Cleantech Group

Spotlight

Materials & Chemicals

Sustainable Aviation Fuels: eJet

June 2023

© 2020 Cleantech Group. Private & Confidential.

eJet: Executive Summary

With policy support and expected innovation, eJet will supply half the world's jet fuel demands by 2050

- Rising social concern over carbon emissions and policy intervention have spurred the growth of sustainable aviation fuels (SAF) and electrojet (eJet), a type of SAF which has a near neutral carbon footprint
- Within the eJet category there are several production pathways with Alcohol-to-Jet and Power-to-Liquids providing the most sustainable and commercially viable opportunities in the sector
  - Alcohol-to-Jet is commercially viable now, and Power-to-Liquids are just rolling out pilot plants
  - Power-to-Liquids avoids long-term feedstock issues that will prevent Alcohol-to-Jet from reaching market dominance
  - To reach commercial viability, Power-to-Liquids producers should experiment with catalyst choice and plant size to reduce energy requirements while renewable energy production scales
- Key production innovations will focus on catalysts, electrolysis, and Direct Air Capture (DAC) technology while balancing access to renewable electricity, airports, and favorable policy incentives
- Nearly all demand for SAF is generated from government incentives and blending mandates to make the fuels cost competitive but more support is needed to advance renewable energy infrastructure (the main expenditure on eJet production) while producers continue optimizing this maturing technology through experimentation
- With continued policy support, expanded production of electrolyzers and reactors, and steady demand for aviation fuel, SAF will provide 88% of all jet fuel in 2050 while eJet alone will provide 52% of all jet fuel

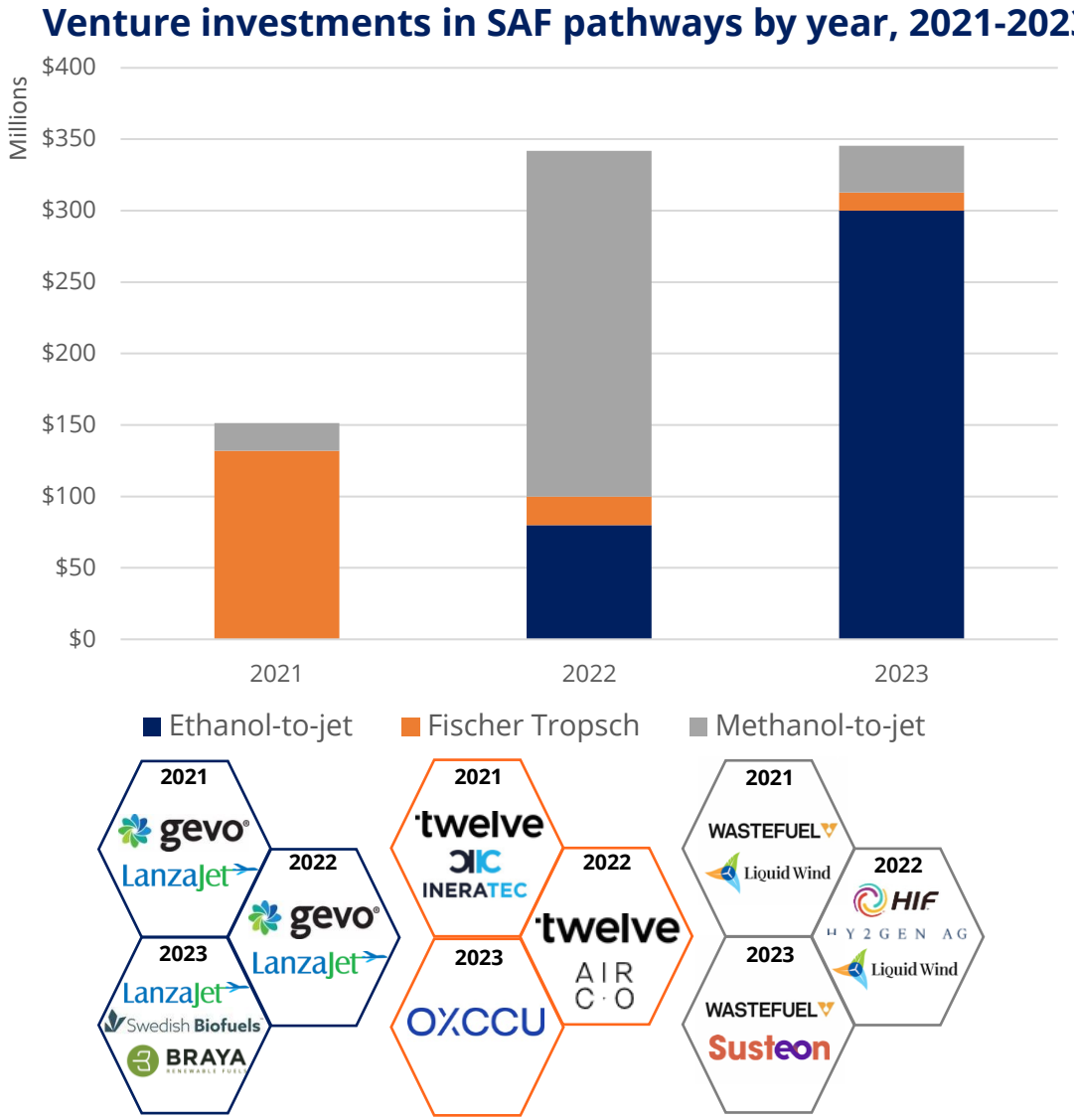


Figure 1: Graph depicts venture investments from seed to growth equity in the three focus SAF pathways from 2021 to Q1 of 2023

Cleantech Group

eJet: Setting the stage

Status quo

- **eJet** is a drop-in aviation fuel replacement made using captured carbon, hydrogen, and renewable energy
- Carbon reduction policies have created heightened demand for aviation fuels with a reduced or neutral carbon footprint
- Despite high demand, each production pathway has a specific scaling constraint limiting immediate or long-term competitiveness in the sustainable aviation fuel (SAF) market:
  - Alcohol-to-Jet (AtJ): Biomass feedstocks cannot be scaled without crop and habitat disruptions (some promise in Algae feedstocks), municipal (Advanced) waste and industrial waste gases have scaling/sorting issues
  - Power-to-Liquids (PtL): Global supply of renewable energy and electrolyzers are not sufficient to meet demand needs
- Demand is currently being filled with a mixture of feedstocks, meeting global fuel needs requires a mixture of each over varying periods

