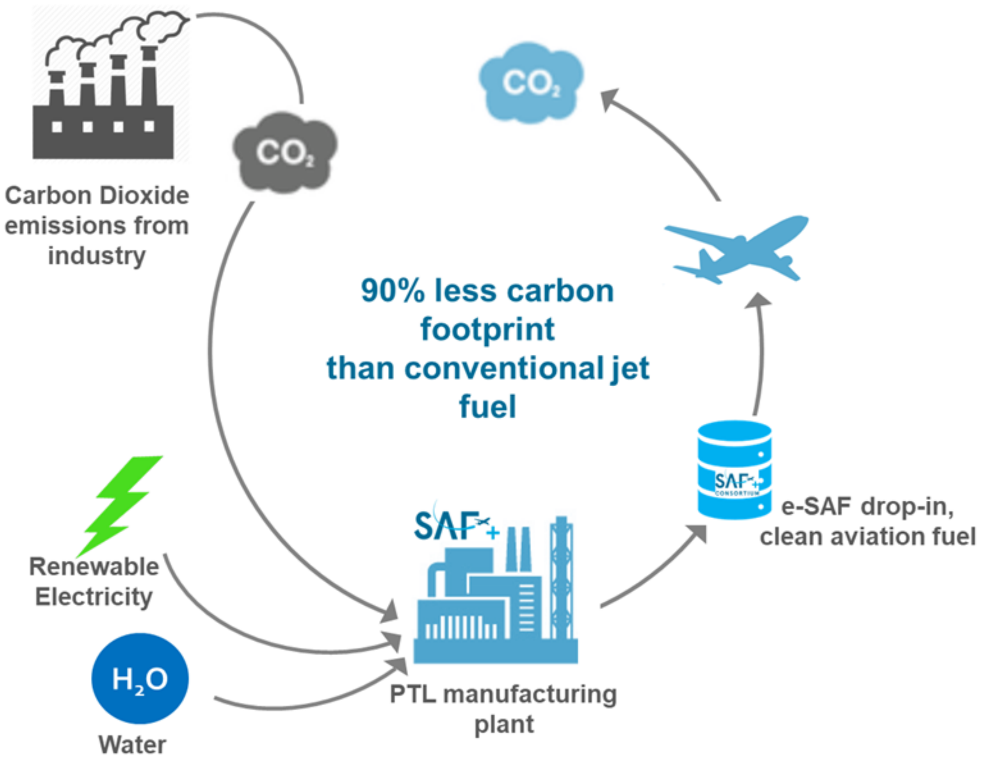
Demand for PTL is real and future market share will be influenced by how fast the levelized cost of green electricity will fall

