CLIMATE TRANSFORMED

# Decarbonizing Aviation with Sustainable Drop-In Fuel Alternatives

Featuring Cyril Yee and Sam Lefkofsky, Third Derivative

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# Welcome to A Climate Transformed

Strategy for the path toward decarbonization and sustainability

A Climate Transformed is a strategy series focusing on the innovations, opportunities, and challenges rounding the largest economic and societal transition of the next 30 years: Decarbonization and sustainability. Each week, we will publish findings based on our interviews with corporate leadership, investors, innovators, and founders that will drive $50 trillion of investment between now and 2050. This will include summaries of our most pertinent conversations as well as editorial content, prioritized towards actionable opportunities for public, private, venture, and corporate investors.

Climate Transformed has broken the world up into 17 sustainability segments. The wide range of topics that we cover is a function of the breadth of challenges that we face across every supply chain for both developed and emerging markets. Within segments as wide-ranging as aviation to sustainable farming are multibillion-dollar investment opportunities as companies transition from a dependence on fossil fuels to supply chains that will positively contribute to our quest for Net-Zero.

These strategy reports will be available to Climate Transform premium members. For access to your free 30-Day trial, please reach out to ***paul@climatetransformed.com.***

In this report, we cover:

**Decarbonizing Aviation with Sustainable Drop-In Fuel Alternatives**

# Decarbonizing Aviation with Sustainable Drop-In Fuel Alternatives

**To add to a recent series of sessions honing in on Green Transport with the likes of Marine Digital and Piaggio Aerospace, we continue the discussion alongside Cyril Yee, Chief Innovation Officer at Third Derivative, and his research associate, Sam Lefkofsky.**

**Takeaways**

Only 0.1 percent of aviation fuel is sustainable and costs two to four times more than fossil-based jet fuel. In contrast, e-fuels are one of the most promising pathways to decarbonizing aviation. The cost of low-carbon hydrogen is expected to drop significantly with technological innovations and cheaper electricity and this will facilitate attractive prices of e-fuels for aviation

**About Third Derivative**

Third Derivative is a program of the Rocky Mountain Institute that brings together startups, investors, and corporations, to help new technologies fight climate change. With its operations running for almost two years, it has provided support to over 100 startups, which have raised about US $500 million.

**Why SAF, and why now?**

Aviation accounts to about two percent of global emissions. It is a big market, and is expected to grow significantly in the future. Annual sales of global jet fuel is expected to grow from US$300 billion to US$450 billion by 2026. The demand for jet fuel is projected to double by 2050. present, only 0.1 percent of the market is sustainable and costs two to four times more than fossil-based jet fuel. Over 300 airlines have committed to purchasing sustainable aviation fuel (SAF) to achieve net-zero by 2050. Governments have started getting involved, such as Norway and France. Governments are starting to provide incentives to change the economics of SAFs. The recently-passed Inflation Reduction Act indicates significant subsidies for SAF.

> *"There's a lot of opportunity for startups and larger companies to partner and direct you across the technology pathway... Multiple partnerships that will be required to deliver synthetic fuel products."*

# Challenges with batteries, hydrogen, ammonia, and HEFA:

- There is a high investment interest in battery-powered airplanes. However, it is not a viable solution for medium and long haul, long hard aviation because of the weight of the batteries that exceed the maximum takeoff weight. The energy density is very low—about 60 times less than jet fuel.

- Hydrogen can either be used to power propeller aircraft using fuel cells, or it could be combusted in a jet engine equivalent to fuel planes. Ammonia is another potential molecule. It has certain advantages in terms of transportability and storage. However, there are no commercial examples of jet-powered hydrogen/ammonia aircraft or engines. The transaction transition expenses are high, estimated to cost up to $6 trillion.

- HEFA biofuels is a mature technology and Lufthansa has several flights based entirely on half the biofuels. Cellulosic and algae biofuels are more environmentally friendly and available. The main challenge for HEFA biofuel is scalability since most of the feedstocks are used for biodiesel already. For cellulose biofuels, feedstocks require significant land use. For algae, the cost of production is relatively expensive.