Development timeline

- **2023-2030:** Biomass provides a commercially viable supply for SAF transition while utilization of municipal/industrial wastes, direct air capture increases to fill feedstock demand
- **2030-2040:** Renewable energy scales, increasing PtL viability but AtJ remains dominant pathway with new use of municipal waste feedstocks
- **2040-2050:** AtJ and PtL are price competitive, but PtL continues to scale while AtJ runs into feedstock plateaus
- Pricing estimates for PtL, with current subsides maintained, place the fuel at $760-900 per ton by 2050 while current kerosene prices range from $630-765 per ton depending on location

Global SAF production capacity by feedstock, 2020-2050, Mt per year

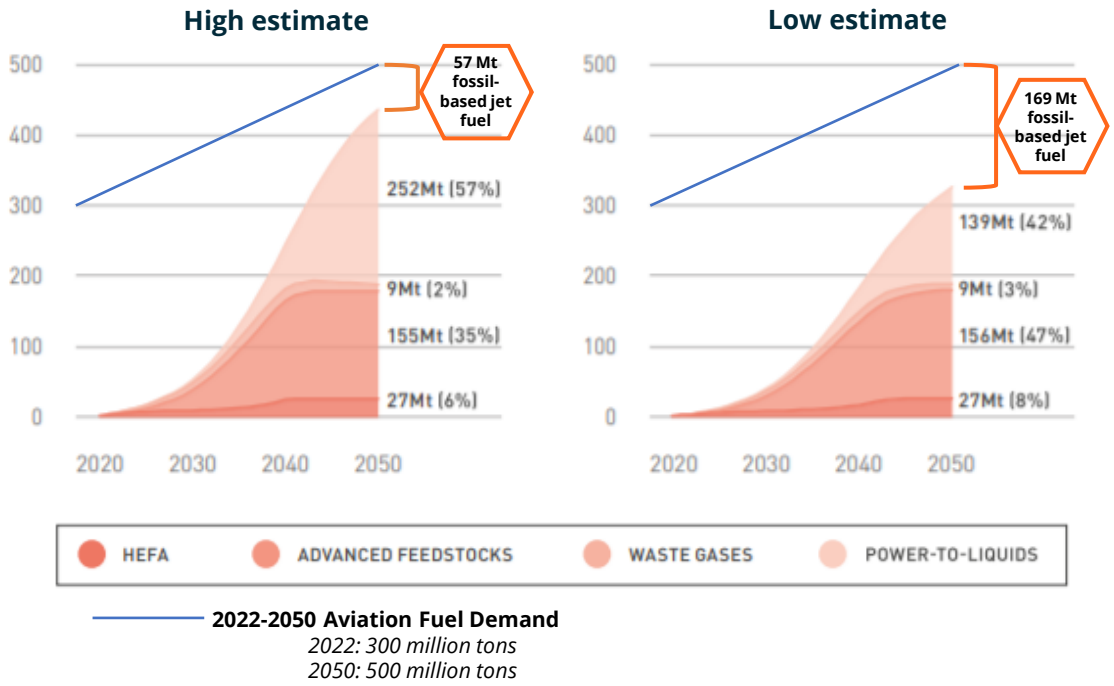


Figure 2: Waypoint 2050?, 2021, Air Transport Action Group

Note: Advanced feedstocks include municipal solid waste, algae, cellulosic biomass, waste oils/fats, woody residues. HEFA (Hydroprocessed Esters and Fatty Acids) feedstocks include cooking oils, vegetable oils, and animal fats.

Cleantech Group

eJet: Power-to-liquid produces the lower-carbon jet fuel, but presents cost challenges today

Alcohol-to-Jet will fill the SAF need while power-to-liquid technologies catch up on cost

PtL using Fischer-Tropsch has limitless scale but several challenges

- Fischer-Tropsch operates most efficiently chemically and economically at a large scale, but the cost of Fischer-Tropsch reactors are very high
- Fischer-Tropsch is extremely energy intensive, **immediate shift to PtL fuels would consume 70% of today's global electricity supply**
- Most PtL Fischer-Tropsch fuels usually contain no aromatics, a key fuel component of kerosene preventing fuel leakage
- Competition vs hydrogen-intensive sectors for access to electrolyzers creates intense production bottlenecks and high prices

PtL - Wait for renewables and optimize production techniques

- Production facilities for Fischer-Tropsch have varied in size with no single optimal result yet due to high capital costs; several companies are experimenting with modular, single reactor systems with a focus on process optimization (Ineratec, Zero)
- Producers are experimenting with a range of catalyst and conversion technologies to reduce energy requirements and need for aromatic additives including plasma and iron catalysts, single step conversions
- Electrolyzer availability will expand naturally while technological innovation occurs simultaneously (proton exchange membranes, solid oxide electrolysis cells)
- PtL has technical issues that will take time to solve, **by utilizing AtJ now, PtL has time for renewable energy scaling, technological development, and facility construction to drive down production costs**
- **Successful PtL players will expand modular pilots in parallel with, and not before, the growth of Direct Air Capture (DAC) carbon sources and renewable energy**

