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Global Gateway

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Day 2: Session 4

Topic

SAF Midstream - Refinery retrofitting and pathway readiness

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CBR Sustainability Partners

CEO & Founder

More than 20 years experience in the chemical process industry, large production infrastructure projects and technology development with focus on green transition of various industries via ClimateTech related innovation (renewable fuel, green chemistry, sustainability, environmental management systems, environmental certification, etc.)

Consulting Focus @ CBR Sustainability Partners

- Commercial project development and deal advisory (due diligences, etc.) of green energy, fuel and chemicals investments and production plant projects
- Renewable fuel and chemical regulatory, commercial and technology expertise

Education

- EMBA -Executive Master of Business Administration-, Kellogg School of Management at Northwestern University / WHU Otto Beisheim School of Management
- Diploma -International Business Studies-, University of Paderborn, Germany / École Supérieure de Commerce de Reims, Grande École / NEOMA Business School, France

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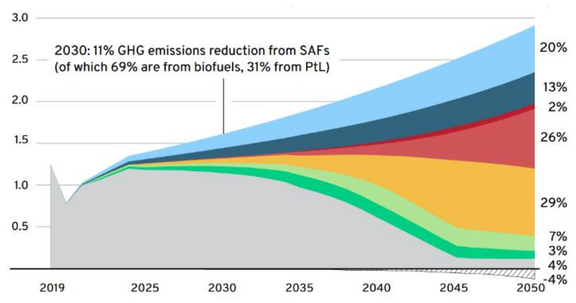
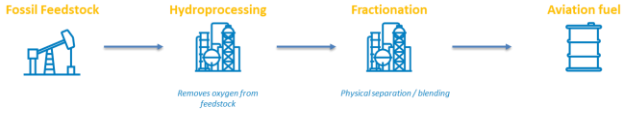
Guiding questions

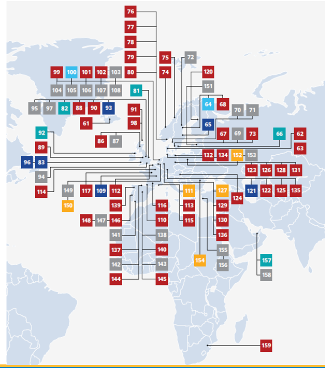


Why is refinery retrofitting critical for decarbonizing the aviation sector?

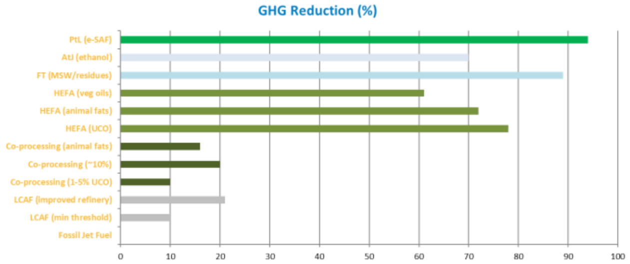


What are the possibilities for co-processing and refinery integration?

What feedstocks eligible under CORSIA can be integrated into existing refineries?



How do retrofitting and new builds shape the current and future SAF landscape?