CO_2 Feedstock

Two ways to capture CO_2

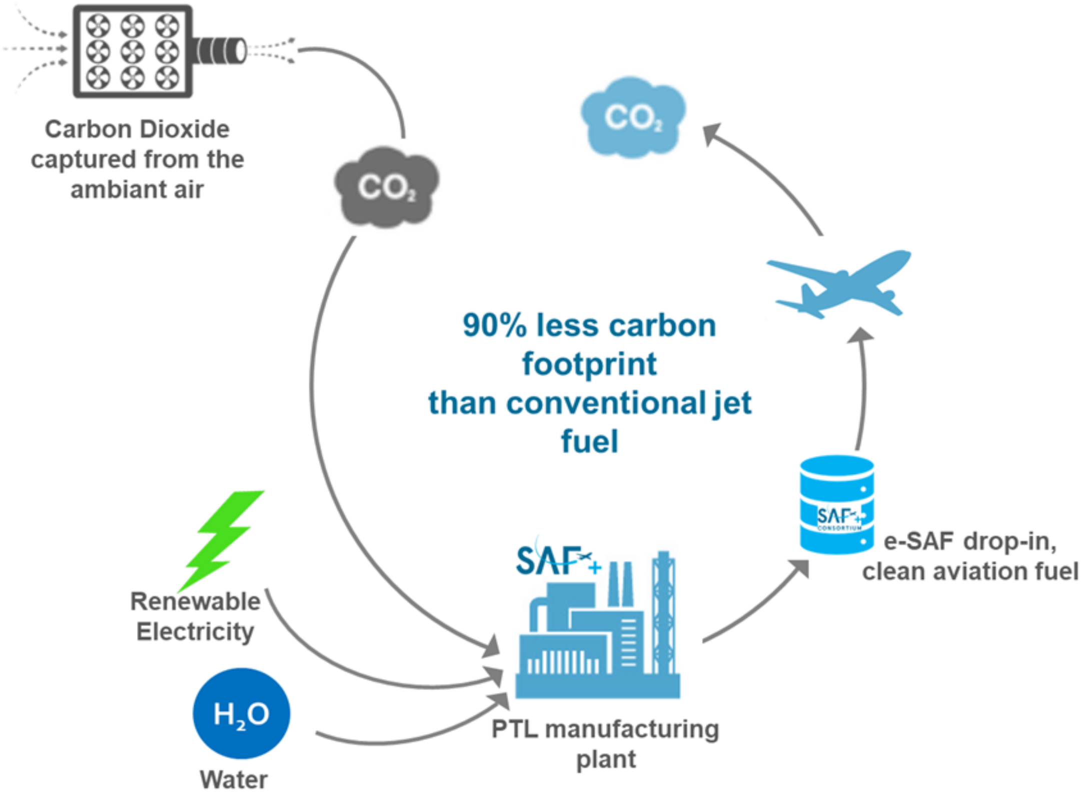
Point Source Capture

CO_2 concentration in industrial effluents:
minimum of 4% and up to 95%
Large scale technology maturity (TRL): 9



Direct Air Capture (DAC)

CO_2 concentration in the ambient air:
0.04%
Large scale technology maturity (TRL): 7



CO_2 feedstock

Point Source vs DAC

- Similarities
  - Both produce same amounts of e-fuels & displace the same amounts of fossil fuels
  - Both yield similar carbon intensities (CI) on life cycle basis & have similar environmental benefits
- Differences
  - DAC consumes more electricity to produce the same amount of pure CO_2 and has a lower technology maturity than Point Source Capture
  - Certain point sources of industrial effluents are controversial

The first generation of large size commercial PTL plants are likely to prefer the use of Point Source Capture