Technical diagram of PtL and AtJ pathways

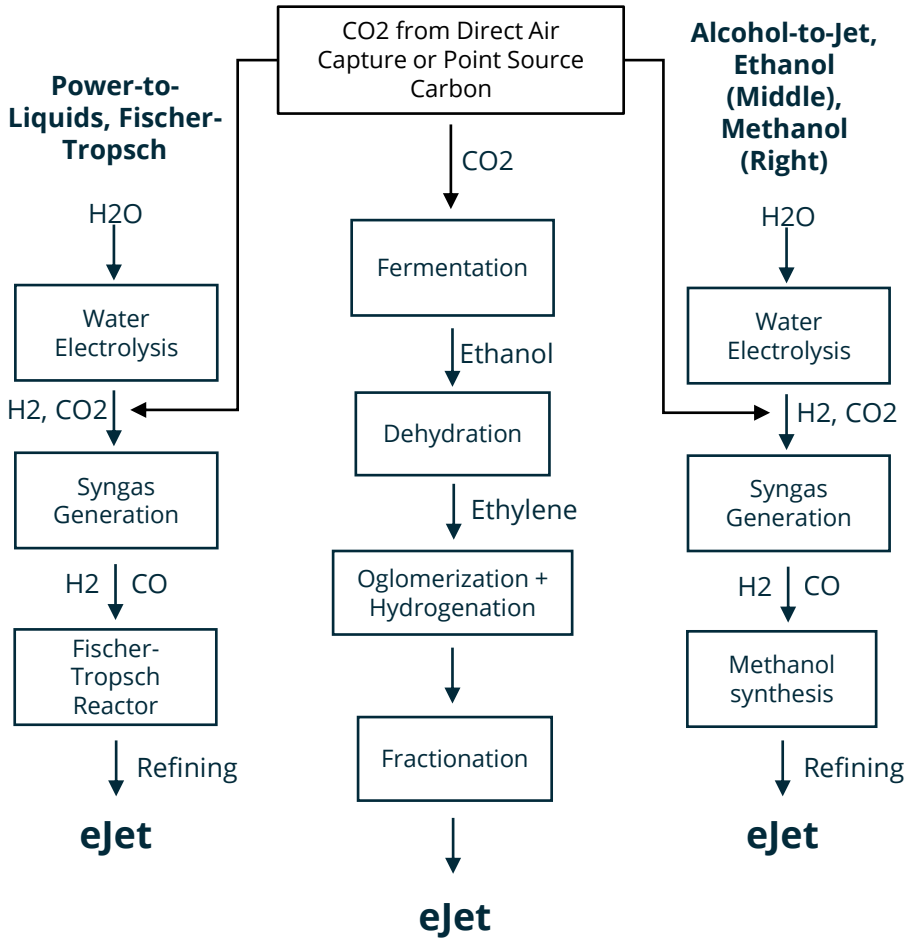
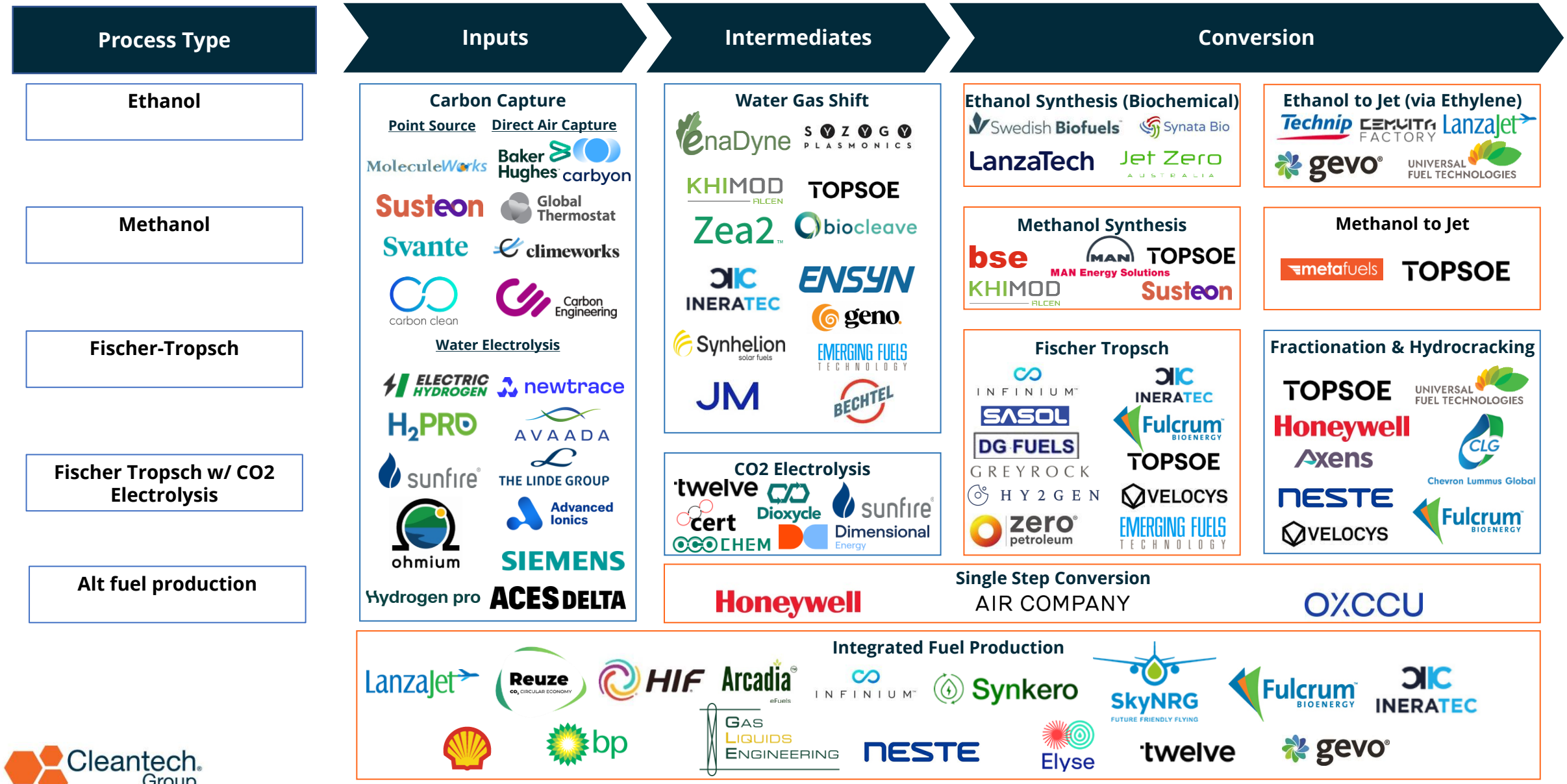