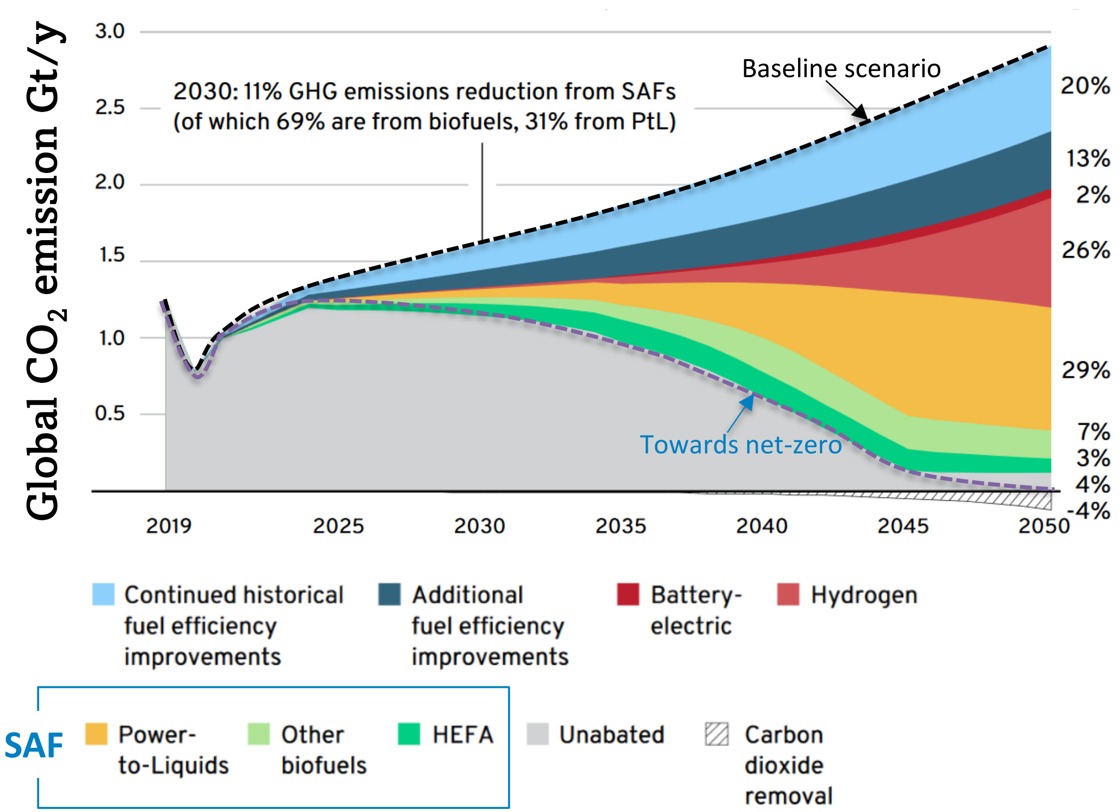


How GHG emissions are different for pathways and feedstock?

SAF as the key enabler of aviation decarbonization

Different technologies contribute across flight segments, with SAF playing a central role in long-haul aviation

SAF is a **key contributor** to **reduce CO_2 emissions** in the decades to come **coexisting** with **more disruptive technologies**.



Why should we talk about **co-processing and overall refinery retrofitting**?

	CO_2 reduction	Time to scale	CAPEX	Role
Co-processing	Low–medium (~5–30%)	Short-term	Low	Bridge solution
HEFA	High (~70–90%)	Near-term	Medium	Main current SAF
FT / AtJ	High	Mid-term	High	Expansion pathways
PtL (e-SAF)	Very high (~90%+)	Long-term	Very high	Scalable future

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Source: Mission Possible Partnership, Making net-zero aviation possible - An industry-backed, 1.5°C-aligned transition strategy, here the Optimistic Renewable Electricity scenario, WEF, 2022; IEA, 2024; ATAG; CBR, 2025.

Refinery retrofitting for Sustainable Aviation Fuel

Unlocking near-term SAF supply via existing refinery assets

SAF supply gap

- EU SAF demand expected to reach **~2.8 Mt by 2030**, while project execution risk remains high
- Global aviation net-zero scenario requires **~300–350 Mt SAF by 2050** → significant scale gap
- **2025 output** is estimated at **1.9 Mt** (approx. 2.4 billion liters), representing **0.6% of total jet fuel consumption**
- Total investment needed estimated at **~€1 trillion CAPEX** for SAF production capacity
- Without accelerated deployment, a **structural supply deficit is expected throughout the 2030 compliance period**

Opportunity

- Existing refining system (~**600–700 refineries globally**) provides immediate industrial base for SAF integration
- Built-in **hydrogen infrastructure and hydroprocessing units** enable direct co-processing of renewable feedstocks
- Refineries already produce **~300 Mt jet fuel/year**, offering scale unmatched by new SAF plants
- Retrofitting avoids greenfield investment → **30–50% lower CAPEX and faster deployment (~2–3 years)**
- **Co-processing can deliver near-term SAF volumes**, bridging the gap until dedicated SAF pathways scale

Retrofitting as a near-term solution

- Retrofitting enables progressive integration of renewable feedstocks, from **~1–5% co-processing up to full unit conversion (~100%)**
- Existing refinery infrastructure (hydrogen, hydroprocessing units) allows **direct SAF integration with minimal modifications**
- Retrofitting requires **~30–50% lower CAPEX vs greenfield SAF plants** by leveraging existing assets
- Implementation timelines are **~2–4 years vs 5–7+ years for new SAF facilities**
- Refinery retrofits can deliver **~1–2 Mt SAF/year in the EU via co-processing**, with significantly higher potential through unit conversion

Refinery retrofitting enables near- to mid-term SAF deployment using existing assets and represents a critical bridge toward large-scale, long-term aviation decarbonization.

