

FUELING NET-ZERO FLIGHT

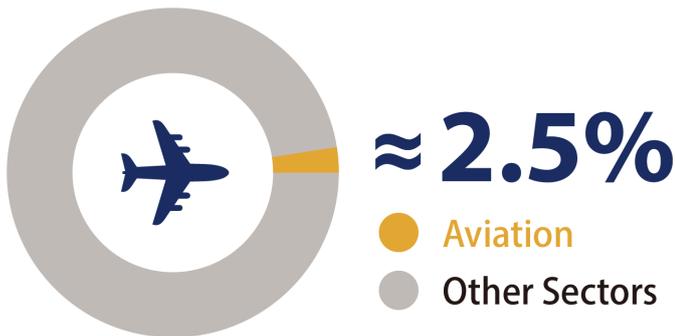


**The Power-to-Liquid (PtL) e-SAF Path to Scalable, Affordable,
and Sustainable Aviation Decarbonization**

EXECUTIVE SUMMARY

Feynman Dynamics (FD) is driven by one core belief: the sustainable transformation of aviation is inevitable, and while its carbon challenges are formidable, they are solvable.

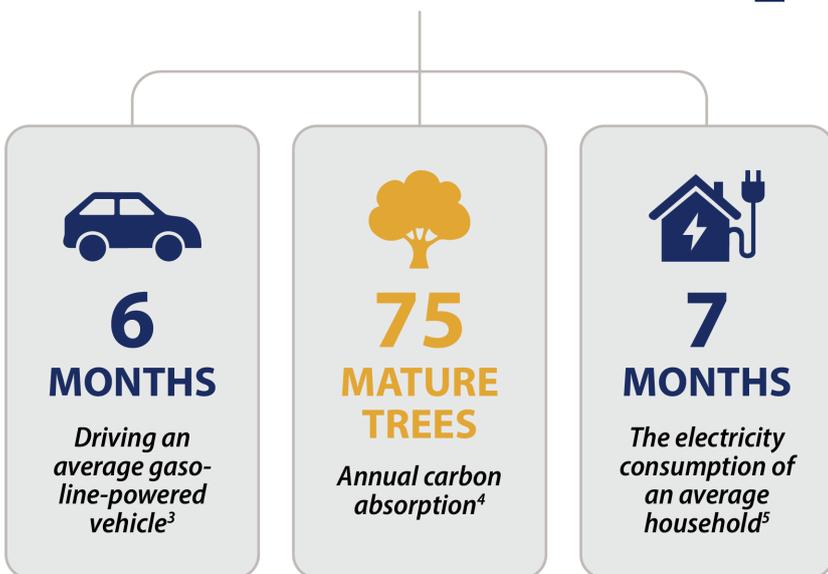
GLOBAL CARBON EMISSIONS



Aviation currently contributes approximately 2.5%¹ of global carbon emissions.

The CARBON FOOTPRINT of a SINGLE PASSENGER on a long-haul flight (Beijing - NYC, ~12,000km)²

≈ **1.6 TONNES CO₂**



Driven by this profound environmental cost, major economies have escalated policy interventions, exemplified by the **EU's ReFuelEU Aviation initiative** and the **U.S. Inflation Reduction Act (IRA)**. In this context, aviation decarbonization has moved from being just an environmental obligation to a key factor in long-term industrial competitiveness.

Sustainable Aviation Fuel (SAF) represents the primary vector for breaking fossil fuel dependence. However, the viability of technical pathways varies starkly. Conventional biomass routes (e.g., HEFA, FT-biomass, AtJ), once the industry's hope, are now constrained by key challenges: feedstock scarcity, land competition, and diminishing returns. These constraints effectively cap their potential to replace fossil fuels at scale. Consequently, the industry must pivot toward more fundamental solutions.

1. IATA (2024) 2024 Aviation Environmental Report, Report No. ENV-2024-01, Geneva.
2. Includes non-CO₂ radiative forcing effects (RFI multiplier ~1.9) for the Great Circle Distance.
3. Based on 15,000 km annual mileage and 0.2 kg CO₂/km average emissions.
4. Assumes global average carbon sequestration of ~21.3 kg CO₂/year per mature tree.
5. Based on average monthly residential electricity carbon footprint of ~230 kg.

EXECUTIVE SUMMARY

Power-to-Liquid (PtL) e-SAF stands as the singular pathway capable of decarbonizing aviation at the necessary scale and pace. Unlike bio-based alternatives constrained by insurmountable feedstock ceilings, e-SAF decouples fuel production from resource scarcity, relying solely on renewable electricity and captured CO₂. Its inevitability rests on three non-negotiable pillars:



UNCONSTRAINED SCALABILITY

*Independent of
agricultural limits*



**90%-
100%**
lifecycle reduction⁶

*Industry-leading
emission reductions*



**a predictable
COST-DOWN
trajectory**

*driven by
technological
learning curves*

**We project that: By 2035, global e-SAF costs will contract by
OVER 50% to \$1,500–\$2,000/TONNE⁷.**

For an industry demanding billions of liters of sustainable fuel, e-SAF is not just an option—it is the only logical and investable pathway to balance global supply demands with net-zero targets.

