High in the Sky with Low CI Hydrogen

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Synthetic paraffinic kerosene made from residues with solar power enables carbon-neutral flight.

Renewable fuels are gaining importance as an alternative source of liquid fuel due their renewability, chemical properties, and lower lifecycle emissions. The aviation industry's global greenhouse gas (GHG) emissions are 2.1% of the global share, and when non-carbon dioxide (CO_2) effects are included, it contributes approximately 4.9% to global warming (CAN, 2020). The international airline industry is committed to climate change goals which includes carbon neutral growth and cutting CO_2 emissions in half by 2050. Synthetic aviation fuels (SAF) are critical to achieve these targets. Hydrogen plays a role in the production of all aviation fuels and low carbon hydrogen can help expand SAF production.

Hydrogen and Jet Pathways
Six categories if SAF are approved as annexes to ASTM D7566. Four pathways with broad applicability are summarized below.

Annex A1 (Fischer-Tropsch FT-SPK is a mixture of iso- and n-alkanes derived from synthesis gas using the FT process. Syngas can be produced from reforming natural gas or from gasifying coal or biomass or the conversion of CO2 to CO with hydrogen. Synthetic fuel is a liquid fuel obtained from syngas, a blend of carbon monoxide (CO) and hydrogen, or carbon dioxide and hydrogen. Syngas is derived from gasification of solid feedstocks like coal or biomass, or by reforming natural gas. Carbon dioxide and green hydrogen are inputs to produce a carbon neutral synthetic fuel. Methods to refine synthetic fuels include Fischer-Tropsch conversion, pyrolysis, and hydrotreating of oils. Fischer Tropsch synthesis and power to fuel pathways involve the reaction of hydrogen with carbon monoxide to make fuel in the case of e-fuels all of the energy is derived from hydrogen. Hydrogen represents about 5% of the energy input for conventional FT and the hydrogen may be produced from the biomass syngas. The addition of supplemental hydrogen allows for the boosting of hydrogen fuel output.

Most synthetic fuels are created by mixing CO and hydrogen (syngas) and are produced through burning biomass and natural gas. Fischer-Tropsch (FT) synthesis is used to convert syngas into liquid hydrocarbon fuel. Fischer-Tropsch certified synthetic fuels are approved as 'drop-in' fuel, where the highest blend is a 50/50 blend of FT synthetic fuel and petroleum fuel.

Annex A2 (HEFA-SPK) consists of iso- and n-alkanes. The alkanes are the product of hydrotreating esters and fatty acids from fats, oils, and greases and from oilseed crops or algae. Most SAF produced today is derived from hydrotreating of oils and fats.

Annex A3 (SIP, hydroprocessed fermented sugar-synthetic iso-paraffins) is a single molecule, a 15-carbon hydrotreated sesquiterpene called farnesane, produced from fermentation of sugars such as sugarcane or corn dextrose. Sugar-based pathways will require somewhat larger amounts of hydrogen compared to HEFA due to the overall stoichiometry of the reaction

Annex A5 (alcohol-to-jet [ATJ]-SPK) is produced from ethanol or butanol. ATJ-SPK consists of iso-alkanes of 8, 12, or 16 carbons when starting from iso-butanol.

Hydrogen Boost

Various technologies use supplemental hydrogen sources as energy inputs and many such configurations are found in literature (Hillestad, 2018). The source of hydrogen affects the life cycle GHG emission and also improves renewable fuel production yield. Figure 1 shows a FT process that converts biomass to cellulosic biofuel using renewable hydrogen as an energy carrier. Biomass is converted to carbon monoxide, carbon dioxide, and hydrogen through gasification and gas conditioning. The same process configuration is adaptable to landfill gas feedstock. Carbon monoxide and hydrogen undergo FT synthesis upgrading, resulting in water as a byproduct. This water is sent through a solar powered electrolyzer to produce hydrogen. The hydrogen is then used in FT synthesis upgrading to produce low carbon cellulosic jet fuel via reaction with CO produced from gasification. With hydrogen production powered by wind and solar energy, lifecycle GHG emissions are over 90% lower than conventional fuels. Renewable hydrogen allows for the utilization of all of the carbon in the biomass. The Fischer-Tropsch process has been in use for over 60 years and has been approved as part of other RFS pathways.