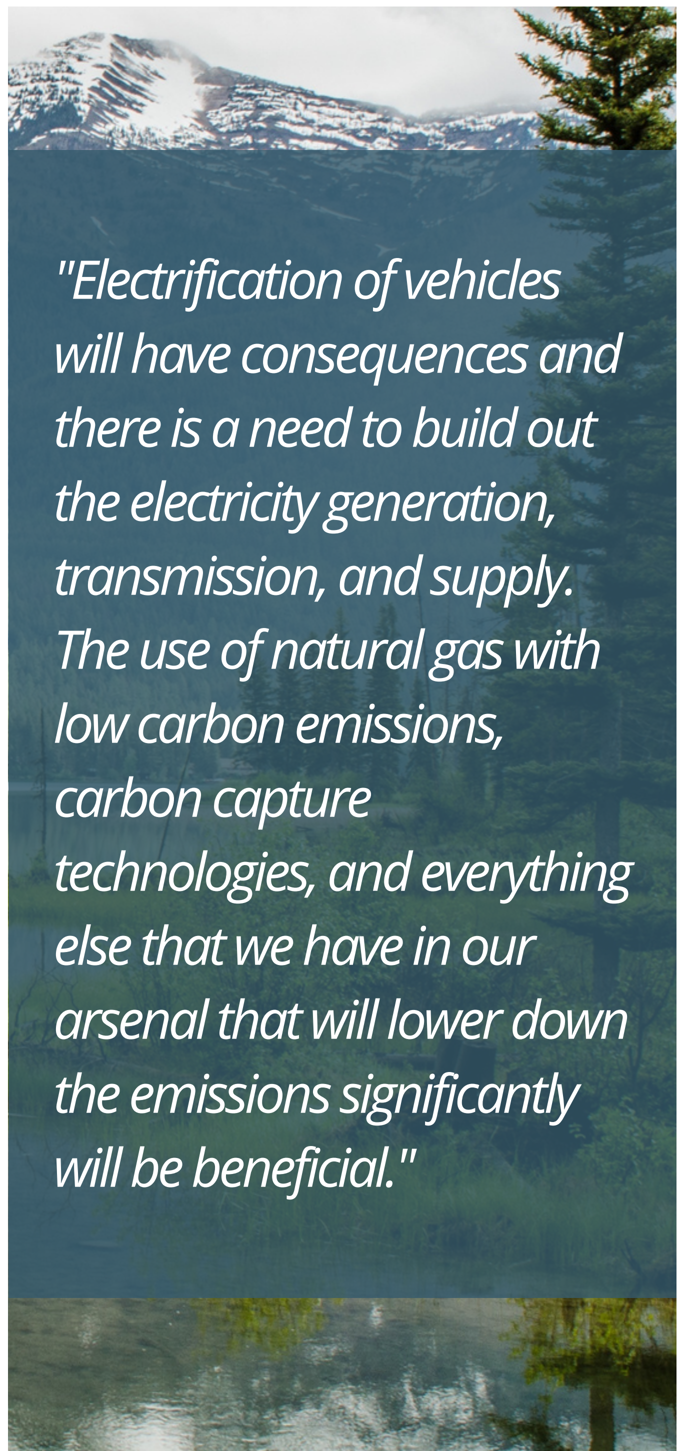
**E-fuel is one of the most promising paths to decarbonization.**

**The promises of e-fuels**

- The conversion of CO2 and hydrogen to SAF are relatively mature technologies.

- The cost of hydrogen is projected to decrease in the coming years.

- E-fuel and biofuel have comparable energy densities to petroleum and can “drop in” to existing infrastructure.



*"Electrification of vehicles will have consequences and there is a need to build out the electricity generation, transmission, and supply. The use of natural gas with low carbon emissions, carbon capture technologies, and everything else that we have in our arsenal that will lower down the emissions significantly will be beneficial."*

## E-fuel pathways

E-fuels are produced by taking green hydrogen/low carbon hydrogen from water or from low emission natural gas, together with captured CO2, and then subjected to chemical conversion processes (Fischer-Tropsh pathway and Alcohol-to-jet pathway). The end-product, synthetic drop-in jet fuels, can be used in the system jet engines today.

At present, small quantities are available but the cost is expected to decrease dramatically. There is also high scalability and they can decarbonize all ~200 billion gallons worth of jet fuel in 2050.

## E-fuels competitive landscape

A lot of different startups are working on syngas at present. One of them is SeeO2, but there are many different innovators such as Twelve, which is a new fuel company that has raised a large amount of money and is working on CO2 reduction single step.

On the Fischer Tropsch side, Shell and Sasol have the largest commercial-scale facilities today. They mostly use coal and natural gas products for FT synthesis. On the alcohol-to-jet side, Exxon Mobil is probably the most established player in that space.

There are a lot of opportunities for startups. Larger companies can help to bring the product across in the technology pathway, and multiple partnerships can help deliver synthetic fuel products.

## E-fuel cost breakdown

The cost of low-carbon hydrogen is expected to drop significantly with technology innovations and cheaper electricity, based on Third Derivative's modeling that is consistent with the reports of IRENA and RMI Green Hydrogen Catapult. In the base case, hydrogen is taken at US$2kg while CO2 at US$30/ton.

Aside from e-fuels, you will also generate diesel and naphtha as co-products which can reduce the jet fuel to about US$2.7/gallon The result is that only about 60 cents on the gallon in order to reach $3.50 or $3.40 per gallon of jet fuel Price drop in green hydrogen is needed for E-fuel for aviation to be in a really attractive price for airlines.