FD is dedicated to accelerating the commercialization of affordable e-SAF through proprietary cost-reduction technologies and gigawatt-scale production capabilities. Leveraging the intrinsic advantages of e-SAF—universally accessible feedstocks, technology-driven cost curves, and massive industrial economies of scale—we target the ability to meet approximately 15% of global e-SAF demand by 2030, supporting a cost-competitive and sustainable net-zero transition for global aviation⁸.

6. ISCC (2024) Lifecycle Emission Assessment for Sustainable Aviation Fuels, Munich.

7. IEA (2024) Sustainable Aviation Fuels Cost Review 2024, Paris.

8. Sinopec (2024) e-SAF Synthesis Reactor Cost Analysis 2024, Beijing.

GLOBAL AVIATION'S GREEN FUTURE:

The Quest for An Affordable Decarbonization Path

Global aviation stands at a defining pivot point. While remaining the artery of global commerce, it is also a rapidly expanding carbon heavyweight. Aviation accounts for 2.5% of global greenhouse gas emissions and 12% of those from the entire transport sector⁹. The industry now faces an existential imperative: aligning with the IPCC's 1.5° C warming trajectory to reach net-zero emissions by 2050.

This decarbonization mandate has transcended aspiration; it is being codified by a tightening global regulatory net. The EU's ReFuelEU Aviation initiative mandates a 6% SAF blending rate by 2030 (scaling to 70% by 2050), with a specific 1.2% (2030–2031 average) sub-target for e-SAF¹⁰. Concurrently, the U.S. IRA offers tax credits up to \$1.75/gallon for low-carbon SAF¹¹, based on lifecycle GHG reductions, while China's "Dual Carbon" strategy has integrated SAF into its renewable infrastructure, launching mandatory blending pilots at strategic hubs. A unified global policy front is forcing industrial transformation.

Yet, a structural chasm persists between policy ambition and industrial reality. The transition is stalled by a single, formidable bottleneck: the absence of a scalable, cost-competitive fuel solution. The industry must secure 300 million tonnes of fuel annually to keep the world moving¹². Doing so without compromising sustainability remains an unsolved equation.

Conventional biomass routes, despite their first-mover advantage and mature hydrodeoxygenation processes, rest on a precarious foundation. They rely on a global inventory of waste oils and fats, which are inherently finite, that even at theoretical limits, they can meet less than 10% of 2030 aviation demand¹³. This is not merely a shortage; it is a structural deficit ensuring that price volatility remains the norm, not the exception. Alternatives like FT-Biomass (Biomass Gasification + Fischer-Tropsch) and AtJ (Alcohol-to-Jet) offer little relief. The former is constrained by the scarcity of lignocellulosic biomass, while the latter faces ethical headwinds as ethanol production competes with food supplies. These routes offer incremental progress but lack the scalability to fundamentally rewrite the industry's high-cost logic.

9. IATA (2024) 2024 Aviation Environmental Report, Report No. ENV-2024-01, Geneva.

10. EASA (2023) Implementation Guidelines for ReFuelEU Aviation (2023 Edition), Cologne; European Union (2023) Regulation (EU) 2023/2364 of the European Parliament and of the Council (Article 12), Official Journal of the European Union, L 314/1.

11. U.S. Congress (2022) Inflation Reduction Act of 2022 (Public Law 117-169, Section 13203), Washington, D.C.: U.S. Government Publishing Office.

12. Liding Industry Research Network (2025) 2025 Global Sustainable Aviation Fuel Industry Analysis, Beijing; IEA (2024) Sustainable Aviation Fuels Cost Review 2024, Paris.

13. DNV (2023) Sustainable Aviation Fuel Outlook 2030, Report No. DNV-SEA-2023-02, Høvik; National Renewable Energy Laboratory (NREL, U.S.).

FEYNMAN DYNAMICS

Aviation needs more than a green future—it demands an affordable one. This reality necessitates a break from legacy feedstocks and a commitment to the only fundamentally scalable solution: Power-to-Liquid (PtL) e-SAF.

