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COME CLEAN, PART 6 - WHY SUSTAINABLE AVIATION FUEL IS TAKING FLIGHT

August 10, 2021

Traveled by air in the U.S. lately? Airports and airplanes are packed to the gills. Unruly passengers are making the nightly news and becoming YouTube sensations. Jet fuel shortages are popping up. But there are other developments in air travel too, including a push by the global airline industry to rein in its greenhouse gas emissions. And the heart of that movement is sustainable aviation fuel, or SAF. While the blending of SAF with conventional jet fuel is not mandated in the U.S., the alternative fuel is gaining altitude, in part because it can generate layers of credits that can be utilized in various renewable fuel trading programs. In today's blog, we look at the current status of renewable fuel in the U.S. aviation sector.

In this blog series, we are reviewing laws and regulations aimed at reducing carbon-dioxide and other greenhouse gas (GHG) emissions from the transportation sector in the U.S. and Canada. Low carbon fuel standards (LCFSs) have been adopted in a number of jurisdictions to help meet increasingly stringent GHG-related goals, which are likely to have sizable impacts on refined products markets. In Part 1 of this series, we provided an overview of various policies that have been adopted and are being discussed to reduce GHG emissions from transportation fuel use. We noted several approaches being taken, all of which measure performance based on carbon intensity (CI), an account of lifecycle GHG emissions associated with producing, refining, distributing, and consuming a fuel, typically measured in grams of carbon dioxide equivalent per megajoule (gCO_2e/MJ). In Part 2, we focused on California's LCFS, which was first implemented in January 2011 and subsequently enhanced. California's LCFS sets CI limits on finished gasoline and diesel fuel consumed in the state each year on a gradually declining scale to meet the 2030 goal of a 20% reduction in the carbon intensity of motor fuels consumed there. In Part 3, we zeroed in on motor gasoline and how ethanol has come to play a major role in increasing the use of renewables. In Part 4 and Part 5, we discussed diesel, and how biodiesel and renewable diesel, respectively, have come to play major roles in increasing the use of renewables. Today, we turn our attention to sustainable aviation fuel (SAF) and discuss the regulations, production, and increasing role of SAF in decarbonization efforts.

In the U.S., jet fuel is the third most consumed transportation fuel, accounting for about 12% of all transportation fuel sold in 2019 — the last "normal" year for air travel — before dropping to about 8% in COVID-impacted 2020 and rebounding to 9% in the first five months of 2021, according to the Energy Information Administration (dashed red line and right axis in **Figure 1**). After many years of development, aviation turbine engines have proven to be reliable and efficient, with a very high power-to-weight ratio. The high energy density of liquid jet fuel enables modern aircraft to fly long distances without the need to refuel. Therefore, use of SAF in existing aircraft engines is currently viewed by many to be the most viable option to achieve GHG reductions in the aviation sector.

