Synthetic fuel could be the answer to aviation’s net-zero goal

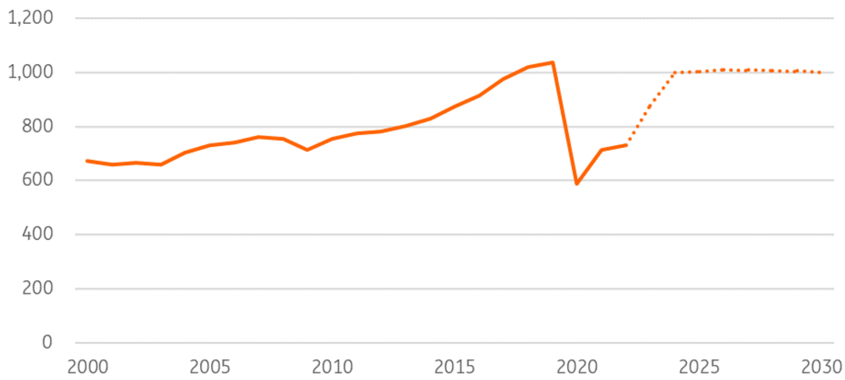
Synthetic fuels could be the technology fix that aviation needs. Their magic is the possibility of near zero-emission flights. Corporate decision-makers are investigating their potential, but uptake isn't happening as quickly as it could

Aviation: an important source of carbon emissions that is hard to abate

The aviation sector was responsible for more than 2% of global greenhouse gas (GHG) emissions in 2021 and these emissions are hard to reduce. Emissions dropped by 40% during the Covid-19 pandemic when planes were grounded but bounced back quickly again in 2022. And keeping planes on the ground is not a realistic scenario to reduce emissions. The consensus view is that the sector is expected to grow at a long-term average annual rate of 3-3.5% per year over the coming years, driven by a more affluent population, especially in Asia. This will push up carbon emissions, with aviation expected to account for more than 8% of global carbon emissions by 2040.

Emissions dropped during the pandemic but are expected to rise again

Global greenhouse gas emissions from aviation in megaton CO2 equivalents



Source: IEA, ING Research

The need for a technology and fuel fix

The aviation sector is one of the hardest-to-abate sectors, meaning that the emissions arising from the sector are either too costly or impossible to reduce with the currently available technology based on fossil fuels. Reducing demand for aviation would help the climate, but that's not the most likely pathway given the consensus view. Hence, a technology fix is needed to reach the net-zero target. Low-carbon technologies can either focus on the fuel (by blending polluting kerosene with cleaner fuels) or the aircraft itself (by implementing new engines that are more efficient or run on a cleaner fuel like green hydrogen).

In this article, we focus on the business case of synthetic aviation fuel as a technology fix for lifecycle carbon emissions. In this respect, we're working with the consensus view of expected demand against the backdrop of current policies.

Blending biofuels is the medium-term solution, but synthetic fuel holds more promise

Currently, conventional jet fuel is the benchmark fuel for planes, and it is made by refining crude oil. In its quest to reduce emissions, the sector currently pursues a combination of three strategies:

1. Renew the fleet by substituting old and inefficient aircraft with new generation aircraft that have better fuel efficiency performance.

2. Improve operational efficiency, for example, by optimising flight routes, reducing and electrifying taxiing, and improving the utilisation of aircraft (increased load factors).

3. Swap fossil fuels with Sustainable Aviation Fuel (SAF).

Fleet renewal and efficiency gains are important but are not expected to significantly reduce emissions given the strong increase in demand for flights. SAF is supposed to make the most difference in the medium to longer term, especially for long-haul flights where the potential for electric and hydrogen combustion is minimal.

Ways to green aviation: long haul flights can't do without SAFs

Main technology options towards net-zero aviation for different flight distances

	2025	2030	2035	2040	2045	2050
Regional & short haul < 1,500 km c.20% of industry CO_2	SAF	SAF	Electric or Hydrogen combustion and/or SAF	Electric or Hydrogen combustion and/or SAF	Electric or Hydrogen combustion and/or SAF	Electric or Hydrogen combustion and/or SAF
Medium haul 1,500-4,000 km c.30% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF potentially some hydrogen
Long haul > 4,000 km c.50% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF

Source: ING Research based on ATAG/EASA/Eurocontrol

As a result, SAF is a key building block of aviation's roadmap towards a net-zero economy and governments across the globe are setting targets. The US is the most ambitious with a 100% target for SAF by 2050. The EU and global aviation sector (via the International Air Transport Association) set a goal of just over 60% by 2050.