To clarify e-SAF's irreplaceable value, we benchmark it against three mainstream technical pathways (HEFA, FT-biomass, AtJ) across critical dimensions: feedstock, emission reduction, maturity, and scalability.

| PATHWAY | MAX REDUCTION(%) VIA WASTE FEEDSTOCKS | MED REDUCTION(%) VIA DEDICATED FEEDSTOCKS | MIN REDUCTION(%) (WORST CASE SCENARRIO) |
|-----------------|---|---|---|
| HEFA | 84% Used Cooking Oil | 80% Tallow/Corn Oil* | 32% Palm Oil |
| Alcohol-to-Jet | 73% Agriculture/ Forestry Residues | 67% Switchgrass | 26% Corn Grain |
| Gasification | 94% MSW (Biogenic) | 88% Miscanthus | 86% Short Rotation Forestry |
| Power-to-Liquid | 92% Renewable Energy | N/A (No biologic feed) | Depends on Grid Renewable Energy |

*Horizontal Comparison of e-SAF versus Three Mainstream SAF Technology Pathways

e-SAF:

The Definitive Solution to Decarbonize Global Aviation

Building on the strategic need for Power-to-Liquid (e-SAF) solutions discussed earlier, the focus shifts from why we should produce e-SAF to how we can produce it effectively to meet the industry's demanding commercial standards reality.

INITIALLY the selection of the production pathway is governed not solely by chemical feasibility but also by the "Regulatory Moat" of airworthiness certification. While numerous innovative "Direct-to-Jet" technologies demonstrate academic potential, they confront the formidable "Valley of Death" delineated by ASTM D7566 and DEF STAN 91-091— the dual global standards for jet fuel. Certifying a new pathway entails a rigorous, multi-year campaign encompassing Tier 1–4 testing, comprehensive OEM engine evaluations, and expenditures amounting to tens of millions of dollars, all without assured final approval. Conversely, the Fischer-Tropsch (FT-SPK) pathway is fully certified under these standards (ASTM D7566 Annex A1) and has accumulated millions of secure flight hours. Consequently, the sole viable strategy to expedite market entry is to circumvent the regulatory bottleneck entirely: we must leverage the validated downstream FT infrastructure and concentrate our innovation upstream on the efficient production of Syngas ($\text{CO} + \text{H}_2$), rather than risking development on uncertified fuel chemistries.

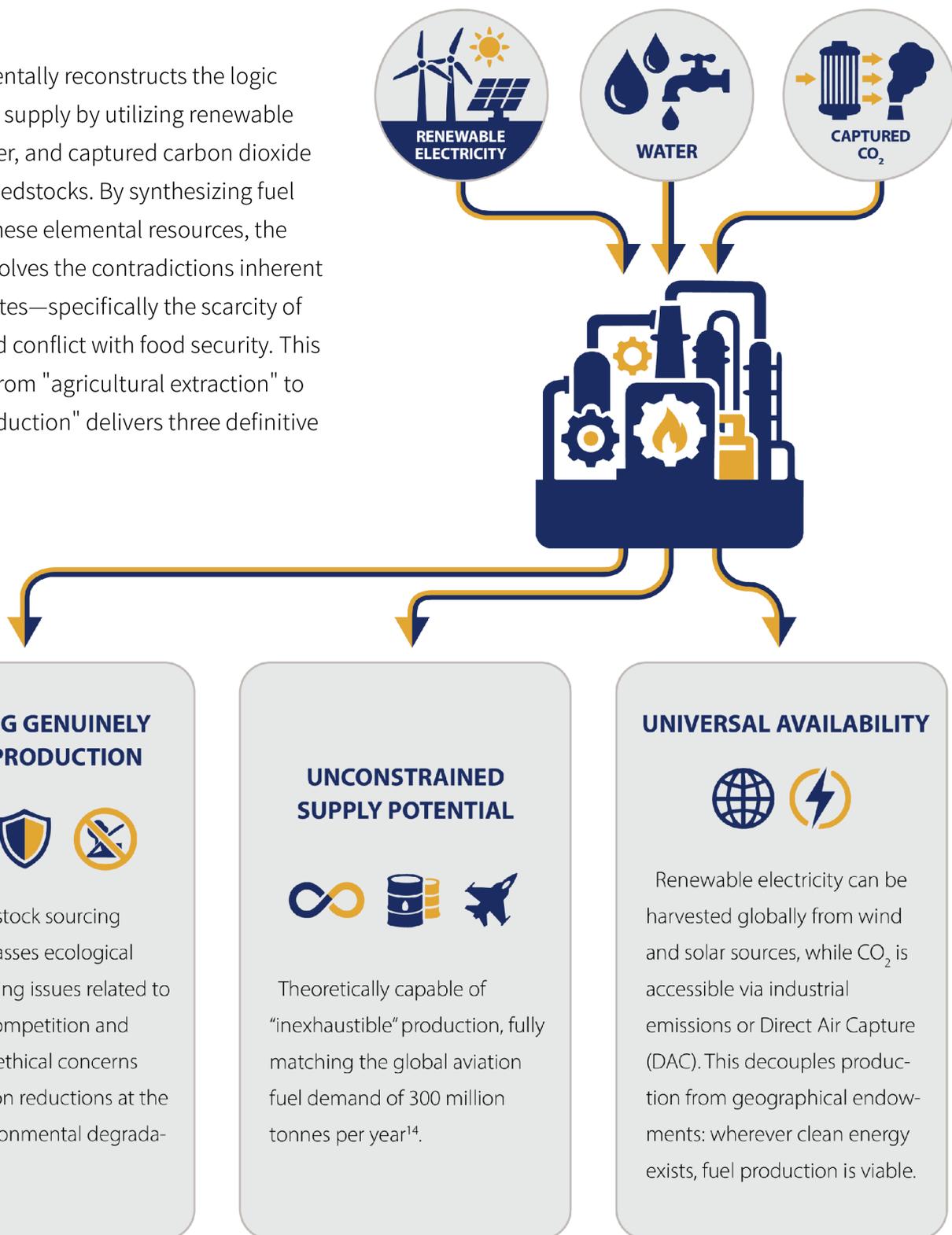
S**ECOND** alternative Syngas and synthesis routes—namely the Reverse Water-Gas Shift (RWGS) and Methanol-to-Jet (MtJ)—are hindered by inefficiencies and complexity. RWGS, a relic of the thermal era, needs over 800° C and excess Green Hydrogen to overcome poor equilibrium, requiring costly gas separation units for unreacted gases and methane. MtJ, a "technological detour" with declining returns, involves multiple steps: reducing CO₂ to methanol, converting to olefins (MTO), then oligomerizing to rebuild the carbon chain. This increases CAPEX and energy loss, with MTO processes favoring lighter fractions over kerosene, leading to lower jet fuel yields and energy-intensive recycling for commercial viability.