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Sources: European Commission (ReFuelEU Aviation, RED II/III), ICAO (CORSIA), IEA Net Zero Scenario (2023), ATAG Waypoint 2050, Concawe refinery studies, European Commission JRC (2022), EASA Environmental Report (2022)

Refinery Retrofitting Pathways for SAF Integration

Comparing co-processing, unit revamp, and full conversion approaches for integrating renewable feedstocks

Refinery retrofitting refers to the **modification, revamping, or repurposing** of **existing petroleum refinery units** to enable the **processing of biogenic or synthetic feedstocks** for SAF production.

Level 1 — Co-processing

- Bio-feedstock co-fed with fossil feed
- Processed in existing unit (no separation)
- SAF diluted in fossil pool
- Fastest implementation
- Uses existing assets

SAF Share: ~1–5% (up to ~10%)

Timeline: ~ 2 years

Typical licensors: Refinery catalysts (e.g. Topsoe, Axens)

Examples:

- Repsol – Spain refineries (~2020)
- TotalEnergies – EU refineries (~2019–present)

Level 2 —Unit revamp

- Existing units modified (hydrotreaters / hydrocrackers)
- Higher renewable feed share enabled
- Pre-treatment + hydrogen integration
- Revamped hydrotreaters, hydrocrackers and pre-treatment units

SAF Share: ~10–50%

Timeline: ~ 2-4 years

Typical licensors: Axens (Vegan), Topsoe (HydroFlex™)

Examples:

- Repsol – Cartagena (Spain), 2023
- Preem – Gothenburg (Sweden, ~2024)

Level 3 — Deep retrofit / conversion

- Units fully converted to bio-feedstocks
- Fossil feed removed
- Dedicated SAF production
- High cost and long lead time

SAF Share: 100%

Timeline: ~ 3-6 years

Typical licensors: Honeywell UOP (Ecofining), Topsoe

Examples:

- Eni – Venice (2014) / Gela (2019)
- TotalEnergies – La Mède (France), 2018
- Phillips 66 – Rodeo (USA), 2024

Retrofitting ranges from minor integration of renewable feedstocks to full refinery conversion into dedicated SAF production assets

Refinery retrofitting in practice – Selected industry examples

Leading refiners are already deploying co-processing, unit retrofits, and full biorefinery conversions to scale SAF production

Level 1 — co-processing

TotalEnergies – Normandy & Antwerp (France / Belgium)

Start: ~2020–2025

Concept: Co-processing of **UCO and animal fats in existing hydroprocessing units**

Capacity: ~50–160 kt SAF/year per site

Key insight:

- **Fastest implementation using existing refinery assets**
- Limited SAF share (~1–5%) but immediate volumes

~20–40 refineries globally already applying co-processing; limited SAF share but fastest deployment (Argus, IEA)

Level 2 —unit revamp

Repsol – Cartagena (Spain)

Start: 2023

Concept: Dedicated hydrotreatment unit retrofit for waste-based feedstocks

Capacity: ~250 kt/year renewable fuels (incl. SAF)

Feedstock: UCO, agri-food waste

Key insight:

- **Higher SAF share vs co-processing (~10–50%)**
- Integration with hydrogen + refinery infrastructure

~10–20 refinery retrofit projects in operation or under development in Europe; accelerating post-2022 (IEA, ReFuelEU)

Level 3 — Deep retrofit / conversion

ENI – Venice & Gela (Italy)

Start: 2014 / 2019

Concept: Full refinery conversion to biogenic feedstocks (HEFA)

Feedstock: UCO, animal fats, waste oils

Capacity: >500 kt/year renewable fuels

Key insight:

- **100% renewable processing → highest SAF potential**
- Requires **major CAPEX and long transition time**

~10+ refinery conversions globally (ENI, Total, Phillips 66, Neste); capacity expanding rapidly toward 2030 targets (IEA, CBR)

Refinery retrofitting is already scaling globally, with >50 projects across all levels, positioning existing assets as a critical enabler of SAF supply before 2030