SAF can be divided into biogenic fuel and synthetic fuel.

Two forms of sustainable aviation fuel: biogenic and synthetic based

Main examples of SAF and the inputs from which they are produced

Biogenic SAF		
HEFA Hydroprocessed esters and fatty acids	Input • plant oils, algae (bio oils) • recycled fats, animal fats (tallow)
AtJ (Alcohol to jet fuel) Biomass to liquid (biochemical conversion: fermentation). Biomass - gas to liquid (thermochemical conversion: gasification)	Input • sugars from crops • agricultural and forestry residues • cellulose
Gas + FT (Gasification + Fischer Tropsch) Fisher Tropsch-process using biomass	Input • forestry residues • agri waste • household waste (MSW)
Synthetic SAF		
E-fuels/Power to jet Fischer Tropsch-process	Input • green hydrogen • carbon

Source: ING Research based on multiple sources

Biogenic fuel is made from plant oils, animal fats, and crops such as sugar or waste. Since plants absorb carbon, biomass is considered carbon neutral according to international standards. It is important to note that the plane continues to emit CO_2, but the lifecycle emissions of these fuels are lower compared to fossil-based jet fuel. Finally, biofuel can easily be used as it can be blended with traditional jet fuel.

Synthetic fuel is jet fuel that has many similarities with fossil-based jet fuel. From a chemical point of view, both fuels are hydrocarbons as their molecules entirely consist of carbon and hydrogen atoms. The big difference is that fossil-based jet fuel is made from oil, which is mined from the ground. Synthetic fuel on the other hand is made through a chemical process in a chemical plant, which (ideally) does not involve fossil fuels. Examples of synthetic fuels are green hydrogen and synthetic kerosene.

In this article, we examine the use case for synthetic fuel in aviation.

The magic of synthetic fuel in aviation

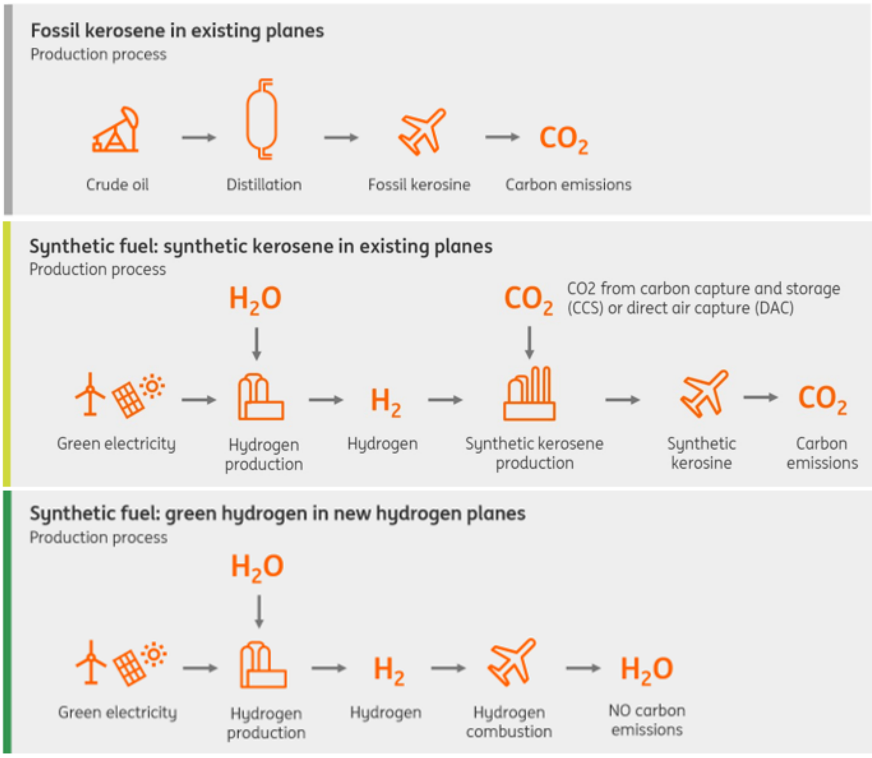
When traditional fossil-based jet kerosene is burnt in the aircraft engine, carbon atoms (C) react with the oxygen in the air (O_2) which delivers energy and creates CO_2. Hence, this option is often seen as the 'grey or dirty technology' that increases carbon emissions and contributes to global warming. The magic of synthetic fuel is that carbon emissions from planes can be drastically reduced when using a green source so they no longer cause carbon emissions to increase. There are two ways to do this, either by replacing the current fleet with hydrogen-propelled planes, or by substituting traditional jet fuel with synthetically-produced kerosene.