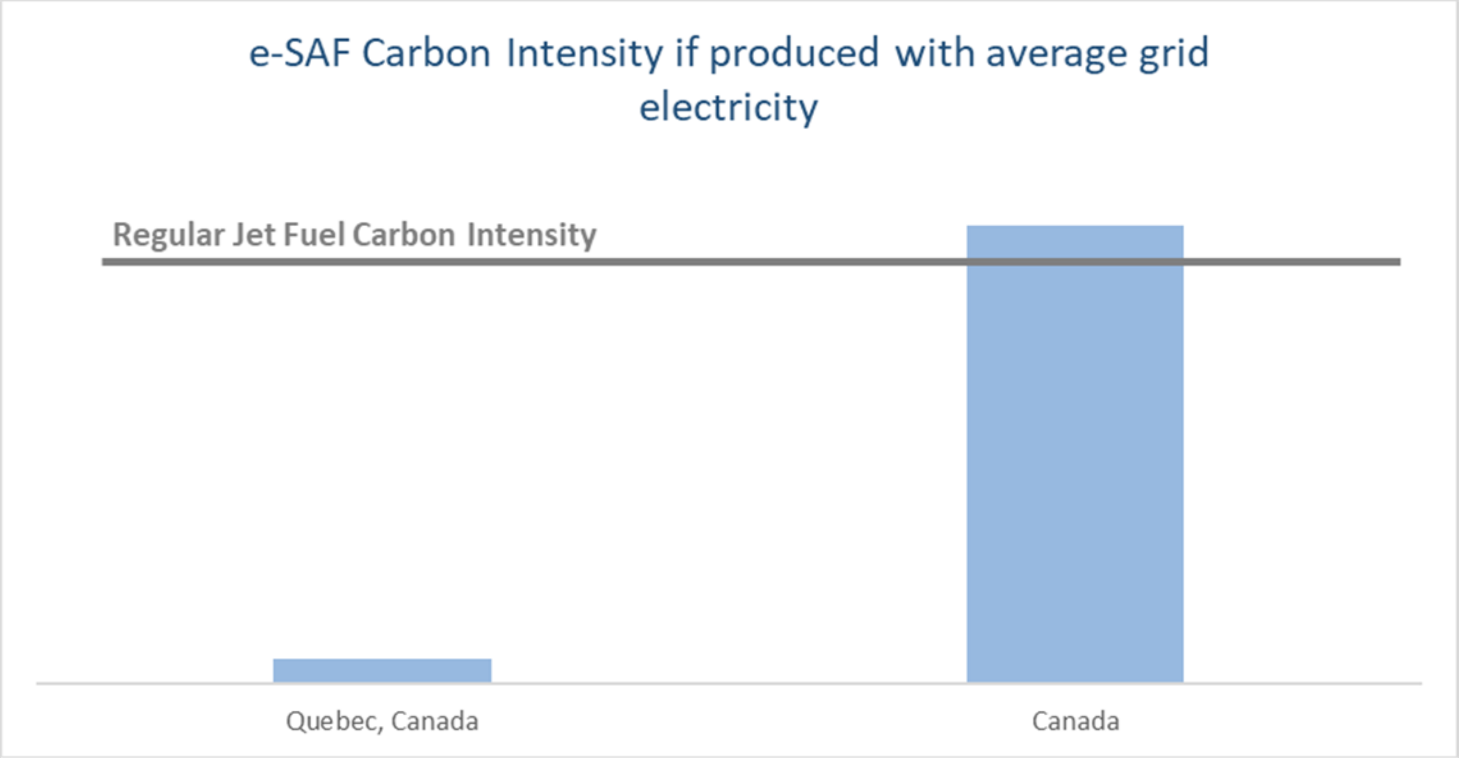
CO_2 feedstock

Different categories of Point Sources

- Energy sectors dependent on fossil fuels – potentially controversial
  - Examples: coal or natural gas power plants, oil & gas extraction, conventional refineries
  - CO_2 origin: fossil fuels
- Hard-to-abate industrial sectors & applications – no-regret
  - Processes or equipment where the complete elimination of CO_2 emissions is not technically possible through process changes or electrification
  - Examples: steel and cement manufacturing
  - CO_2 origin: fossil fuels or carbonates (limestone)
- Biomass feedstocks processing - biogenic
  - Example: ethanol and biogas manufacturing, pulp & paper, biomass incinerators and power plants, biomass gasification
  - CO_2 origin: fermentation, combustion, gasification of biomass feedstocks