SAF pathways comparison – From mature biofuels to scalable synthetic routes

Each pathway offers a trade-off between maturity, cost, scalability, and integration potential within existing refining systems

	HEFA	Fischer–Tropsch (FT)	Alcohol-to-Jet (AtJ)	Power-to-Liquid (PtL)	Co-processing *(refinery integration)*
Feedstock type	Lipid-based (triglycerides, FFA)	Lignocellulosic / solid carbonaceous	Alcohol-based	Synthetic carbon (CO_2 + H_2)	Oxygenated lipid
Feedstock examples	UCO, animal fats, vegetable oils	Forestry residues, MSW, agricultural waste	Bioethanol, biomethanol	Captured CO_2 (DAC / point source), green H_2	UCO, tallow, vegetable oils
Process concept	Hydroprocessing (HDO + isomerization)	Gasification → syngas → FT synthesis	Alcohol → olefins → paraffins	Electrolysis → synthesis (FT/methanol route)	Co-hydroprocessing
Integration level	Standalone	Standalone	Standalone	Standalone	Integrated into existing refinery
Product type	HEFA-SPK (synthetic paraffinic kerosene)	FT-SPK	AtJ-SPK	e-SAF (synthetic hydrocarbons)	Mixed hydrocarbon stream (no pure SAF stream)
Blending limit (ASTM)	≤50%	≤50%	≤50%	≤50% (pathway dependent)	No fixed limit (property-based compliance)
CAPEX level	Medium	Very high	High	Very high	Low
Key advantage	Most mature, proven	Flexible feedstock base	Uses existing alcohol markets	Scalable long-term (no biomass constraint)	Fast deployment, low CAPEX
Key challenge	Limited feedstock availability	High complexity, CAPEX	Feedstock competition	High cost, energy demand	Limited SAF share, process constraints

- **HEFA and co-processing** enable **near-term deployment** leveraging **existing infrastructure and low CAPEX**
- **FT, AtJ, and PtL** provide **long-term scalability**, but require **higher investment and longer development timelines**
- **Refinery integration** (co-processing / retrofitting) acts as a **bridge** between immediate SAF supply and future dedicated production

LCAF vs co-processing vs biorefinery – Conceptual and technical comparison

Transition from emission reduction (LCAF) to carbon substitution (co-processing)

	LCAF (CORSIA)	Co-Processing (Refinery Integration)	Biorefinery (Standalone SAF)
Definition	Lower Carbon Aviation Fuel (CORSIA term) – fossil fuels with reduced lifecycle emissions	Co-processing of biogenic oils + fossil feedstock in existing refinery units	Dedicated refinery using 100% biogenic or synthetic feedstocks
Feedstock	Fossil (crude oil, gas)	Fossil + lipid-based waste	Biogenic carbon
Typical output	Jet-A1, diesel (lower CI fuels)	Mixed hydrocarbon stream (Jet, diesel, naphtha)	SAF (HEFA, FT, PtL), dedicated products
SAF share	Not SAF (LCAF only)	~1–10% typical	up to 100%
CAPEX	Low	Very low (retrofit)	High to very high
Time to market	Immediate	Short-term (months–few years)	Long-term (3–6+ years)
Scalability	High (existing fossil system)	Limited (feedstock + blending constraints)	High (but capital-intensive)
Regulatory role	Transitional (CORSIA)	Transitional (ReFuelEU compliance support)	Long-term decarbonization solution
Key constraint	Limited emission reduction potential	Feedstock availability + refinery limits	Cost, infrastructure, scale-up