## Innovation opportunities

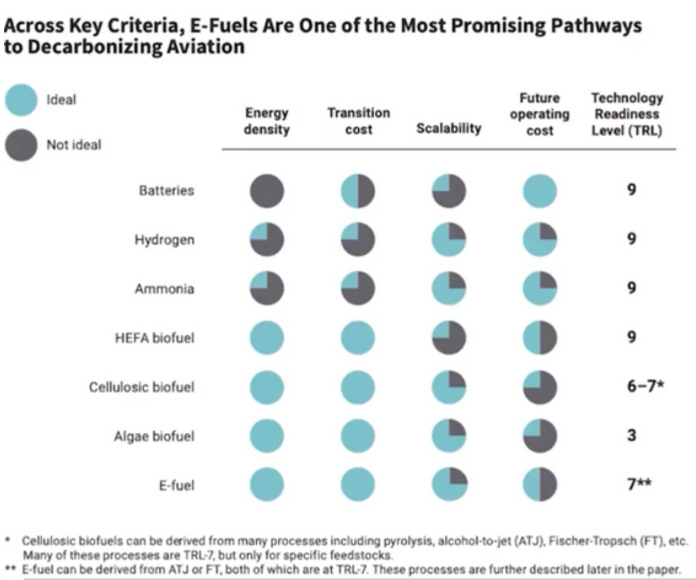
For biofuels, there's an opportunity for technologies that can create vegetable oil or methanol from methane, which reduces land use. Novel enzymes that avoid thermochemical pretreatment and reduce the cost of conversion is also being explored. Two startups are working on thermochemical or electrolytic co-reduction of water and CO2 to syngas e-fuel. There are also innovations in novel catalyst development using materials informatics and modularized Ft reactors that reduce loading. For biofuel and e-fuels, there are new innovations in novel techniques that reduce the energy requirement in ethanol distillation and new catalysts to upgrade to jet fuel.

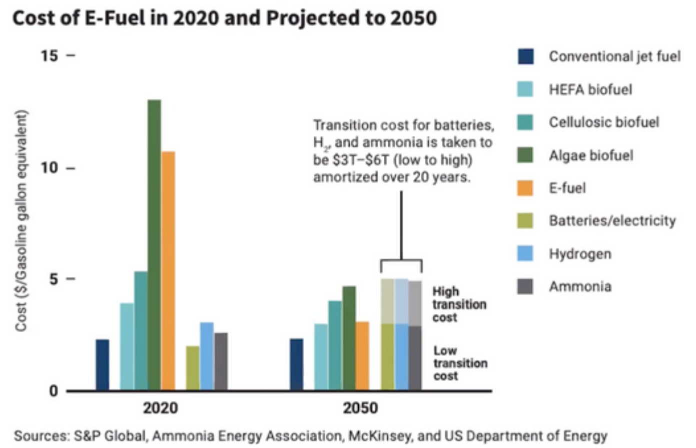
# Questions & Answers

***Will renewable energy be the bottleneck for Green Hydrogen?***

It is preferred to use the term "low carbon hydrogen" instead of purely green hydrogen. You can take natural gas that is responsibly sourced, with very little upstream, leakage, etc, and produce low or zero-carbon hydrogen. Green hydrogen is absolutely a challenge. The biggest obstacle in making the systematic fields of SAM outline but there also needs to be improvements in the process.

In terms of electrification of the energy grid, there are not a lot of tools in the toolbox that can replace the energy-dense fossil fuels that we have been using for a very long time. Electrification of vehicles will have consequences and there is a need to build out the electricity generation, transmission, and supply. The use of natural gas with low carbon emissions, carbon capture technologies, and everything else that we have in our arsenal that will lower the emissions significantly will be beneficial.




***What is the future of the cost of CO2 as an input into e-fuels?***

The cost for carbon capture is going to drop significantly in the future. At present, there are very pure sources of carbon coming from ethanol plants, methane steam reform, etc. Ethanol plants carbon stream is over 99% pure, thus, it is possible to capture ethanol plants' carbon and use that for other purposes. The ethanol plants in the US alone meet 15-20% of the US SAF requirements. It costs below US$30 per ton to capture from these ethanol plants. Aside from that, there are also technologies that reduce the cost of point source capture. There is a startup in our portfolio that uses compact membrane systems to attain US$30 per time capturing CO2 from power plants. There is enough blue gas out there to solve our SAF problems. Basically, direct capture of CO2 in the atmosphere is thermodynamically very energetic. You need a large amount of air to capture a small amount of CO2, compared to something like ethanol where it is almost entirely CO2 you are working with.