1. If green hydrogen is directly used in hydrogen planes, no CO_2 can be formed as the whole process is free of carbon atoms. In the hydrogen combustion engine, hydrogen (H_2) reacts with oxygen (O_2) and the engine simply emits water (H_2O). That's why we have illustrated this option in dark green in the visual below. Unfortunately, hydrogen-propelled aircraft are far from proven technology and are not likely to enter the market at a significant scale anytime soon. Airbus, for example, has the ambition to introduce the world's first zero-emission commercial hydrogen aircraft by 2035.
2. A more realistic option for the medium term is the use of synthetically-produced kerosene in existing planes, either by having them run fully on synthetic kerosine or on a blend with fossil kerosine. Synthetic kerosene is produced with hydrogen, preferably green hydrogen as green hydrogen does not produce carbon emissions. Hydrogen can react with carbon monoxide (CO) to form hydrocarbons that have the same characteristics as fossil-based hydrocarbons. In chemistry, this is known as the Fisher-Tropsch-process, which is a proven technology and can be applied on a large scale. The beauty of this process is that carbon monoxide (CO) can easily be made from carbon dioxide (CO_2), which is the root cause of global warming. Large amounts of CO_2 are potentially available from carbon capture and storage technologies (CCS). And in the future, CO_2 might also be taken from the air through direct air capture (DAC).

*Although we focus on CO_2 emissions and the direct impact from combustion, synthetic kerosene still emits nitrogen oxides (NOx) and water vapour in the air, just like current fossil-based jet fuel. This leads to 'radiative forcing' and contrails and has an additional climate impact which remains.

Fossil-based jet fuels cause CO2 emissions to rise, synthetic kerosine still emits CO2 but also uses CO2 and green hydrogen does not involve CO2 at all