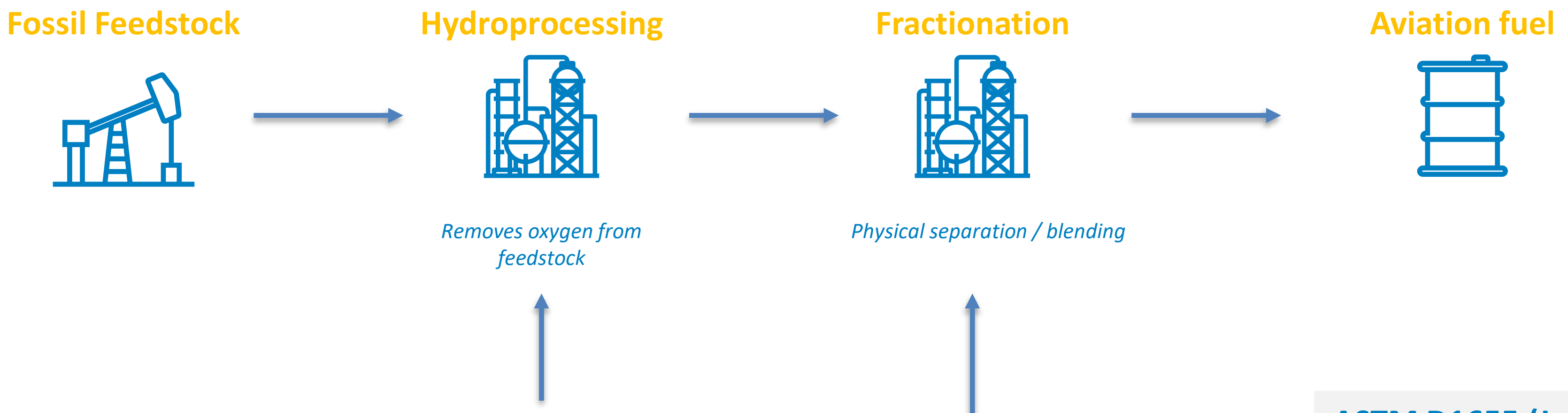
From LCAF to SAF: Increasing Decarbonization Depth

- LCAF reduces emissions through **process-level improvements** (CCS, low-carbon H_2, efficiency)
- However, **fossil carbon remains in the fuel** → limited decarbonization potential
- Co-processing introduces **biogenic carbon into refinery streams**

→ Enables **partial substitution of fossil carbon with renewable carbon**

Co-processing and refinery integration for Sustainable Aviation Fuel (SAF)

Integration point determines co-processing feasibility, while ASTM defines fuel compliance



ASTM D1655 A1.2.2.1
Co-hydroprocessing
→ raw feedstock + reaction

1–5% (typical), up to ~10%
- Used Cooking Oil (UCO)
- Vegetable oils (rapeseed, palm, etc.)
- Animal fats (tallow)

ASTM D1655 A1.2.2.3
Co-fractionation
→ finished hydrocarbons + separation

Up to 50%, fuel specification limits (e.g. aromatics balance)
- HEFA product (SPK)
- Fischer-Tropsch (FT) liquids
- Hydrotreated bio-oils
- Synthetic blending components

ASTM D1655 (Jet A1 standard)
- Defines **fuel properties**, not production pathways
- Co-processing allowed if fuel meets spec
- No fixed % limit → **property-driven compliance**

ASTM D7566 (SAF standard)
- Defines **approved SAF pathways** (e.g. HEFA, FT, PtL)
- Blending limits (typically **≤50%)**

Approved feedstocks – Regulatory frameworks applicable to co-processing

EU applies a strict list-based approach (Annex IX), while CORSIA defines a broader, sustainability-driven feedstock pool

Approved feedstock

ReFuelEU

Legal basis
- ReFuelEU Aviation Regulation
- RED II / RED III → Annex IX (Part A & B)
- RFNBO rules (Delegated Acts)

Eligible feedstocks
- Annex IX Part B (core today):
  - *Used Cooking Oil (UCO)*
  - *Animal fats (Cat 1 & 2)*
- Annex IX Part A (advanced):
  - *Agricultural residues*
  - *Forestry residues*
  - *Algae, waste streams*
- Synthetic (RFNBO):
  - *CO_2 + renewable H_2*

CORSIA

Legal basis
- CORSIA Eligible Fuels (CEF)
- Approved Sustainability Certification Schemes

Eligible feedstocks
- Waste-based:
  - *Used Cooking Oil (UCO)*
  - *Animal fats*
  - *Industrial waste streams*
- Residue-based:
  - *Agricultural residues (straw, husks)*
  - *Forestry residues*
  - *Municipal solid waste (MSW)*
- Biomass / energy crops (conditional):
  - *Dedicated energy crops (sustainability criteria)*
  - *Algae*
- Synthetic / non-biogenic:
  - *CO_2 (point source / DAC)*
  - *Renewable hydrogen (PtL)*

SAF deployment is governed by three layers: **Fuel standards (ASTM), feedstock eligibility (regulation)** and **sustainability verification (certification)**.