T**HIRD** low-temperature CO₂ electrolysis, combined with the Fischer-Tropsch process, emerges as the sole architecture capable of disrupting this cost trajectory by adopting a "Manufacturing Logic." By substituting the thermal complexity of the Reverse Water Gas Shift (RWGS) process and the extended process chain of Methanol-to-Jet (MtJ), this pathway provides the most direct and selective route from electrons to certified hydrocarbons. It redefines the central conversion unit from a custom-engineered chemical vessel into a modular electrochemical stack, thereby enabling production to leverage the cost reductions associated with mass manufacturing observed in the solar and battery industries (Wright's Law). Significantly, this modularity permits the system to operate at ambient temperatures and to ramp instantaneously using intermittent renewable energy sources—thus capturing the lowest-cost green electrons without the separation penalties or thermal inertia characteristic of traditional chemical processes. Consequently, this approach offers a robust, certified, and economically advantageous solution for scalable electro-sustainable aviation fuel (e-SAF) production.

LIBERATING SUPPLY:

e-SAF Unlocks Unlimited Feedstock

e-SAF fundamentally reconstructs the logic of aviation fuel supply by utilizing renewable electricity, water, and captured carbon dioxide (CO₂) as core feedstocks. By synthesizing fuel directly from these elemental resources, the technology resolves the contradictions inherent in biomass routes—specifically the scarcity of arable land and conflict with food security. This strategic shift from "agricultural extraction" to "industrial production" delivers three definitive advantages.



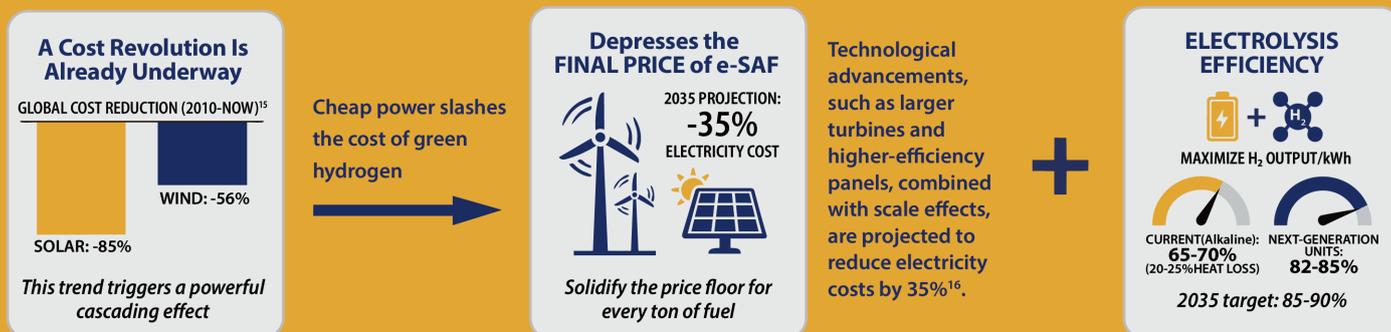
14. Liding Industry ry Research Network (2025) 2025 Global Sustainable Aviation Fuel Industry ry Analysis, Beijing; IEA (2024) Sustainable Aviation Fuels Cost Review 2024, Paris.