Production process of fossil kerosene and synthetic fuel



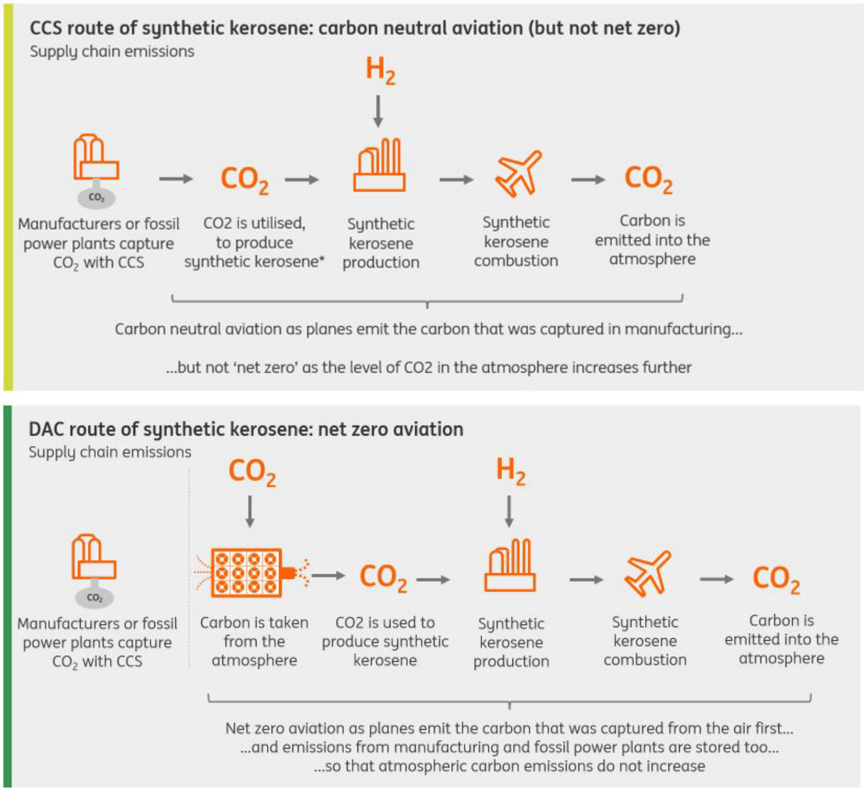
Source: ING Research

Synthetic kerosene can be carbon neutral and even near net zero

The advantage of synthetic kerosene is that it can be used in existing planes. We understand that it can be blended with current jet fuel. The current blend maximum is 50%, but it is expected that blends up to 100% will be certified in due course, so that planes can fully run on synthetic kerosene. And this is expected to be possible with relatively minor adjustments to the plane. While substituting a proven fuel in an existing engine always involves technicalities, the point is that no new engines or planes are needed for the use of synthetic fuel in aviation. And that's why they are so promising.

CCS route allows for carbon neutral aviation, DAC route for near net-zero aviation

Two major production processes of synthetic kerosene



Source: ING Research

The production of synthetic fuel requires a lot of CO2 and that can be sourced with carbon capture techniques such as CCS and DAC (in this article we leave aside biogenic ways to capture carbon).

1. CO2 can be sourced by applying carbon and capture storage techniques to industrial sites that emit a lot of carbon, for example in the steel, cement, and chemical industry. CCS is a proven technology that is expected to grow in the coming years. In that way, planes emit the carbon that is captured in other industries. We label that carbon neutral aviation as the carbon emissions are captured from other industries first. We would not call this net zero, as the carbon emissions in the supply chain (including the sector where the CO2 is captured) remain the same.
2. CO2 might in future also be sourced from the atmosphere through a technique called direct air capture. The promise of DAC is that it can make aviation (near) net zero as it takes out the CO2 from the air that is needed to produce synthetic jet fuel. The plane still emits carbon, but on a net basis, the whole process does not produce emissions (provided that the DAC installations run on green energy). So, while synthetic kerosene based on DAC holds great promise, it is important to realise that DAC is still in the prototype and pilot phase. Currently, only 18 plants are in operation worldwide, which capture an amount of CO2 that equals the emissions of just 870 cars.

To summarise: sourcing the CO2 for the production of synthetic kerosene by utilising industry point sources or power plants will eventually still lead to emissions after the combustion of the fuel by the plane. If the CO2 used is directly captured from the air, aviation will be (near) net zero. What then remains are the climate effects of NOx and water vapour.

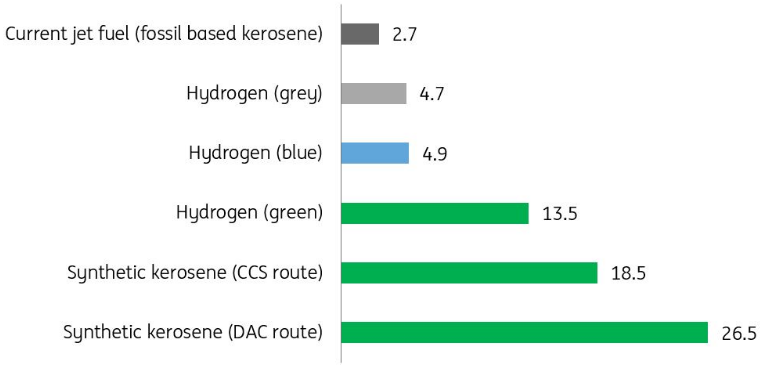
It's the economy stupid: synthetic kerosene currently is 7-10 times more expensive

So, it is clear by now that synthetic fuel can radically green the hard-to-abate aviation sector and put the sector on a pathway to net-zero emissions. The obvious question then is, why hasn't it happened already? Why aren't we using synthetic fuel in planes, in particular synthetic kerosene that can be used in existing planes? The answer is pretty simple. The technology is still in its infancy and the process is energy-intensive by itself, even with mature technology. So, from an economic point of view, synthetic kerosene is very expensive.

Green hydrogen, for example, is about five times more expensive than current jet fuel (kerosene) and requires large investments in new hydrogen-propelled aircraft. Synthetic kerosene can be used in existing aircraft, but it is about seven times more expensive via the CCS route (carbon-neutral aviation). The cost gap increases further for (near) net-zero aviation. Synthetic kerosene with the use of direct air capture (DAC route) is about 10 times the cost of traditional jet fuel.