Figure 3: PtL and AtJ Technical Diagram

eJet: Value chain



Cleantech Group

eJet: The ABC's

Discussion

Attractiveness

- $100-250 billion market by 2030, up 50x from $5 billion market in 2023, several competitors trying to optimize all at once, high competition to secure exclusive partnerships but demand still larger than supply
- Incumbent oil and gas producers have been slow to invest in expensive reactors with high competition, providing opportunity for start-ups to experiment with electrolyzers, conversion reactors (Fischer-Tropsch and single step), and plant size while still selling any SAF they produce
- Policy incentives for carbon utilization, hydrogen production, fuels production, blending quotas, credit schemes in EU & US amongst other legislative packages at the state and country level are stimulating demand
- Traditional fuel providers (Exxon, BP, Shell) are all actively engaging innovation and forming partnerships across production pathways or investing in disruptive technologies to improve their production capabilities and efficiency
- Byproducts from eJet production including synthetic diesel or chemicals can be sold to offset high operating costs for plants

Business Models

- **Project integrators,** like HIF, license or purchase leading technologies from multiple companies to form centralized production processes that deliver eJet to large consumers such as airlines
- **Equipment providers** like Siemens (electrolyzers) and OXCCU (catalysts) produce best in-class technical components for large scale facilities
- Honeywell and Universal Fuel Technologies offer novel conversion methods that they **license** to project integrators without their own technologies
- Companies with proven technology processes and capital can then diversify income streams by operating as both **integrated fuel producer** and **equipment provider/licensor** (E.g. Ineratec supplying both modular reactors, components to larger producers, and eJet)
- Companies with influence beyond aviation fuels such as Siemens or Honeywell also provide **engineering management and consultation** services to aid in plant construction and technology integration

Competitive Trends

- Several companies attempted large-scale, fully integrated fuel production (mostly through acquisitions) but CAPEX/OPEX remains too high for commercial viability, recent industry move to two competing trends:
  - **Highly specified AtJ project management** with several companies collaborating under a larger manager such as HIF, Infinium
  - **Modular PtL production units** in which companies create many small units betting on future technology optimization (Zero, Ineratec)
- Two trends for plant location: **where renewable energy is widely available** already and **proximity to airports**
- Despite low rates of full acquisition, early to mid stage companies compete for large airline/energy contracts by creating partnerships across the value chain to fill production holes
- Single step conversion is only at the research stage but showing promising signs of energy optimization if scaling is validated
- Renewable energy requires approximately a decade to scale to commercial demands for SAF and 15-30 years to reach full production capacity for eJet with emphasis on high potential areas such Australia, Texas, and Brazil

Cleantech Group

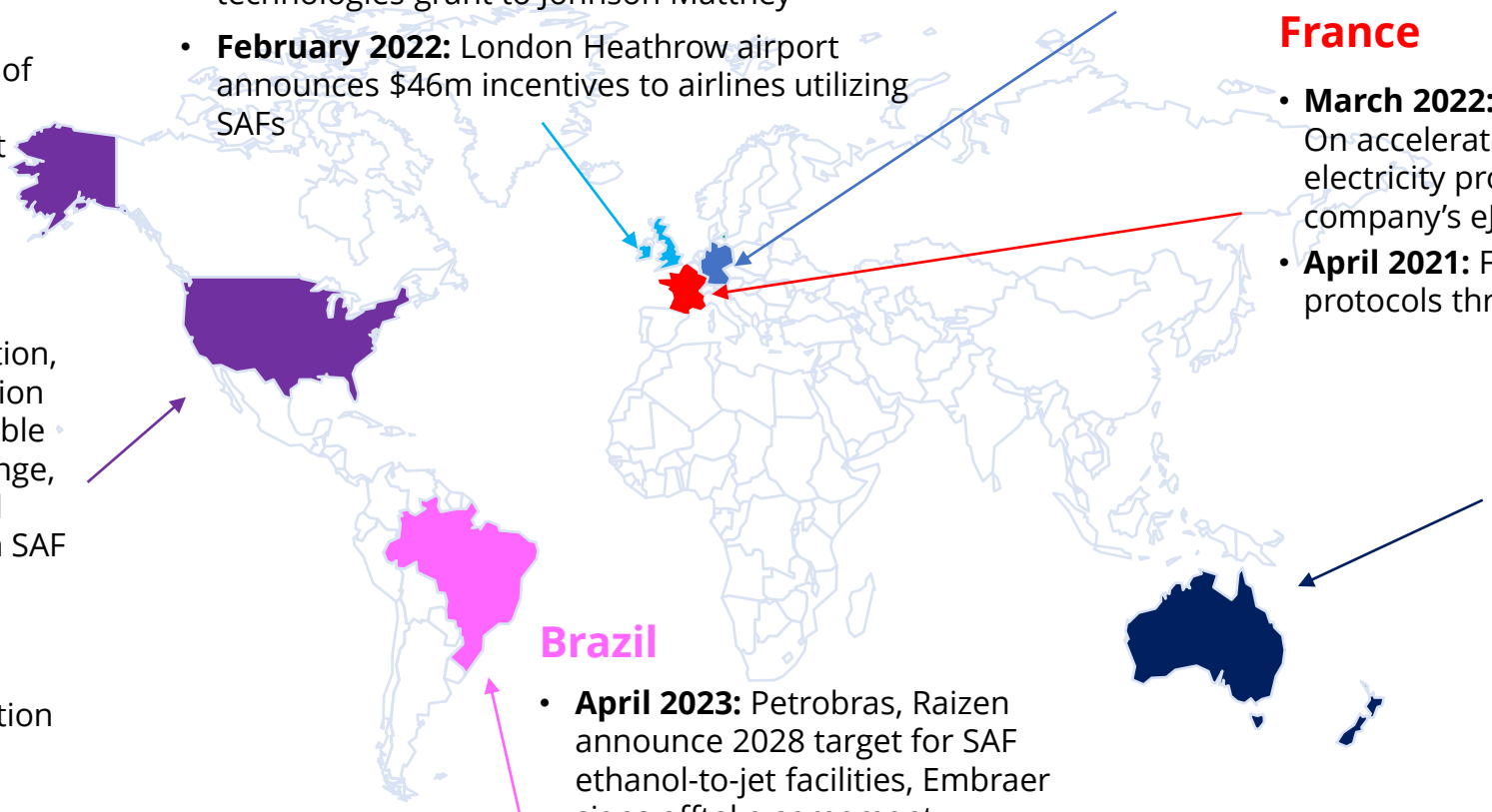
eJet: Regional drivers, sources of innovation, pilots