LIBERATING VALUE:

e-SAF Delivers "Affordable Sustainability"

e-SAF shifts fuel production from resource economics to scalable manufacturing economics. Anchored by renewable electricity costs, electrolysis efficiency, and hardware optimization, e-SAF follows a "technology cost curve" that inevitably declines with scale. By leveraging these industrial dynamics, e-SAF offers a clear rationale for cost reduction, presenting the only viable pathway toward cost parity that balances affordability with sustainability.

The cost trajectory of e-SAF is anchored by its most critical input: renewable electricity. Derived from wind and solar, this clean energy accounts for over 60% of total production expenses.



Inside the plant, electrolysis efficiency is the primary lever for doing more with less. By maximizing hydrogen output per kWh, engineering optimization directly attacks the largest operational cost. Current alkaline electrolyzers operate at 65-70% efficiency, losing 20-25% of energy as heat. Next-generation units have already achieved 82-85%, targeting 85-90% by 2035¹⁷. A 10% efficiency gain reduces green hydrogen costs by 6-8%

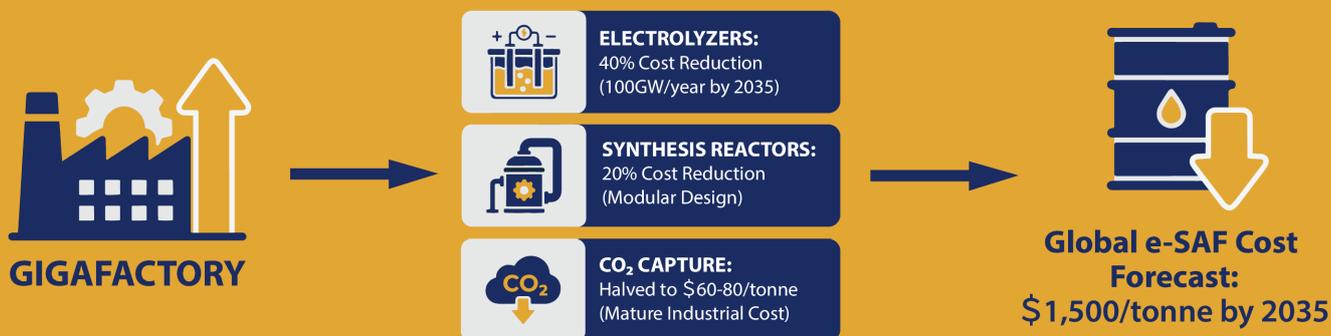
— a substantive reduction translating to a **\$150-\$200/ TONNE DROP in final e-SAF costs**¹⁸.

15. IRENA (2024) Renewable Power Generation Costs in 2023, Abu Dhabi.
16. IEA (2024) Sustainable Aviation Fuels Cost Review 2024, Paris.
17. IEA (2024) Sustainable Aviation Fuels Cost Review 2024, Paris.
18. McKinsey & Company (2023) The Economics of Green Hydrogen for Aviation, New York.

LIBERATING VALUE:

e-SAF Delivers "Affordable Sustainability"

The final driver stems from the industrialization of core hardware. As production shifts to "gigafactories," economies of scale are rapidly diluting capital costs for electrolyzers, CO₂ capture systems, and synthesis reactors. By 2035, global electrolyzer production capacity is projected to reach 100 GW/year, driving a further 40% cost reduction. Parallel evolutions are reshaping the value chain: modular design has reduced synthesis reactor costs by 20%, while mature industrial CO₂ capture costs have halved to \$60-100/tonne compared to a decade ago. This mass-manufacturing logic establishes a clear downward trajectory: global e-SAF costs are projected to fall to \$1,500/tonne by 2035¹⁹.



Critically, this cost reduction does not compromise sustainability. In stark contrast to the 60–80% emission ceiling of the HEFA route, e-SAF maintains more than 90% lifecycle emission reduction rate and can achieve negative emissions via Direct Air Capture (DAC)²⁰. This secures its position as the only scalable pathway to high-impact decarbonization.