# Questions & Answers

***Is battery tech in aircraft destined to fail?***

It is meant to work for short-haul flights. It is good for helicopter replacement or car replacement. So there is a market for it and to gain profit from it. However, it does not make much sense to solve the climate problem by using small aircrafts. The amount of startups exploring the use of battery-powered airplanes is proportionate compared to those working on e-fuels, which have a larger climate impact opportunity. There is an undervalued opportunity on the e-fuel side.

***What is the future of less scalable solutions such as HEFA and Cellulose?***

We need to explore all the available solutions out there. For instance, there is a lot of waste biomass coming from agricultural waste and wood chips from pulp and paper mills, etc. and these must be transformed into high value products instead of just burning them in the field or burning them for power. However, the main challenge is collecting that biomass in an economical manner and placing them in a central processing facility. There is also a need for technical and logistical innovations to address the heterogeneity of biomass waste so they can be converted into economically usable energy. There are a number of decarbonizing alternatives for land transportation, but for aviation, the weight and volume of the aircraft becomes a large constraint. Thus, it is the most attractive and highest potential for these synthetic fuels.

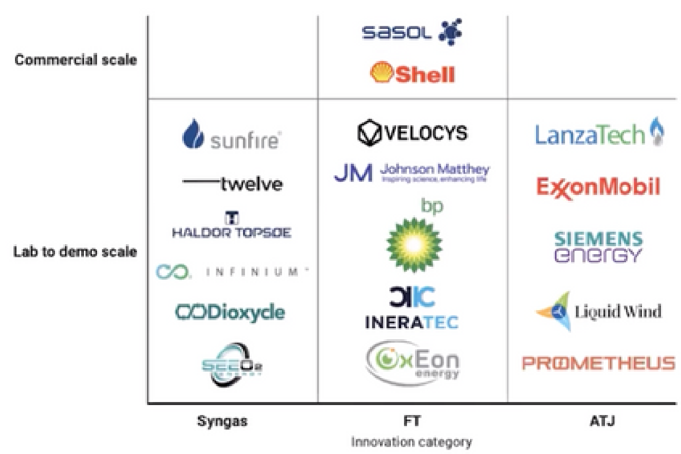
***Green, blue, and turquoise hydrogen***

Green hydrogen is basically taking water and electricity and deriving hydrogen from that. There are a lot of different innovations in green hydrogen. Currently, we have around 10 startups working on different green hydrogen innovations that are bringing down the capital costs while boosting the efficiency of those technologies.

Blue hydrogen is produced similar to conventional hydrogen generation where hydrogen is produced from natural gas through steam methane reforming but there is low carbohydrate which leads to the need for carbon capture technologies.

Turquoise hydrogen uses methane pyrolysis technique, which is basically breaking down methane into its components, so there are no CO2 emissions. Carbon capture technology is not needed. The natural gas used for blue and turquoise hydrogen production is low cost, so these have cheaper price points than green hydrogen. There is no need to worry about the classification of hydrogen in terms of their "color". It is better to identify them as low carbon hydrogen, measure their overall process emissions, and know their cost. Then, these can be deployed because the world has a great need for these low carbon hydrogen molecules.

**E-Fuels Competitive Landscape**



# Questions & Answers

***Is there a role for point-source in commercial aircraft?***

It is not a great value proposition. You would need extra fuel to transport these as well as the $CO_2$ that you captured, so there is a huge logistics challenge that also entails a lot of expense. It would be better to capture $CO_2$ from an ethanol or petrochemical plant because the dollar per ton of $CO_2$ captured would be a lot less than from a mobile source like that.

***What will drive SAF adoption in the next five years?***

It is expected that the Inflation Reduction Act will play a huge role. For instance, California has low fuel standards and they are providing very significant subsidies or price support to help reduce the price premium. Thus, it is conceivable that some of these projects that we were discussing could gain profit if they can get cheap enough electricity. It's a multi-stakeholder effort to catalyze this area.

***RMI's start-up involved in Syngas, Fischer Tropsch, ATJ***

Most of the startups are on the hydrogen side. To recap, syngas is a gaseous mixture of hydrogen and carbon monoxide. One of the startups working on this is SeeO2 and they are building a co-electrolyzer, which is a single electrolyzer device. An electrolyzer is an electric chemical device that runs the current through water then splits the water into its constituents. On the other hand, the co-electrolyzer is a single device that can take water ($H_2O$) and give hydrogen, as well as take $CO_2$ and then give CO. There are two sorts of feedstocks that get the syngas out.  Because of the simultaneous processes happening, there are economies of scale benefits and attractive outputs as well.

Another company working on syngas is OMC Hydrogen. Similarly, they are doing a one-step process to get syngas from water and $CO_2$ but instead of using an electrolyzer, they are using a thermal chemical process applying the metal oxide that they discovered. There are lesser innovations in the Fischer Tropsch but there are massive 20 billion dollar plants in that space already. There are some startups working on smaller sizes, easier to scale up, more efficient, and less expensive.