Fuel standards
(ASTM D1655, ASTM D7566)
- Fuel properties
- Blending limits
- Conversion pathways

Regulatory frameworks
(ReFuelEU, RED III, CORSIA)
- Which feedstocks are allowed
- Sustainability criteria
- Compliance rules

Certification schemes
(ISCC, RSB)
- Traceability (chain-of-custody)
- Lifecycle emissions compliance

Retrofitting economics vs greenfield SAF

Refinery retrofitting vs Greenfield SAF – Cost and timeline comparison

	Co-processing	Unit retrofit (HEFA integration)	Full conversion (biorefinery)	Greenfield SAF (HEFA/FT)	eSAF / PtL
Typical CAPEX (€)	€5–30M	€100–400M	€500M–1,500M	€800M–1,500M	€1,000M–3,000M+
Timeline	<2 years	2–4 years	3–6 years	5–8+ years	5–10 years
SAF share	1–5%	10–50%	~100%	100%	100%
Cost per ton SAF – Today (€/t)	€900–1,300	€1,300–2,000	€1,400–2,200	€1,600–2,500	€3,000–6,000
Cost per ton SAF – 2040 (€/t)	€900–1,400	€1,200–1,800	€1,200–2,000	€1,400–2,200	€1,500–3,000
Role	Compliance / blending	Scale-up bridge	Dedicated SAF	Long-term bio SAF	Long-term

Sources: IEA, EASA, ICCT, Deloitte, IEA Bioenergy Task 39, Concawe, CBR

TotalEnergies La Mède (France)

- ~€275–300M conversion CAPEX (~500 kt/year renewable fuels)

ENI Venice biorefinery

- ~€200–300M retrofit (first conversion wave)

Phillips 66 Rodeo (USA)

- ~$850M–1.2B full conversion (~800 kt/year capacity)

Hydrogen cost = critical driver

- Up to **30–50% of OPEX** for hydroprocessing pathways

Feedstock cost dominates economics

- UCO / waste oils = **70–85% of total SAF production cost**

Refinery integration reduces CAPEX by ~30–70%

- Reuse of hydrotreaters, utilities, storage

Avoided infrastructure cost

- No need for new logistics, tanks, hydrogen systems

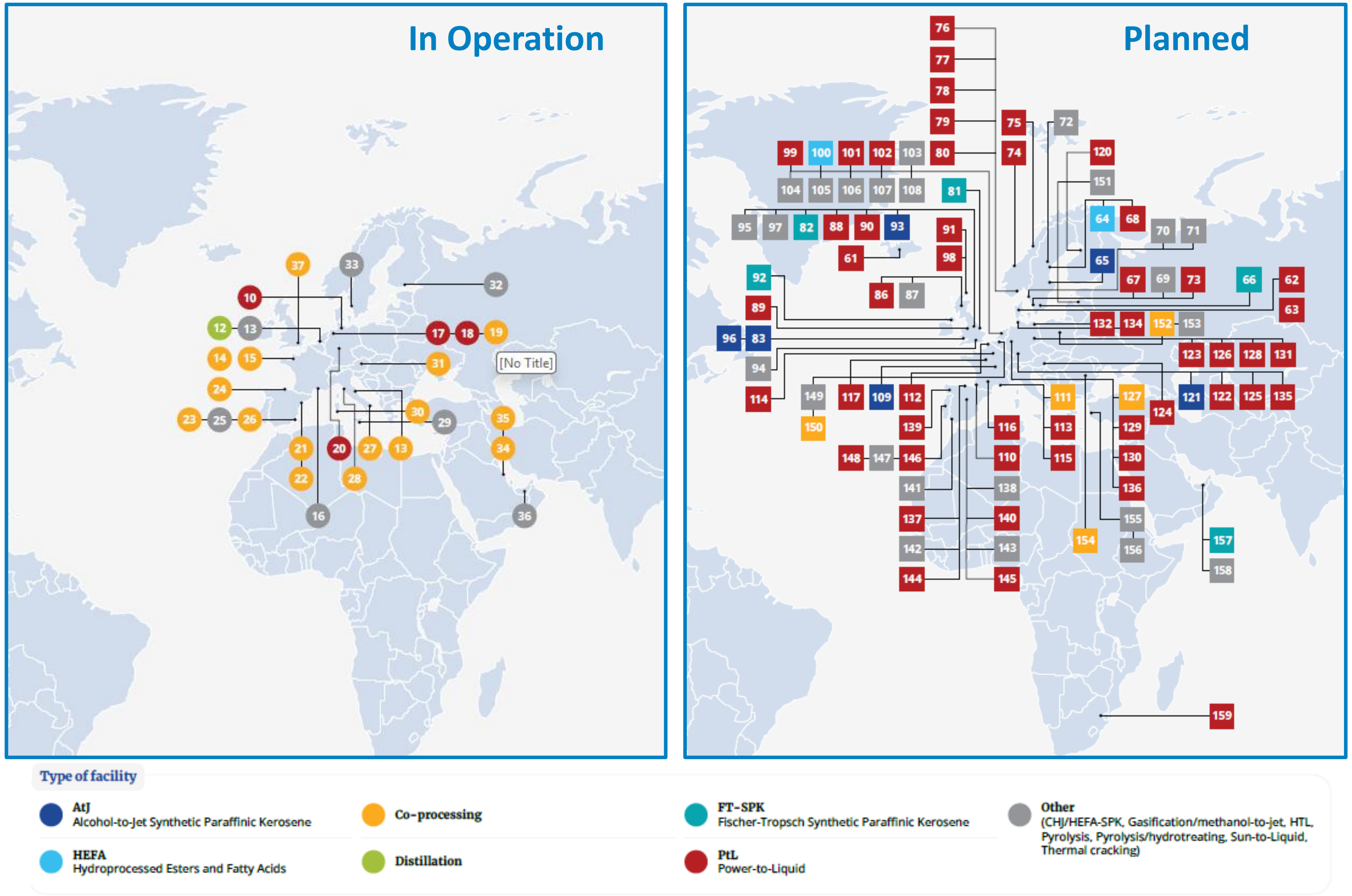
Blending constraints limit revenue upside