19. IEA (2024) Sustainable Aviation Fuels Cost Review 2024, Paris.

20. ISCC (2024) Lifecycle Emission Assessment for Sustainable Aviation Fuels, Munich.

LIBERATING ACCESS:

e-SAF Enables Global Sharing

Traditional SAF pathways remain tethered to the rigid geography of biomass: waste oils track population density, while agricultural residues are locked to specific farming belts. This reliance creates a natural "geopolitical bottleneck and capacity lock-in" e-SAF, conversely, heralds a true liberation of resources. It requires only two ubiquitous inputs: renewable electrons and CO₂. The former anchors freely in global renewable-rich zones; the latter sources flexibly from industrial emissions (e.g., steel, cement) or creates an infinite loop via Direct Air Capture (DAC). Fuel production is thus no longer dependent on scarce feedstock locations but can migrate freely to global energy hubs. From the sun-drenched deserts of North Africa to the wind-swept coasts of the Nordics, any region with cheap green power can instantly transform into a "new-era oil field." e-SAF effectively realizes the principle of "Production Follows Power," establishing a model of "borderless globalization" free from traditional geopolitical constraints.

This revolution in resource acquisition triggers a profound restructuring of the global supply chain. The traditional SAF trade relies on a fragile, expensive linear model: bulky biomass must be shipped across oceans to processing hubs, with costs spiking alongside mileage. In contrast, e-SAF constructs a decentralized, high-elasticity network:

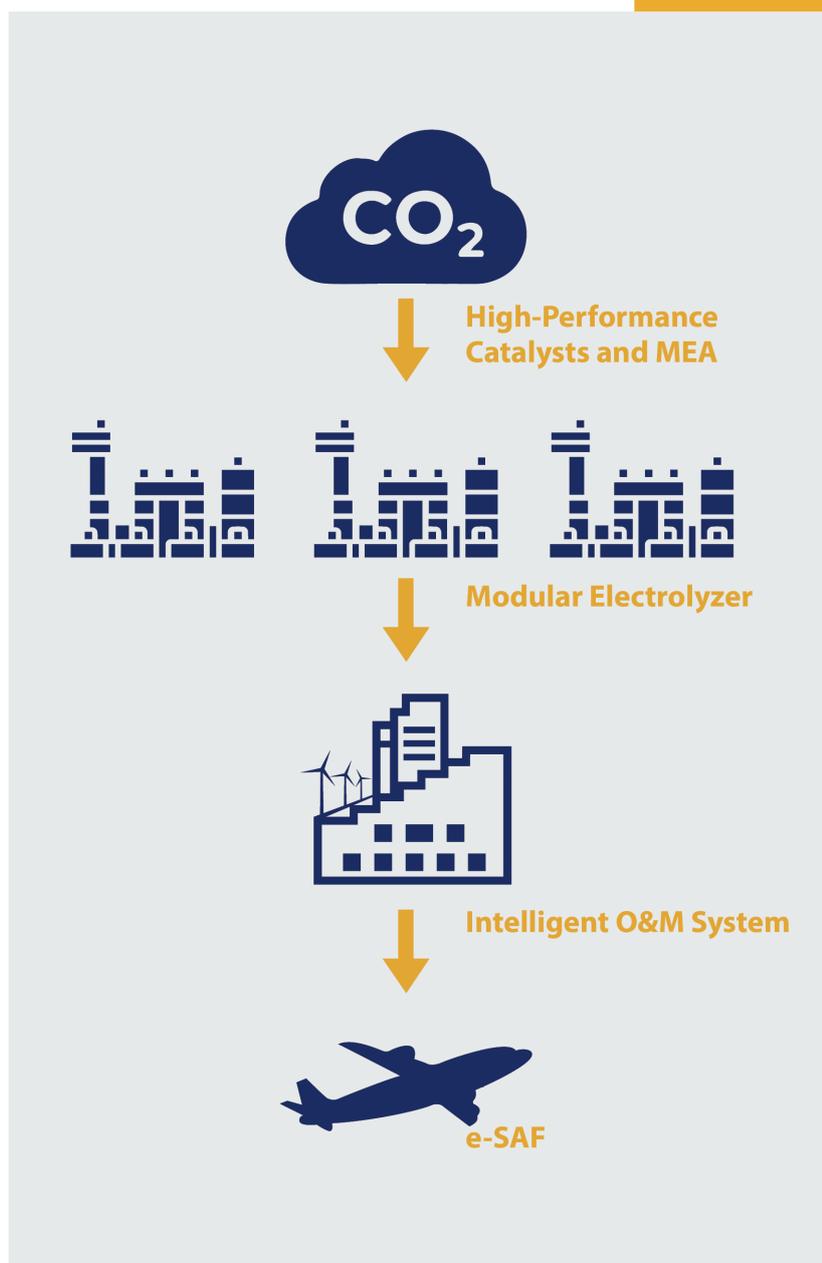


FD'S SOLUTION:

Making Green Fuel Economically Viable

To bridge the gap between e-SAF theory and reality, the industry must solve a critical equation: reconciling industrial viability with power volatility and prohibitive costs. This challenge defies solution through single-parameter optimization.