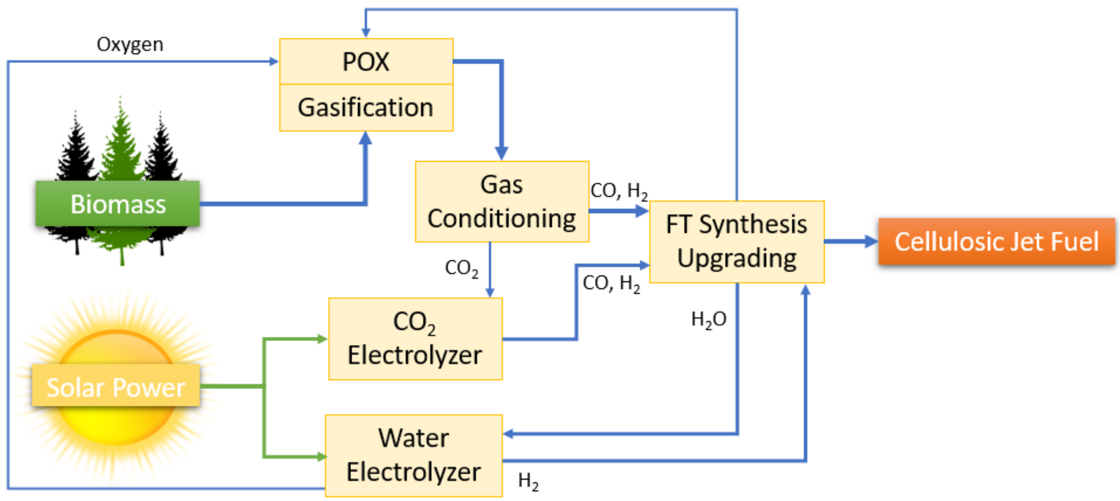

Figure 1. Renewable jet fuel production process from biomass and solar power. Blue lines indicate feedstock material flows while green lines indicate energy flows.

Policy Drivers

Numerous policy drivers provide an incentive for the use of low carbon hydrogen at both federal and state levels. Sources of low carbon hydrogen include electrolysis with renewable power or reforming of methane with low carbon sources of biogas as well as numerous other production methods. The role of low carbon hydrogen is either is enabled directly through the policy or helps with additional fuel volume and credit generation. The requirements for leading policies are briefly summarized.

EPA RFS - Renewable Fuel Standard

RFS requires renewable fuel production with categories for biomass to aviation fuel via Fischer Tropsch or pyrolysis for cellulosic fuels and hydrotreating of oils and fats for advanced biofuel. Ongoing evaluations will determine the role of hydrogen for new fuel pathways. (EPA, 2010; EPA, 2021). EPA is examining the effect of bonding carbon atoms obtained from biogenic carbon dioxide with hydrogen atoms obtained from fossil fuels. The RFS regulations at 40 CFR 80.1426(f)(4) determine the number of gallon-RINs generated for fuel that is produced by co-processing renewable biomass and non-renewable feedstocks simultaneously to produce a fuel. A concern for technologies using hydrogen power to convert biomass to biofuel is that the hydrogen used in processing would be considered a feedstock instead of an energy carrier. The distinction between a feedstock and an energy carrier is important; since hydrogen is not derived from biomass, it would not meet the requirements of a renewable feedstock under the RFS. If hydrogen were considered a feedstock, the resulting fuel would not be assigned the full value of its energy content under the RFS2. According to the regulation, RINs are assigned to the percentage of fuel that is derived from a renewable feedstock.

LCFS - Low Carbon Fuel Standards in California Oregon Washington and other states

LCFS regulations require the production of low carbon fuels with more credits generated for lower carbon intensity fuels. The use of supplemental low CI hydrogen would both increase fuel output and lower the carbon intensity of fuels.

CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation

Airlines have committed to a 10% reduction in the carbon intensity of aviation fuels with an incentive to produce more SAF at a lower carbon intensity. CORSIA was approved in June 2018 that the international aviation sector is expected to collectively reduce its annual emissions by approximately 2,000 million tonnes of CO2 in 2050. The International Civil Aviation Organization (ICAO) anticipates in the early stages of CORSIA emission reduction goals will be met through carbon offsetting as the advanced alternative jet fuel industry develops. In later stages, emission reduction goals are expected to be met with alternative jet fuels and improved aircraft efficiency. By avoiding use of offsets, airline and environmental groups comply with

IRA - Inflation Reduction Act

Inflation reduction act provides for a producer tax credit for low carbon intensity hydrogen with the lowest threshold value at 0.45 kg CO_2e/kg hydrogen. Investment tax credits are also available for low carbon fuel production systems. The GREET model from Argonne National

Laboratory is required to assess the greenhouse gas (GHG) emissions from hydrogen production.

Low carbon hydrogen plays a critical role in aviation and the combination of policies leads further supports the role of low carbon hydrogen.

Emission Impacts

Various fuel pathways result in significant GHG reductions compared to petroleum jet as shown in Figure 2. Hydrogen is an integral part of all of the fuel production route. Boosting fuel output with FT fuels will reduce the carbon intensity (CI) but the more profound effect is the production of more fuel. E-fuels are an extreme example where all of the energy is derived from hydrogen. The CI values shown below are from the GREET model and the hydrogen boost cases represent the elimination of grid power and increase in yield from conventional FT pathways.

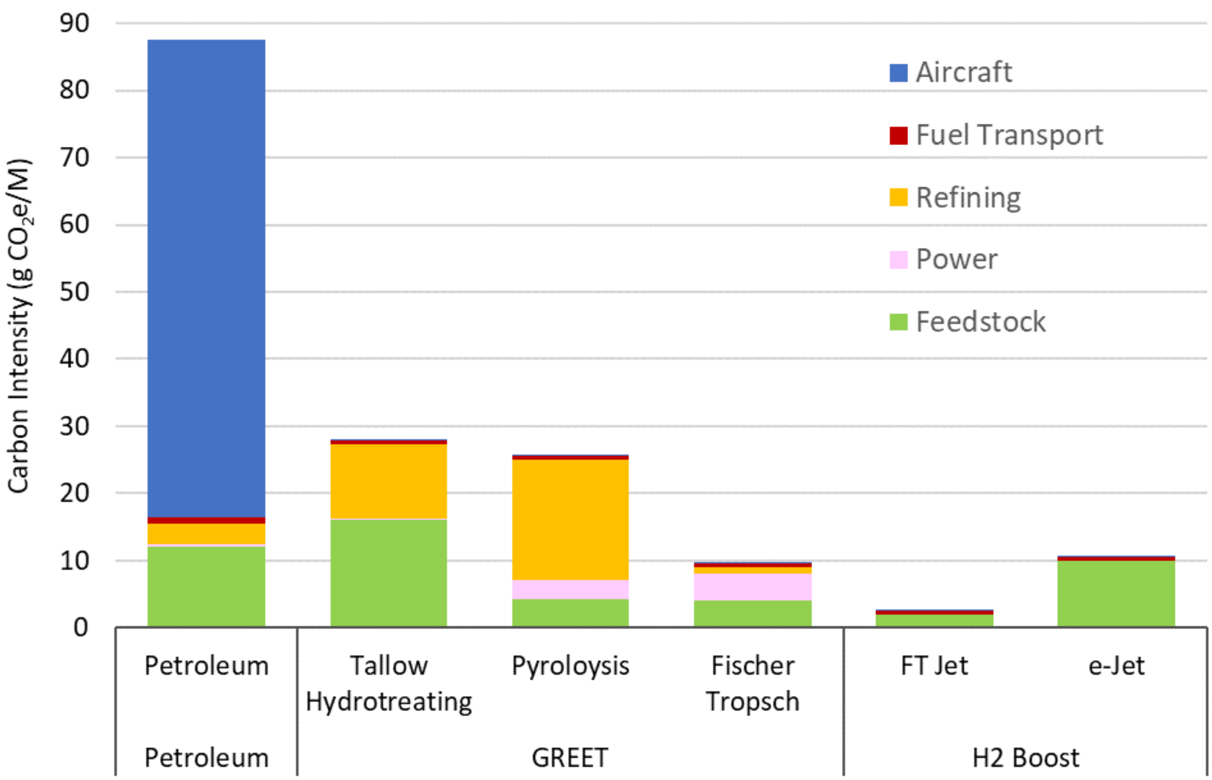

Figure 2. Renewable hydrogen lowers the GHG intensity of all jet fuel pathways.