- Co-processing SAF diluted in fossil pool

Retrofitting shifts SAF deployment **from capital-intensive greenfield investments to asset optimization strategies** — **accelerating deployment by 3–5 years** while **reducing upfront CAPEX by up to 70%**, but with inherent limits on scale and decarbonization depth.

Current SAF landscape vs future pipeline

Near-term SAF supply relies on refinery integration, while long-term growth depends on scaling synthetic pathways.



Source: Argus SAF Capacity Map 2025

Current production vs pathway pipeline

- Today's SAF production is **heavily concentrated in lipid-based pathways (HEFA)**, with **co-processing contributing a meaningful share of early volumes**.
- Co-processing is already deployed across multiple European refineries (e.g. TotalEnergies, Repsol, BP), providing **low-CAPEX SAF volumes from existing assets**.
- Argus data shows that **most upcoming SAF capacity remains based on hydrotreatment (HEFA-type)**, with only **limited near-term contribution from synthetic pathways**.

Co-processing potential

- If fully utilized, refinery co-processing in Europe only could deliver:
  → **~1.7 Mt SAF/year at ~5% integration level**
- Current technical limits:
  → **~1–5% renewable feedstock input (typical industrial practice)**
- Co-processing is recognized as:
  → **Lowest-cost SAF pathway leveraging existing infrastructure**