Synthetic kerosene is currently the most expensive fuel option for aviation

Indicative unsubsidised cost of kerosene and synthetic fuel in euro cents per seat per kilometre



Source: ING Research based on energy prices from Refinitiv

*Fuel costs for a Boeing 787-10 Trent airplane with kerosene prices at 1.18 €/liter, gas prices at 55 €/MWh, power prices at 150 €/MWh and carbon prices at 90 €/ton carbon. Note that these prices for gas, power, coal and carbon represent current EU prices and also (roughly) anticipated prices for 2023 in forward markets (as of February 10th). Based on these input prices, hydrogen production production costs are around 2.75 €/kg for grey hydrogen, 2.90 €/kg for blue hydrogen and 8.00 for green hydrogen. Finally, we have assumed CCS cost at € 100/ton carbon and DAC cost at 500 €/ton, which is fairly common, although carbon removal technologies show extremely wide cost ranges depending on project specifics.

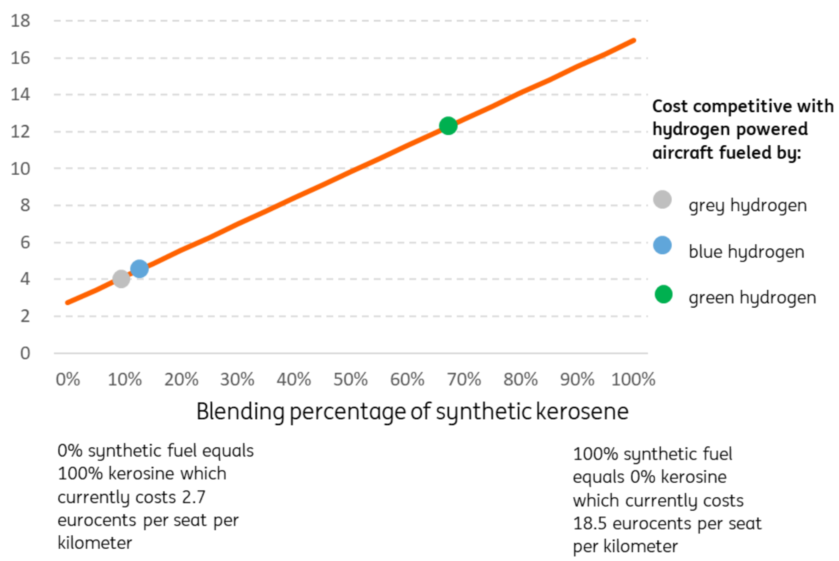
Blending synthetic kerosene with traditional jet fuel allows for incremental increases in fuel costs

Blending fossil kerosene with biogenic fuels is common practice in aviation and this can also be done with synthetic kerosene. Blending small fractions of synthetic kerosene with traditional kerosene helps limit the increase in fuel costs, while it reduces carbon emissions from aviation. It also helps to kick-start the production of synthetic kerosene as the industry simply cannot replace the vast amounts of fossil kerosene anytime soon.

Our analysis shows that blending rates of around 10% make the blend competitive with the fuel costs of grey hydrogen, while the blend can be used in existing planes and hydrogen only in yet-to-be-developed planes.

A blend of traditional jet fuel and 10-15% synthetic fuel is cost competitive with grey and blue hydrogen, cost competition with green hydrogen allows for 65-70% blending

Indicative unsubsidised fuel cost* per seat per kilometre for different blending rates



Source: ING Research based on energy prices from Refinitiv

*Note as in previous graph applies. Note that the graph shows the CCS route as CCS technology is much more mature compared to DAC technology

Blends of traditional kerosene with up to 15% synthetic kerosene can be cost-competitive with blue hydrogen. Such a blend would almost double the fuel costs in aviation (in our example from 2.7 cents per seat per kilometre to just under 5 cents).

Green hydrogen involves no emissions at all, but is still much more expensive to produce compared to grey and blue hydrogen and thus allows for much higher blending rates to be cost-competitive with synthetic kerosene (up to 70% in our example).

Synthetic kerosene could be 70% cheaper by 2050...