United States

- **December 2022:** US Dept. of Transportation announces $33M grant for Velocys eJet facility
- **September 2022:** US Department of Energy, Department of Agriculture, Department of Transportation, and Environmental Protection Agency announce Sustainable Aviation Fuel Grand Challenge, a research and commercial support body for American SAF production
- **2020-2021:** Elemental Excelerator funds several startups in the eJet production chain including Heliogen, Twelve, and ZeroAvia

United Kingdom

- **July 2022:** Advanced Fuel Fund announces $112M awards to Alfanar Energy, Fulcrum BioEnergy, LanzaTech, and Velocys
- **April 2022:** Gov. announces $500M hydrogen technologies grant to Johnson Matthey
- **February 2022:** London Heathrow airport announces $46m incentives to airlines utilizing SAFs



Germany

- **August 2022:** Lufthansa finalizes six-year SAF purchase agreement with Shell using four different production pathways
- **September 2021:** Lufthansa and German government agree to purchase one million gallons of SAF over next decade in transition from biofuels to eJet

France

- **March 2022:** TotalEnergies Announces TotalEnergies On accelerator to focus on European renewable electricity production and integration with company's eJet production
- **April 2021:** France mandates jet fuel-SAF blending protocols through 2050

Brazil

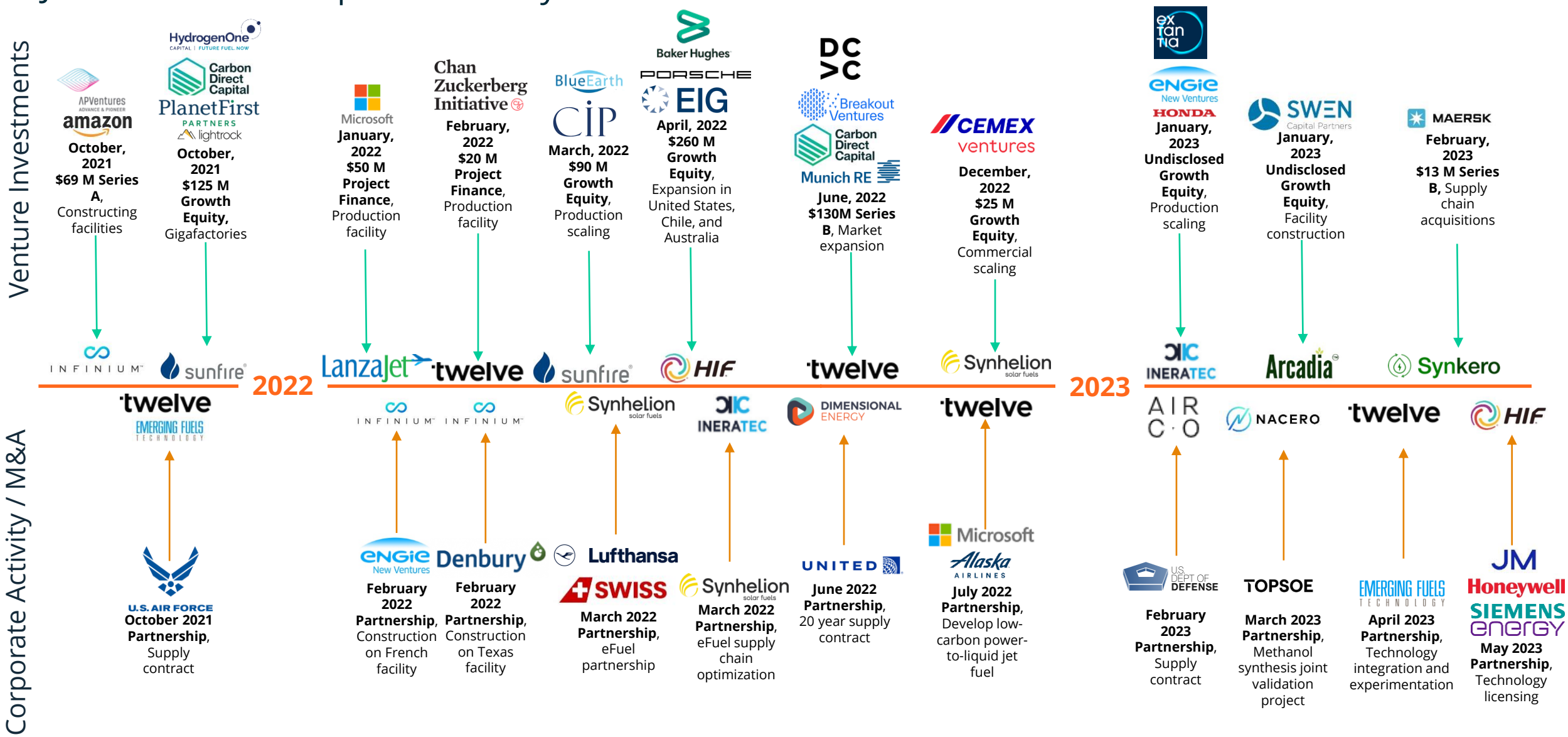
- **April 2023:** Petrobras, Raizen announce 2028 target for SAF ethanol-to-jet facilities, Embraer signs offtake agreement
- **October 2022:** Brasil BioFuels begins work on $410M SAF facility with direction on eFuels production from Topsoe

Australia & New Zealand

- **March 2023:** Queensland Gov. grants $3M to LanzaJet and Jet Zero Australia to develop first ethanol AtJ plant
- **February 2023:** Airbus, Air New Zealand, Christchurch Airport, Fortescue Future Industries, Hiringa Energy, and Fabrum establish The Hydrogen Consortium, a joint technology partnership to advance hydrogen powered aviation