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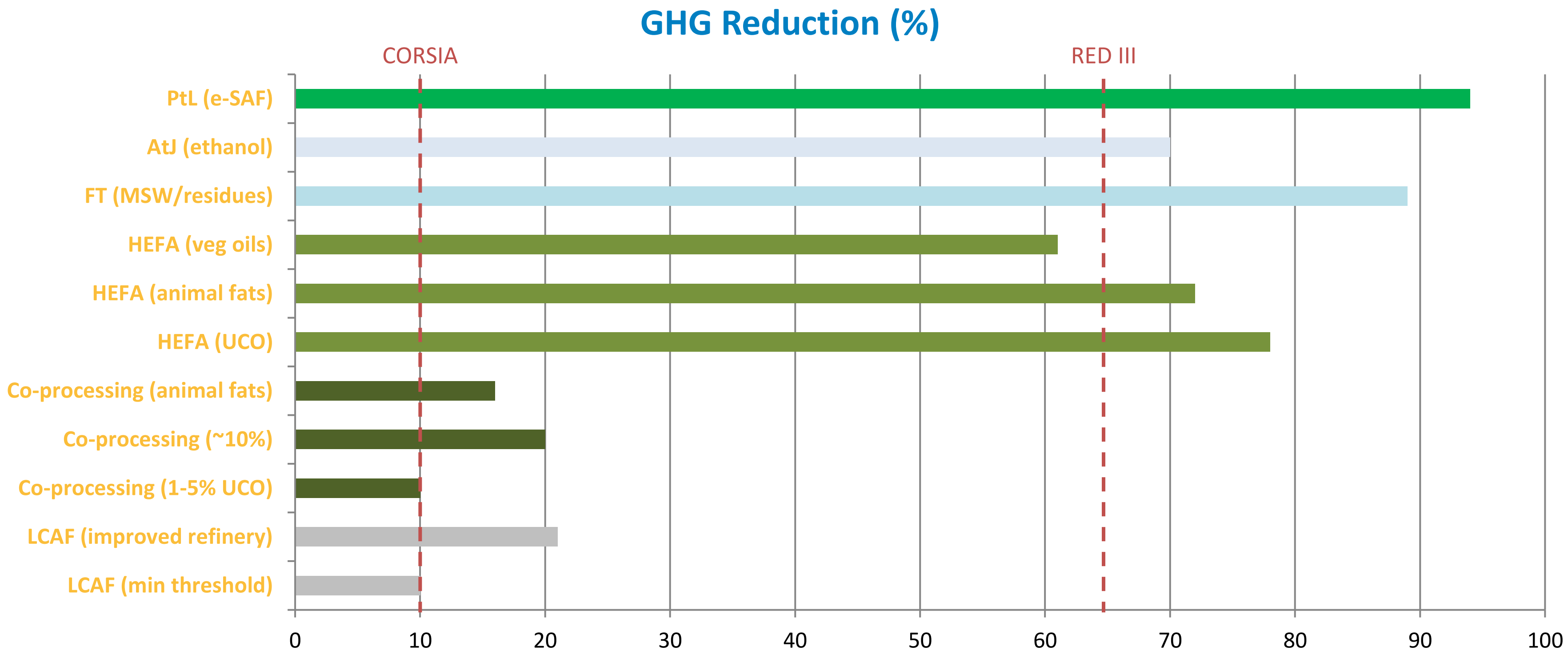
GHG reduction potential across SAF pathways and co-processing

Co-processing delivers limited emission reductions compared to SAF pathways due to low renewable carbon share.

Reference Value (**CORSIA**)
89 g_{CO2e}/MJ

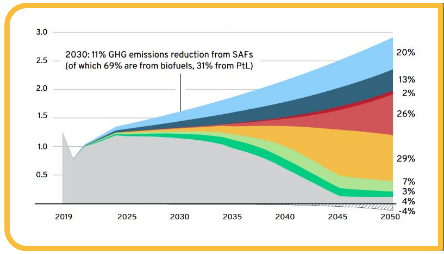
Reference Value (RED III)
94 g_{CO2e}/MJ



Sources: ICAO (CORSIA), JRC (2022), IEA, Concawe, EASA (2022), ATAG, Mission Possible Partnership

- **LCAF and co-processing provide incremental GHG reductions** by optimizing fossil-based systems and introducing limited renewable carbon.
- **Standalone SAF pathways (HEFA, FT, PtL)** achieve significantly higher emission reductions due to full or near-full substitution of fossil carbon.
- **Co-processing impact is constrained by low feedstock share (~1–10%)**, resulting in limited overall CO_2 reduction potential.

Key take-aways

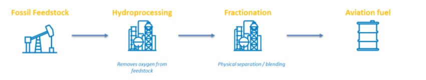


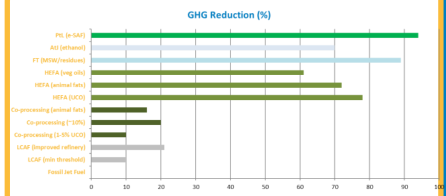
SAF is essential but scale gap remains critical.

SAF is the only scalable solution for long-haul aviation, yet supply remains far below policy targets.

Co-processing enables immediate SAF volumes.

Co-processing leverages existing refinery assets to deliver low-CAPEX, near-term SAF contributions.





Impact is structurally limited.

Low renewable feedstock share (~1–10%) constrains GHG reduction and total SAF output.

Dedicated SAF pathways are required mid-to-long-term.

HEFA, FT, and PtL are essential to achieve decarbonization objectives and scale beyond incremental gains.

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