Electricity Supply

Carbon Intensity of electricity has a major impact



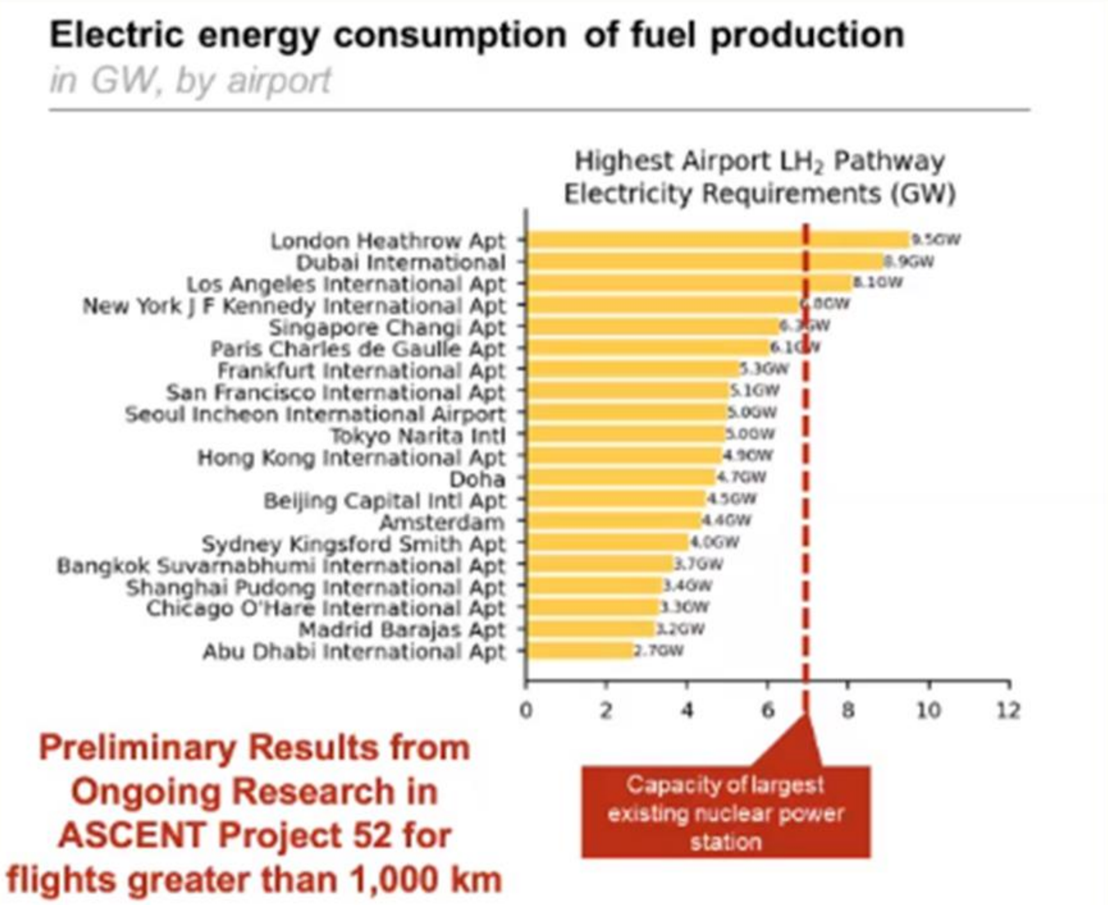
Source: SAF+, calculated with source data for electricity grid CI data Ourworldindata.org and HydroQuebec

In certain regions, local low-carbon grid can yield an e-SAF with more than 90% reduction compared to regular jet fuel

Electricity

How much clean electricity would be needed

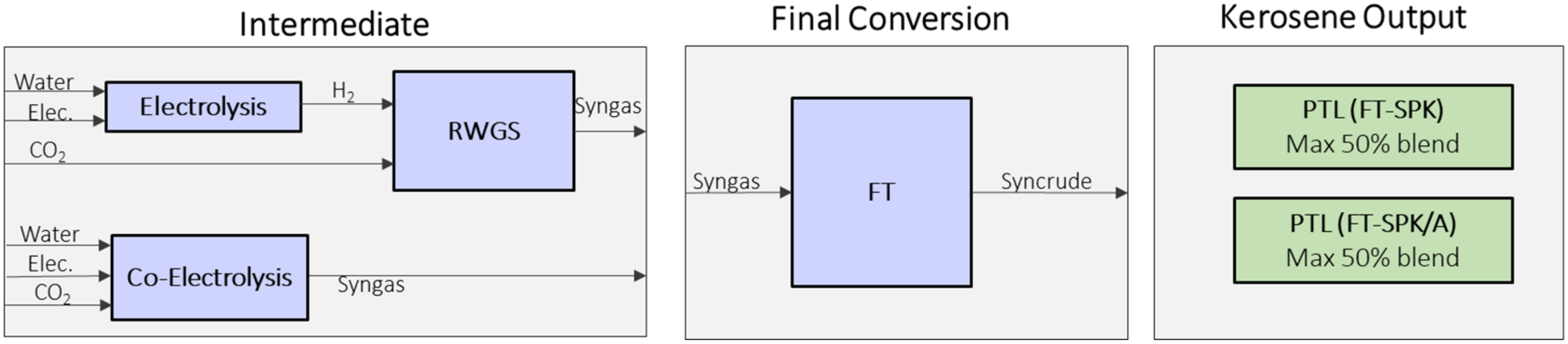
- ASCENT estimates of the power needed to produce e-SAF for all flights greater then 1,000 km in the world's 20 largest hubs
- Combined power required of 110 GW, around 15% of the global installed solar power capacity in 2019



For comparison:
U.S. power generation capacity (2019): 1.2 TW
Cumulative global PV capacity (2019): 627 GW