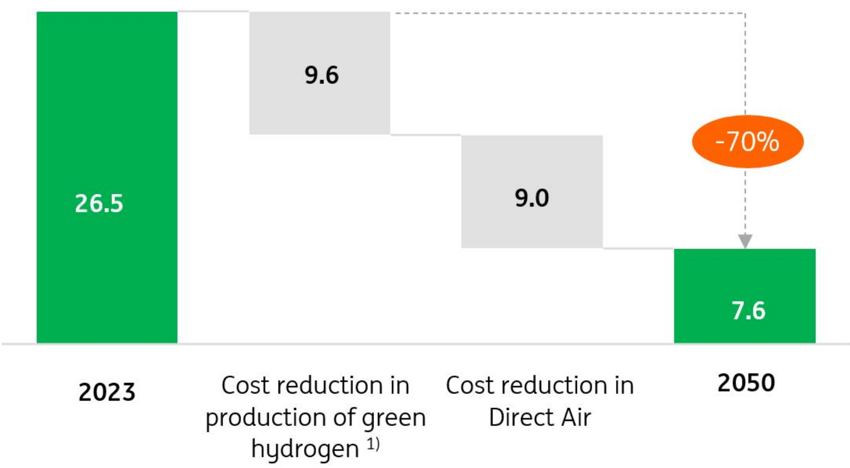
Unsurprisingly, synthetic fuel like green hydrogen and synthetic kerosene is relatively expensive. These new technologies are basically still in the piloting phase rather than the scale-up stage where most of the learning occurs and the technology gets cheaper quickly.

We expect the cost of green hydrogen to come down from €8/kg currently to about €3/kg by 2050 (a 60% cost reduction in real values), which implies fuel costs of around €5 per seat per kilometre. Most of the decline is driven by cheaper power prices and to a lesser extent by lower investment costs and efficiency gains for electrolysers.

Synthetic kerosene could become 70% cheaper by 2050, driven by cost declines of green hydrogen and direct air capture. Still, fuel costs are expected to remain considerable (around €7.6 per seat per kilometre or almost three times the current cost of fossil kerosene).

Synthetic kerosene could be up to 70% cheaper by 2050

Development of indicative unsubsidised cost of 100% synthetic kerosene (DAC route*) in € per seat per kilometre



Source: ING Research

1) Reduction in production cost of green hydrogen from about 8 €/kg today in Europe to about 3 €/kg by 2050 (real values) 2) Reduction in the cost of Direct Air Capture (DAC) from about 500 €/ton carbon today to about 50 €/ton carbon by 2050 (real values). Note that technology induced cost declines are expected to be much bigger for DAC compared to CCS as CCS is already quite a mature technology

...but still won't fly without policy support

It is hard to tell how these anticipated costs of green hydrogen and synthetic kerosene compare to the cost of traditional jet fuel by 2050 or, most likely, a blend of traditional jet fuel with biofuel.

The most uncertain factor is the oil price in a net-zero economy. Will oil-producing countries flood the market with oil as soon as global oil demand drops rapidly? In such a scenario, the production of fossil-based jet fuel remains extremely cheap. Or will a drop in global oil demand cause large geopolitical frictions which might push oil prices higher for a prolonged period? Such a scenario might reduce the price gap between traditional jet fuel and synthetic kerosene in the future.

In any case, our analysis clearly shows that polluting jet fuel is very cheap and that the green alternatives are expensive. This leaves room for policymakers to intervene by taxing dirty technology or subsidising clean technologies. Without such policies, the use of synthetic fuel is unlikely to take off in aviation making it impossible for the sector to reach net zero by 2050.

In the meantime, airlines are likely to experiment with synthetic fuel on three levels:

1. Strategy departments are incorporating synthetic fuel in the company's pathways towards net-zero emissions. The availability of biogenic fuel might be limited in the future and the company can reduce emissions further with synthetic fuel.
2. Airlines are likely to form joint ventures with market leaders in the chemicals industry to develop synthetic fuel.
3. Airlines are likely to closely work with their large clients as some are pushing for synthetic fuel in their quest to lower their scope 3 emissions from business flights.

In doing so, airlines will stand ready when the business case becomes more viable.

For more on this topic, read here about the eight lessons to get it right in fuelling a net-zero economy with synthetic fuels.

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