FD returns to industrial first principles, moving beyond lab-scale chemistry to confront the gritty constraints of production scenarios. By fusing breakthrough materials, flexible modular architecture, and adaptive intelligent strategies, we have engineered a systemic solution that renders green fuel production not merely "technically feasible," but "economically viable."



HIGH-PERFORMANCE CATALYSTS AND MEMBRANE ELECTRODE ASSEMBLY (MEA):

e-SAF Unlocks Unlimited Feedstock

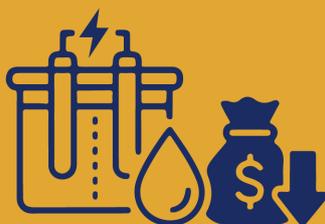
FD's proprietary MEA is the engine of economic CO₂ conversion. Current low-temperature CO₂ electrolyzers face significant performance bottlenecks compared to mature PEM water electrolysis. The industry average suffers from poor energy efficiency (typically 30–40%, roughly half that of PEM systems) and unstable selectivity (<80% for CO production). FD leverages fundamental material innovation to overcome these limitations, establishing a decisive performance advantage that translates directly into business value:



**ENERGY
EFFICIENCY
>50%**

(Drastic OPEX Reduction)

We achieve a massive increase in CO yield per unit of electricity. Since electricity constitutes the majority of the e-SAF cost structure, this efficiency breakthrough drives a substantive, structural decrease in unit production costs.



**HIGH PRODUCT
SELECTIVITY OF
CARBON MONOXIDE
>90%**

(Capital Savings)

Our electrolyzer paired with in-house developed advanced MEAs can produce reaction generates high-purity CO steadily with negligible impurities. This radically simplifies the process, eliminating the need for complex downstream separation equipment and delivering significant savings on both Capital Expenditure (CAPEX) and Operational Expenditure (OPEX).



**10,000+
HOURS
DURABILITY**

(Guaranteed Capacity Utilization)

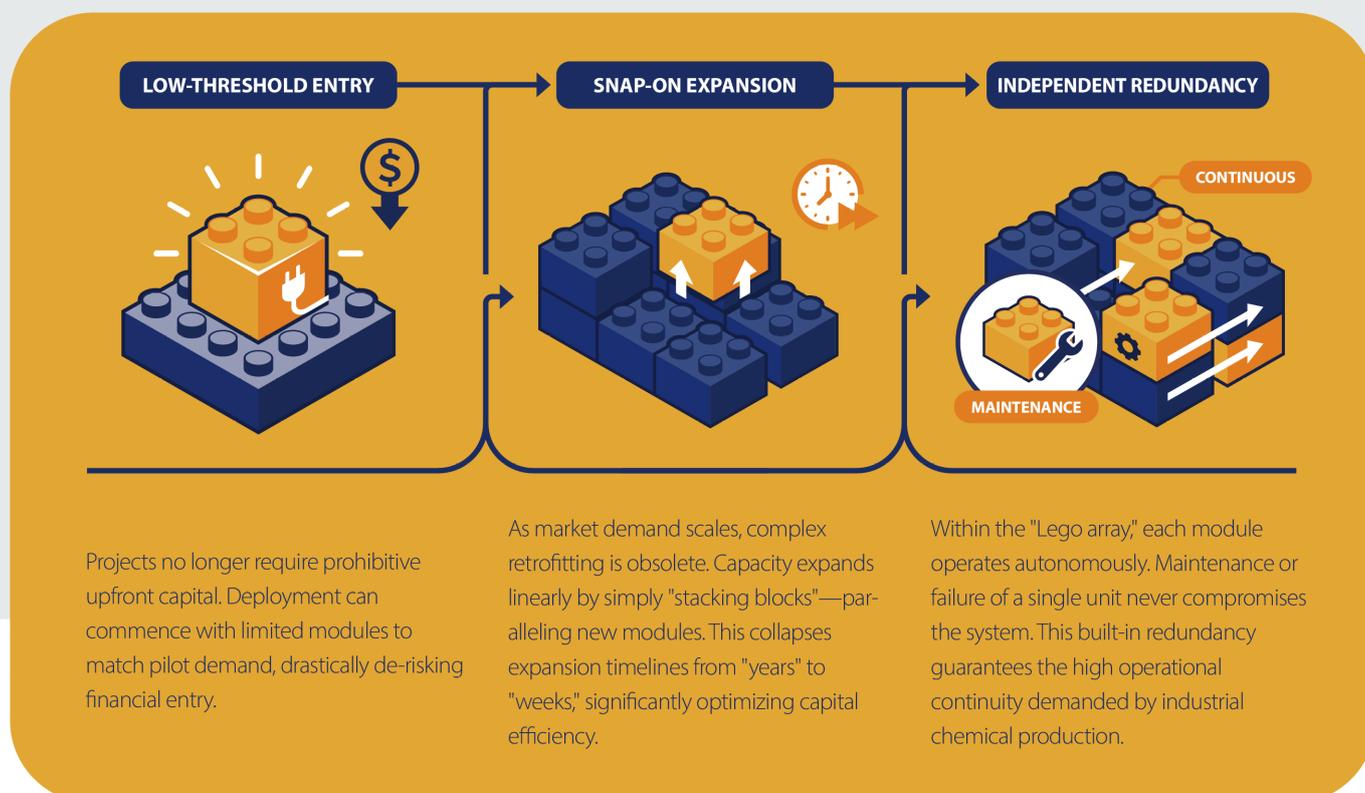
Validated through rigorous industrial testing, our electrolyzer components possess extreme durability. For large-scale continuous production, this minimizes maintenance downtime, ensuring asset continuity while eliminating the hidden capacity losses and replacement costs associated with component degradation.