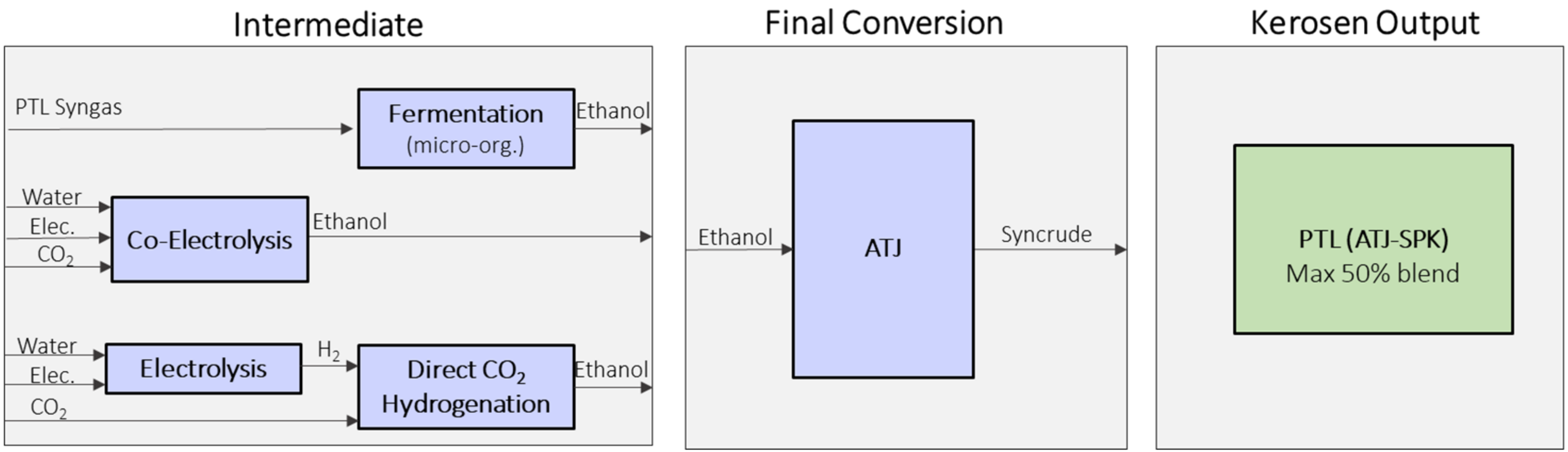
Graphic and data courtesy of MIT from ASCENT Project 52

Fischer-Tropsch pathways



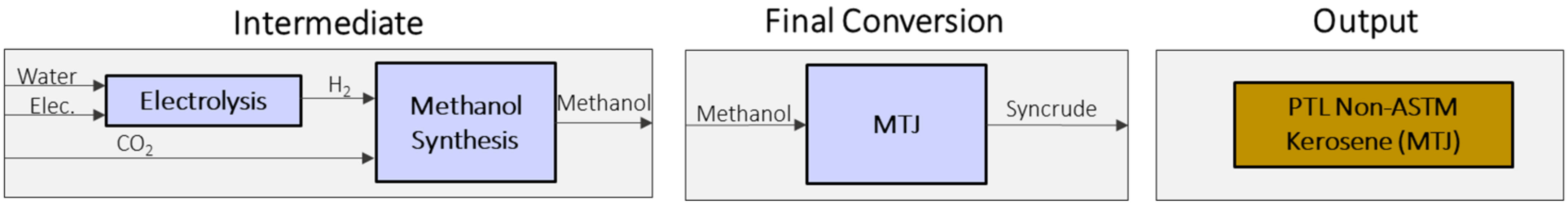
This pathway complies with ASTM D7566 - Annex 1