The benefit of renewable hydrogen is reflected in the fraction of hydrogen that contributes to the total fuel product. In the case of hydrogen boosted fuels over 50% of the fuel energy is derived from hydrogen.

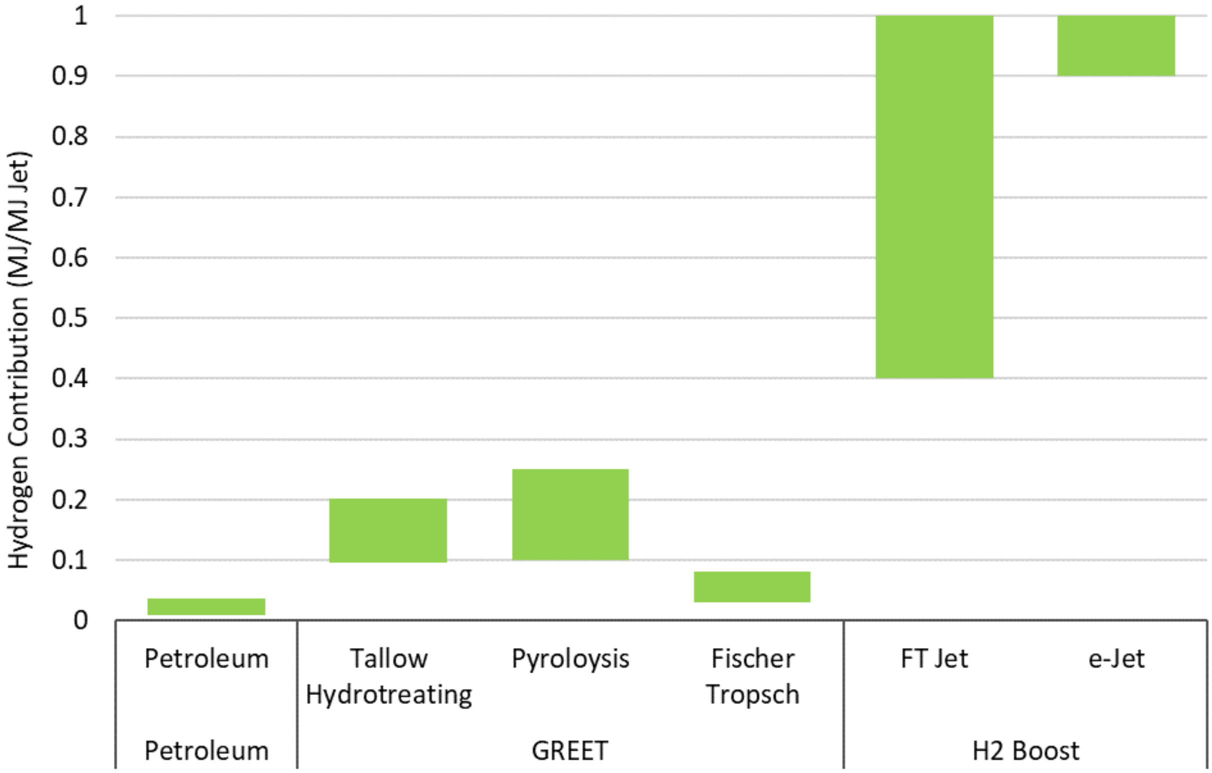

Figure 3. Renewable hydrogen can contribute to more jet fuel production by doubling the FT fuel output with full scale hydrogen boost. In the case of e-fuels, all of the energy is derived from hydrogen.

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