MODULAR ELECTROLYZER:

Building Capacity Like "Lego" Blocks

Building upon our high-performance MEA, FD has re-engineered the electrolyzer as a Standardized Modular Reaction Unit. This design resolves the industry's "monolithic rigidity" pain point, fundamentally rewriting the logic of capacity deployment. Traditional electrolysis relies on massive, integrated structures where capacity is fixed at inception. Expansion in that model requires heavy capital for new facilities and construction cycles measured in years.

FD pivots to a "scale-out" strategy rather than the traditional "scale-up" model. Instead of pursuing larger, riskier monolithic units, we have engineered the mathematically optimal "Lego" brick—a standardized building block designed for replication. By simply adding more of these optimized units to increase capacity, this architecture transforms high-risk, one-time fixed asset investment into a flexible, step-function investment:



FD has fully validated the industrial feasibility of this model through on-site pilots. The dual advantage of "Flexible Scaling + Stable Production" positions FD with a distinct competitive edge in commercial deployment.

INTELLIGENT O&M SYSTEM:

Real-Time Adaptive Software Strategy for Power Intermittency

The industry faces a central paradox: the conflict between the inherent volatility of green energy (wind, solar) and the rigid stability required by chemical synthesis. Traditional solutions attempt to "fight" this volatility by stacking expensive energy storage hardware, drastically inflating Capital Expenditure.

FD employs active adaptation, using real-time dynamics strategies to align the chemical process chooses active adaptation: using software-defined strategies to force the chemical process to align with energy fluctuations. Our proprietary Intelligent O&M System is not a passive monitor, but an intelligent decision-making nexus with a constantly iterating online feature store engine evolved from formed by trained on massive native data sets. Through two core mechanisms, it maximizes the utilization of volatile energy without compromising safety:

MILLISECOND-LEVEL DYNAMIC LOAD FOLLOWING



The system analyzes real-time power fluctuations (voltage, frequency) against critical internal parameters (temperature, pressure, reaction stoichiometric ratio). Leveraging built-in characteristic algorithms and the feature store, it generates optimal operating strategies in milliseconds, dynamically adjusting reaction conditions. This means the electrolyzer no longer relies on constant baseload power but can "surf" the peaks and troughs of renewable energy, maintaining high output even under unstable grid conditions.



SHIFTING FROM "REACTIVE REPAIR" TO "PROACTIVE DEFENSE"



Powered by FD's proprietary MLOps framework, the system predicts trends rather than reacting to failures. It identifies anomalies—such as local temperature spikes or minor decay—in advance, triggering protection or maintenance directives before failure occurs. This eliminates equipment wear and safety risks at the source, ensuring absolute asset safety under high-load operations.



The commercial value proposition is underpinned by inherent system simplicity: FD's electrolyzer clusters enable direct coupling with variable renewable energy sources (solar and wind), obviating the need for capital-intensive external energy storage and grid-stabilization infrastructure. This architecture materially reduces upfront capital expenditure (CAPEX) while ensuring the long-term economic sustainability of large-scale production through intelligent risk-mitigation frameworks.

Furthermore, FD's superior ability to orchestrate and integrate global industrial competencies—stemming from its extensive supply chain network, large manufacturing capacity, and access to cost-effective materials—establishes a robust foundation for e-SAF advancement. By leveraging this consolidated industrial base, FD can materially accelerate the scaling and deployment of e-SAF solutions, delivering a more expedited, commercially viable pathway for the entire market.



Aviation decarbonization is a paradigm shift: from extraction to manufacturing, fuel evolves from an infinite resource to a scalable industrial product. FD's proprietary breakthroughs and supply-chain velocity erase the Green Premium.

The era of exploration is closed. We deploy gigawatt-scale e-fuel factories today, turning net-zero flight from an environmental imperative into a profitable reality.

MANUFACTURING THE INFINITE SKY