Cleantech Group

eJet: Investment/corporate activity



Investment → Activity ⇢ Partnership → Acquisition

eJet: Innovator examples

Positioning: Early-stage producer of 100% drop-in kerosene, gasoline, and diesel utilizing Fischer-Tropsch PtL pathway

Market insight

- Established partnerships in renewable energy production avoid grid tariffs, dramatically improving operating costs
- Fischer-Tropsch produces waxes that slow production, experimentation with catalysts and reactors helps eliminate these

Company insight

- 100% drop-in ability and presence of aromatics validated with UK Royal Air Force pilot, have since completed two additional contracts and taken on Babcock International as a new customer
- Plan to roll out several small production facilities in Europe and optimize each one under PlantZero.2 project

Milestones:

- **June 2023:** PlantZero.1 now operational and producing fuels
- **September 2022**: Construction begins on PlantZero.1, SAF will fulfill contract to UK Royal Air Force
- **November 2021**: Provided fuel for world's first flight with eJet in partnership with the Royal Air Force

Capital: Undisclosed

Contact: Jeff Benesch, COO

Positioning: SAF production integrator utilizing Methanol Synthesis and renewable energies to produce drop-in eJet and other electrofuels

Market insight

- Demand for product is high in North America and diversified production facilities will increase with legislation and planned expansion in Europe
- Production bottlenecks are intense and mounting with demand for green hydrogen
- Waiting for Fischer-Tropsch to become viable misses an immediate market opportunity

Company insight

- Fully functional production facility in Chile, authorization and permitting ongoing for Australia and Texas facilities
- Currently limited by electrolyzer bottlenecks but have long-term partnerships with best-in-class producers that should expedite commercial viability

Milestones:

- **April 2023**: receives environmental permit authorizing construction and operation at first US eFuels facility, partners with Idemitsu Kosan to break into Japan market
- Technology partnerships with leading energy corporations (Honeywell, Siemens, Johnson Matthey)
- 4 operating, 8 planned eFuels facilities with an anticipated 2.4B gallons production capacity

Capital: $260 million

Contact: Anthony McMaken, Director of Finance

Positioning: Producer of modular reactors for Fischer-Tropsch PtL pathway as well as full integration project organization

Market insight

- Companies with validated reactor technologies can get trapped in searching for partners instead of pursuing independent modular production opportunities
- Fischer-Tropsch reactors must be more selective with location than AtJ, proximity and partnership with DAC partners as well as renewable energy potential should be upmost geographic priority

Company insight

- Flexibility with reactors, modular plants, and large plants position Ineratec as a market leader
- Remain one of the few eFuel producers with large scale plants and are actively expanding in Europe, South America with several government partnerships

Milestones:

- **April 2023**: Announced plans to break ground on SAF facilities in Chile, Germany, and the Netherlands
- **January 2023**: Raised an undisclosed Series A
- Partnerships and technology agreements with Sasol, Synhelion, Sunfire, Siemens, Neste, Climeworks, Clariant

Capital: $35 million

Contact: Tim Böltken, Founder and Managing Director

eJet: Innovator examples

OXCCU

Positioning: Early stage eJet producer with novel catalyst, reactor, and single step conversion Fischer-Tropsch PtL technologies

Market insight
- Early stage eJet producers focus on utilizing production byproducts for additional revenue streams, OXCCU produce biodegradable plastic from waste streams
- Disrupting market with more efficient catalysts, conversion techniques only works with project integrators in the market

Company insight
- Provide multiple technology solutions in value chain with modular reactors and proprietary catalyst technology
- Primary production advantage over competition is their direct conversion method that massively reduces CAPEX
- Targeting several oil, aviation, chemical companies as commercial partners for their pilot plant

Milestones:
- **June 2023:** Announced $22.7 million Series A funding round
- University of Oxford spinout with incubation from IP Group and their VC platform Kiko
- Recently developed iron-based catalyst for one-step conversion, now working on modular reactors

Capital: $23 million

Contact: Andrew Symes, CEO

INFINIUM

Positioning: Large scale PtL producer with full integration except carbon capture technologies

Market insight
- Long-term planning, selective partnerships, and careful geographic analysis help create supply chains for carbon dioxide and renewable energy that are insulated from outside competition
- Consider production of synthetic diesel and gasoline to be a method to validate PtL and gain traction with investors, aviation customers

Company insight
- Identify localized carbon dioxide suppliers and renewable energy suppliers as plant partners, no sign of integrating these steps
- Direct competitor to HIF Global with similar geographic operations in Texas and expansion into Europe
- Performing internal research on catalyst optimization

Milestones:
- **February 2022**: Announce partnership with Denbury to develop eJet plant in Brazoria County, Texas
- **February 2022**: Announce partnership with ENGIE titled Reuze, a massive CO2 to eJet conversion plant in France
- Developed new catalyst technology to reduce wax creation and optimize production capability

Capital: $69 million

Contact: Liz Myers, VP of Business Development

UNIVERSAL FUEL TECHNOLOGIES

Positioning: Early-stage Alcohol to Jet producer utilizing flexiforming technology to convert ethanol to eJet

Market insight
- Market has several feedstocks all simultaneously competing for attention, technology needs to incorporate this availability
- Lack of aromatics in eJet requires blending and shipping expenses to make fuel drop-in ready

Company insight
- Scaling will require partnership with a refinery or existing production facility
- Current clients are focused on less developed markets where feedstocks vary (Paraguay, Malaysia)
- Ability to accept diverse feedstocks allows for large degree of technological and market flexibility
- Fuels have aromatics, eliminating need for blending

Milestones:
- **May 2023:** Seed round from Claire Technologies Corporation will help rebuild laboratories
- Partnerships with Chevron, aviation companies, and SAF producers using Fischer-Tropsch
- Have achieved competitive production with major alcohol to jet producers