ATJ pathways



This pathway complies with ASTM D7566 - Annex 1

Methanol to Jet (MTJ) pathway

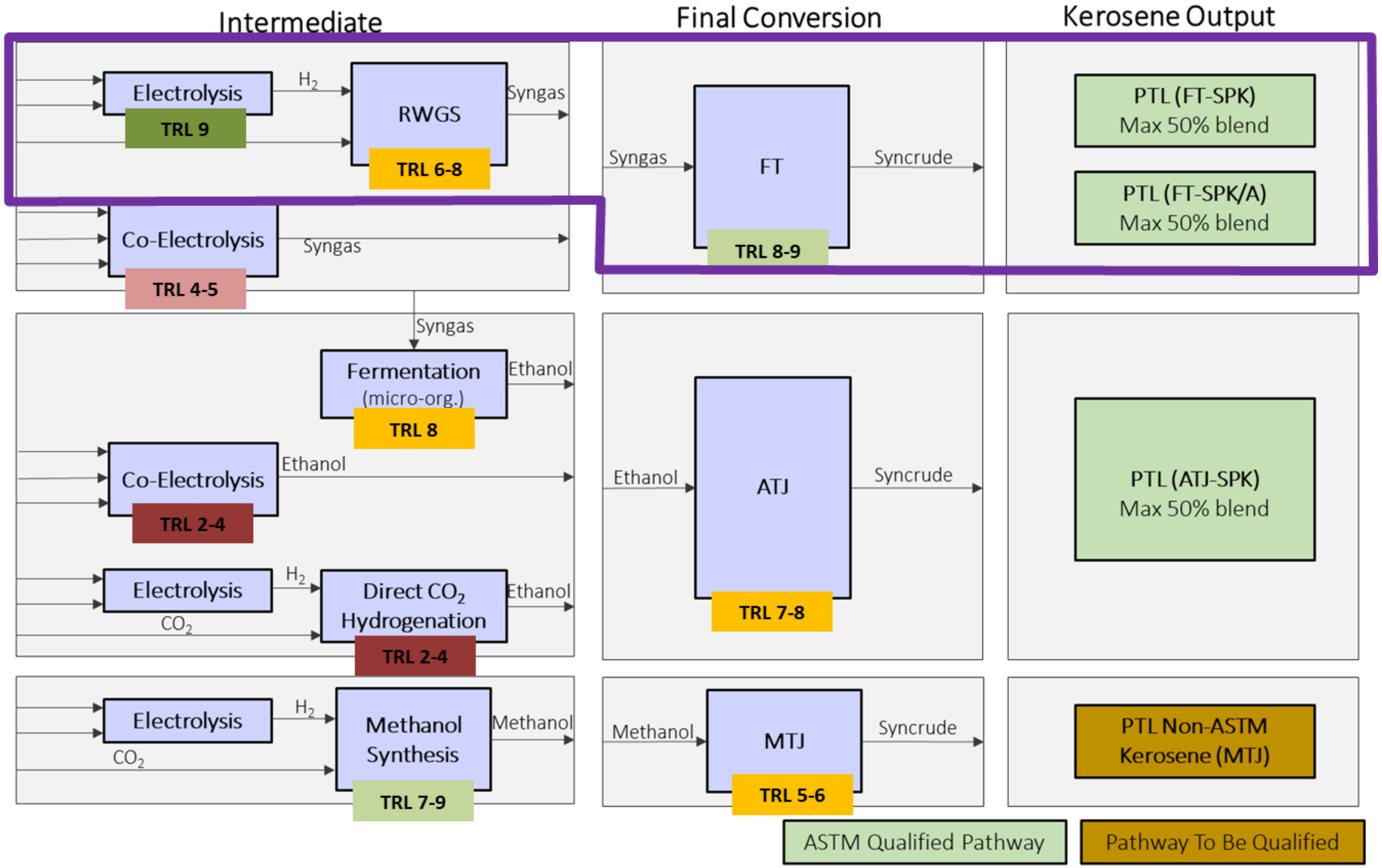


This pathway needs to undergo an evaluation process under ASTM D4054

Technological Pathways

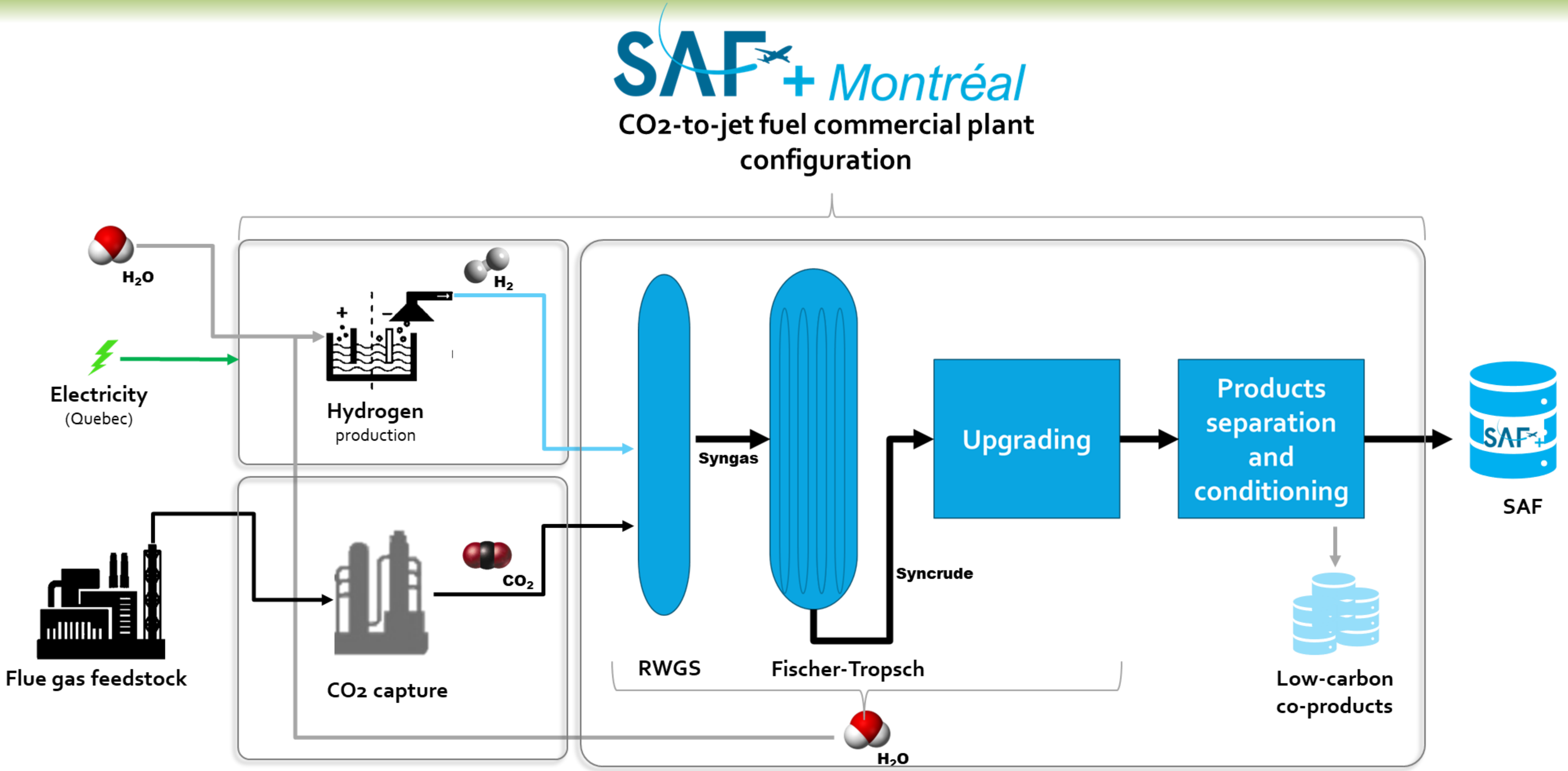
Technology maturity level estimates

Pathway that is currently most mature while being already ASTM D7566 compliant

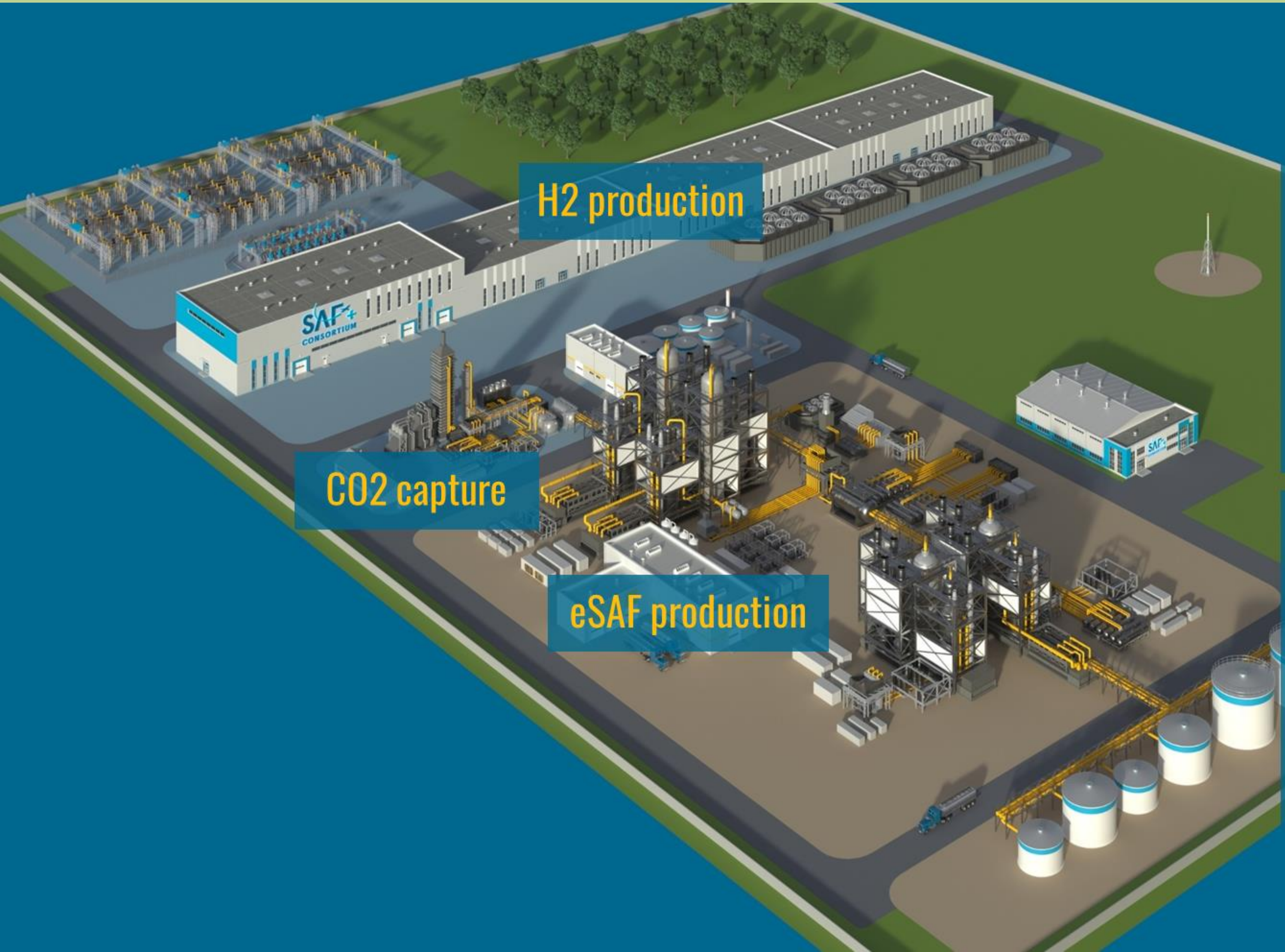


TRL= Technology readiness level
Minimum 1, Maximum 9

SAF+ project showcase



SAF+ project showcase



Montreal Commercial Plant characteristics

- 90 M liters/year (23.8 MGPY) of e-SAF
- 20 M liters/year (5.3 MGPY) of e-Naphtha
- Production of 40,000 t/year of H_2 on-site
- Capture of 267,000 t/year of CO_2
- Investment of USD 1.5 B

Fuel characteristics

- ASTM D7566 compliant
- First e-SAF deliveries in 2027
- Carbon intensity reduction > 90%

Conclusion

- Several technical pathways are possible, but only some are currently listed in ASTM D7566
- Technology maturity varies between proposed solutions, with some ready for first commercial deployments
- No commercial size operating plant yet, but several projects underway with potential for starting operations before 2030
- The choice of CO_2 and electricity sources have a big impact on OPEX, carbon intensity and on social acceptability

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Questions & Answers
Open discussion

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Closing Remarks

ICAO

THANK YOU