Capital: $1 million

Contact: Alexei Beltyukov , CEO

Cleantech Group

eJet: Accelerator/Incubator ecosystem members

	Role	Investments, Partnerships, and Accomplishments
Breakthrough Energy	• Breakthrough Energy is a climate technology organization that supports innovation through investment, accelerator programs ($1 billion program Breakthrough Energy Catalyst), and policy advocacy	• Breakthrough Energy Venture's investments in the SAF value chain include Electric Hydrogen, H2Site, H2Pro, Heirloom, Sierra Energy, Sustaera, Verdox, and Zero Avia • Breakthrough Energy Catalyst's recent investment in LanzaJet's AtJ production plant is supported by large corporations such as American Airlines, Bank of America, and Microsoft
C2V CARBON TO VALUE INITIATIVE	• Carbon to Value Initiative is an accelerator supporting technologies that turn carbon dioxide into valuable products and services • Focus on commercializing innovative technologies through three-year cohorts and connecting corporations, government actors, and NGOs	• Investments and incubation for companies across the SAF value chain including: Cemvita Factory, CERT, Air Company, Lydian, and MoleculeWorks • Carbon to Value Initiative is a collaboration between Urban Future Lab, Greentown Labs, and Fraunhofer USA • Carbon to Value Initiative companies have gone on to raise over $340 million in follow-on fundraising from their incubation period
Aviation Impact Accelerator	• Aviation Impact Accelerator is a non-profit supporting net-zero aviation technologies by connecting aviation industry leaders and policymakers • Aviation Impact Accelerator also provides research analysis and emissions modeling to support their partnership strategies	• Partnerships include: **universities** (Cambridge University, UCL Air Transportation Systems Lab, University of West London, University of Melbourne), **corporate** (Siemens Energy, Heathrow, Rolls-Royce, Boeing, Etihad Airways, Satavia), and **policy** (World Economic Forum, Cambridge Zero, SMI, MathWorks, 4Air) • Developed *Resource to Climate Comparison Evaluator (REECE)* to evaluate cost and impact of SAFs and *Journey Impact Simulator* to evaluate long-term fuel impacts of SAFs and other technologies

eJet: Incumbents

	Positioning	Engaging Innovation
SIEMENS energy	• Energy solutions provider with growing involvement in green hydrogen production and renewable energies • Siemens has identified a market opportunity in the manufacturing of hydrogen electrolyzers for companies like Ineratec or HIF facing bottlenecks in production • Also connect governments, airlines, chemical producers, and hydrogen innovators to form distribution and research partnerships through MoUs and development agreements	• **March 2023**: Partners with Air Liquide to construct electrolyzer production facility in Berlin, contracts with HIF as electrolyzer supplier • **February 2023**: Forms Abu Dhabi consortium with Masdar, TotalEnergies, and Marubeni to develop UAE and Egypt's hydrogen supply capabilities • **June 2022**: Launch Green Fuels Hamburg consortium with Airbus, Uniper, Technical University of Hamburg, the Hamburg Senate, and the Hamburg Airport to deploy hydrogen powered aviation solutions in Germany • **March 2022**: Launch $100 million fund for American decarbonization startups
TotalEnergies	• French oil and gas company moving into eJet and renewable electricity production • Operate TotalEnergies On accelerator to identify and develop renewable electricity startups for eJet needs, recently sold $400 million venture portfolio to focus on this sector • Focused on advancing production capabilities through partnering with airports including Charles de Gaulle, Le Bourget, Clermont-Ferrand, and Bordeaux-Mérignac airports	• **July 2022:** Began one year pilot program with delivering SAF to Singapore's Changi Airport to test Asian fuels market • **May 2022:** Invests in several renewable electricity startups including: Sereema, Green Eagle Solutions, Granular Energies, Tokwise, and Eliq • **March 2022:** Announced TotalEnergies On accelerator • **February 2022**: Partnered with Honeywell, Siemens to transition general SAF production into eJet focused production
UNITED AIRLINES	• Large, commercial aviation company engaging with emerging SAF innovations such as alternative aircraft manufacturing, fuel producers, and feedstocks • Facilitates corporate involvement from JPMorgan Chase, Boeing, GE Aerospace, Honeywell, and Air Canada through partnership in their innovation venture funds (United Airlines Ventures Sustainable Flight Fund) • Multiyear uptake agreements in fulfillment with corporate transition and state-enforced policy goals	• **March 2023**: Invests $5 million in carbon capture and conversion company Svante with planned technology partnership with Dimensional Energy • **February 2023**: Founds United Airlines Ventures Sustainable Flight Fund, a $100 million fund designed to support start-ups focused on decarbonizing air travel by accelerating the research, production and technologies • **June 2022**: Signs 20-year purchase agreement for 300 million gallons of eJet produced by Dimensional Energy • **June 2022**: Invests in Dimensional Energy with specific focus on bolstering Dimensional's Fischer-Tropsch production capability

Cleantech Group

eJet: Policy ecosystem members

	Role	Points of view
ICAO	• Sets methodologies and standards for SAFs usage and Low Carbon Aviation Fuels (LCAF) • Sets policy goals for global aviation industry (Ex: international aviation of net-zero carbon emissions by 2050) • **Economic support for smaller states transitioning to SAFs** (Dominican Republic, Trinidad and Tobago, Kenya, Burkina Faso)	• Partnered with the United Nations Development Programme to develop the *Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)* • **Builds a road map for the entire aviation industry to meet goals outlined in the *Paris Agreement*** • Partnered with the European Parliament to edit and refine their *Fit for 55* legislative package and broader *European Green Deal* legislation goals
European Parliament	• Sets regulations regarding carbon and greenhouse gas emissions • Set policy goals for European aviation industry (Ex: meeting Europe's segment under the *Paris Agreement*) • **Economic and regulatory support for start ups**, airlines, and businesses committed to propelling innovation in SAFs	• **June 2023**: Final steps on passing the *Fit for 55* package to reduce EU aircraft CO2 emissions by around two-thirds by 2050, requires a progressive growth in EU SAF blending starting at 2% and growing to 70% over 25 years, funds and subsidizes new renewable electricity projects • **December 2022**: Passed emissions trading regulations for the aviation sector - **Deployed $1.76 B to SAF producers** and eliminated corporate carbon allowances - Was developed in tandem with ICAO's *Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*
World Economic Forum Clean Skies for Tomorrow	• Develop **cross-sector initiatives** to spur development of SAFs while supporting aviation innovations • Primary goal is **to facilitate conversations between innovators to reduce burden of investment** • Partners include: Airbus, Boeing, BP, Chevron, Shell, Honeywell, and Exxon	• Partnered with McKinsey to create the *Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation,* a comprehensive analysis of global SAF progress and goals • Organized the Sustainable Development Impact Summit, highlighted by commitments from Air New Zealand, American Airlines, Qatar Airways, Airports Council International, Boeing, Shell, and BP to power global aviation with 10% SAF by 2030

Cleantech Group

eJet: pre-commercial innovation

Ecosystem	Source		Innovation and Status
University Research		• The University of Michigan's Aerospace Department is a leader in aviation technology solutions including autonomous systems and sustainable aviation	• Created the Michigan Initiative for Sustainable Aviation (MISA) to leverage several disciplines in advancing fuel, aviation, and materials solutions in aviation • Partnered with Delta Airlines to supply SAF and study various concerns on fuel physics modeling
		• The Oxford Science Park is a university research facility supported by Singapore's sovereign wealth fund GIC and Magdalen College Oxford • Provide laboratory facilities and incubation services to startups	• Provided facilities to Oxford Chemistry Department spinout OXCCU and currently house the offices/laboratories of Oxford spinout Velocys • Connected OXCCU and similar energy and chemical startups with the IP group who has provided over $1 billion to scale various deep tech ventures
National Labs	 	• National Renewable Energy Laboratory (NREL) is a US Department of Energy National Laboratory specializing in renewable energy infrastructure • SAFFiRE is a NREL spinout owned by D3MAX LLC	• Developed SAFFiRE pilot plant test project utilizing ethanol Alcohol-to-Jet pathways • **June 2022**: Received the only federal pilot-scale operating grant for SAF production, US Department of Energy SAF Grand Challenge Grant, and matching funding by Southwest Airlines (Possibly ~$300k) • Hoping to move into production phase by August 2023
		• Argonne National Laboratory is a US Department of Energy National Laboratory managed by the University of Chicago specializing in energy and materials technology	• Contracted LanzaTech to develop a federal SAF plant initially using biogenic carbon sources • Study fuel's fluid physics and publish comprehensive fuel property suggestions for producers to optimize fuel structure and enhance gas turbine engine performance • Research on aromatics, particulates, and contrails

Cleantech Group

eJet: Keep an eye out for

Power-to-Liquids are the long-term answer, but require renewable energy expansion and policy support to reach potential

Market milestones

- Availability of cheap and abundant renewable energy will be necessary for deployment of eJet production in the long term with certain regions E.g. **Australia, Chile, Brazil, Middle East as most viable production sites**
- Traditional energy companies (BP, Shell) will **transition large scale HEFA projects to PtL as technology is validated** and biomass feedstocks run into availability issues
- Aviation companies (Jet Blue, American, United, Lufthansa) will continue investing in fuel producers and securing long-term supply contracts to meet blending quotas and carbon offsets market, primarily HEFA for now
- Small companies with success in modular production need to scale by building larger plants or several production facilities
- External support from accelerators will focus on renewable electricity generation and DAC while eJet innovators experiment with optimizing production technology

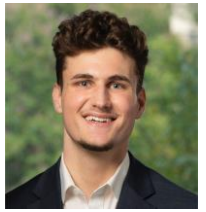
Innovator milestone

- Scaling requires three primary cost reductions:
  - **Renewable electricity cost reductions of about 30 percent**, achieved through additional scaling and optimizing reactor energy demands
  - **Wider commercial availability of high-efficiency PtL technology, leading to cost reductions of about 50 percent**
  - **Efficient and scaled DAC of carbon, resulting in 50 to 80 percent cost reductions**
- Companies must experiment with optimal electrolysis providers, catalyst type to drive down electricity demands while grid scales
- Scaling DAC in areas with access to renewable energy reduces spending on tariffs, grid costs
- **PtL innovators must work with regulators/airlines on engine compatibility testing** and incorporating aromatics in the production process
- Driving down price with process optimization through innovation such as single step conversion (OXCCU and Air CO), plasma catalysts, co-electrolysis, modular production

Regulatory/Policy milestones

- Estimated infrastructure costs of $1.1-1.5 billion between 2023-2050 to reach mandated eJet production needs (Waypoint 2050)
- US incentives eJet producers with tiered credits of $1.25-1.75 per gallon depending on percent reduction of lifecycle GHG emissions, $130 per ton of CO2 utilized through DAC (45Q), $3 per kg of green hydrogen (45V)
- EU parliament created roadmap until 2050 peaking at 70% blending mandate with SAF that has 80% reduced lifecycle GHG emissions
- EU: Sub-mandate for e-kerosene, 0.7% in 2030, 8% in 2040 and 28% in 2050; considering traditional jet fuel tax but leaving financial incentives to member states
- US IRA and EU Green Deal providing billions to scale wind and solar renewable production
- Canada finalized a roadmap to achieving net zero aviation by 2050

Materials & Chemicals: Sector research



Cleantech Group tracks the start-ups, scale-ups, investors & multinationals

from across the region & the world shaping the future of the Materials & Chemicals industry

Recent Published Research

- **Spotlight:** Flood Resilient Infrastructure (Q1)

Upcoming Topics

- **Spotlight:** Cathodes (Q2)

Upcoming Events

- **Cleantech Forum Asia** – *Meet the top innovators, investors & incumbents driving cleantech in Asia – Singapore – June 6 - 7, 2023*

Analyst – Parker J. Bovée

- Focused on emerging innovation & trends across cleantech sectors, including water, advanced materials, & corporate sustainability.
- Prior to joining Cleantech, Parker developed wildfire prevention technologies with VegaMX and researched socioeconomic implications of gambling legalization at the RXN Group.
- Parker earned a Bachelor's degree in History and Public Policy from the University of California, Berkeley where he specialized in the history of American environmental entrepreneurship.

Championing Sustainable Innovation, Catalyzing Business Opportunities

Cleantech Group's research, consulting and events catalyze opportunities for sustainable growth powered by innovation.

Cleantech Group

Contact us at research@cleantech.com