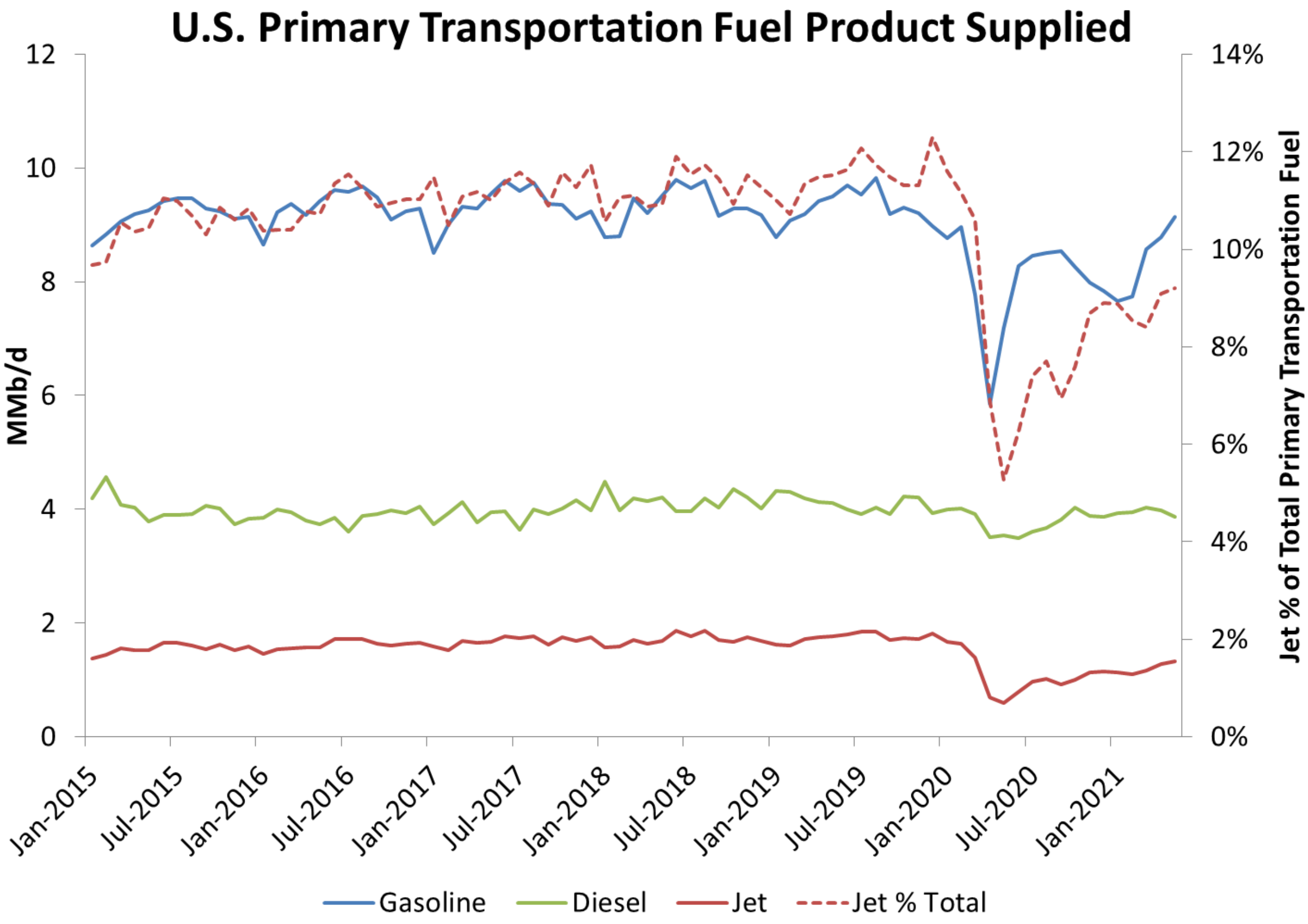
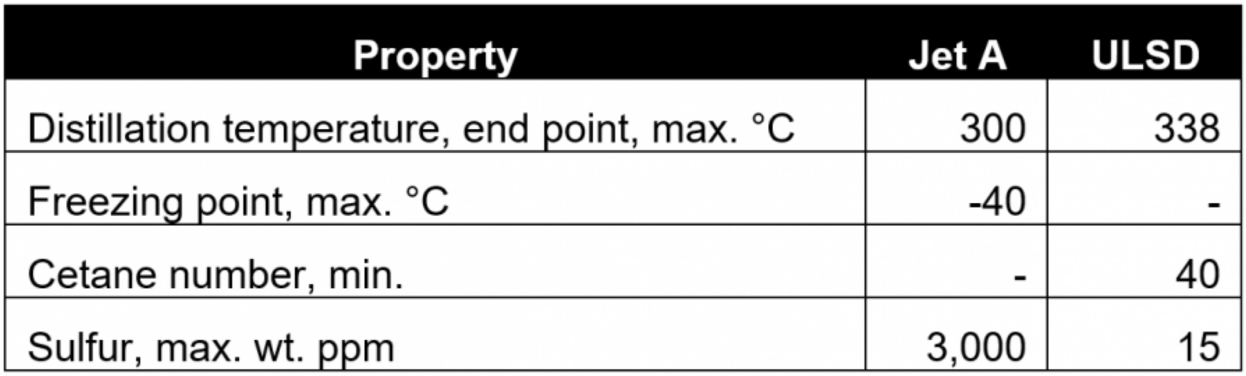


Figure 1. U.S. Primary Transportation Fuel Product Supplied by Fuel Type. Sources: EIA, Baker & O'Brien

Fuel Properties, Specifications, and Certification

Conventional jet fuel has a composition similar to diesel and there is considerable overlap in some of their properties. Likewise, SAF manufactured from renewable feedstock is in many ways similar to renewable diesel (RD). In a typical petroleum refinery, conventional jet fuel and diesel are processed in similar processing units, with catalysts and operating conditions adjusted somewhat to effect modestly different product specifications. A key resulting difference is that jet fuel is "lighter" than diesel — both in density and distillation range. Diesel specifications allow longer-chain hydrocarbons than do jet fuel specifications, resulting in a higher distillation end point (the boiling temperature correlating to the heaviest components in the fuel). Other key differences between jet fuel and diesel include sulfur content, cetane number (an octane-like measure), and cold-flow properties like freeze point. See **Figure 2** below for a comparison of select quality differences between diesel and jet fuel.



Property	Jet A	ULSD
Distillation temperature, end point, max. °C	300	338
Freezing point, max. °C	-40	-
Cetane number, min.	-	40
Sulfur, max. wt. ppm	3,000	15

Figure 2. Jet Fuel and Diesel Specifications. Sources: ASTM, EPA

Why are there differences between jet and diesel fuel specifications? The last time you were on a flight, you may have seen the in-flight entertainment system indicate just how incredibly cold it can get at high altitude. At 35,000 feet, the air temperature is well below zero degrees Fahrenheit. (Who wants to worry about a frozen fuel line when you are halfway across the Pacific?) The cold flow properties of jet fuel are a very important safety consideration. No biodiesel components, i.e., fatty acid methyl esters (FAME), or other oxygenated oils, can be blended into jet fuel. Why? As we discussed in Part 5, the oxygenated components in biodiesel mean bad news for the cold-flow performance properties required of jet fuel.

Nearly all commercial aircraft and airport fueling infrastructure built to date has been designed based on the supply of (fossil-based) jet fuels compliant with conventional jet fuel specifications defined and published in the ASTM D1655 standard: Standard Specification for Aviation Turbine Fuels (see **Figure 3**.) To avoid the need for separate fueling infrastructure (remember "water-loving" ethanol from Part 3?) or new turbine engines, it is vital that SAF be fully compatible with existing aircraft, i.e., it must be a true "drop-in" fuel, essentially indistinguishable from the fossil-based conventional jet fuel used today. In fact, all types of SAF permitted for commercial use to date have been tested and approved by an industry consortium of turbine engine and airframe original equipment manufacturers (OEMs). Although this "fit-for-purpose" testing can cost millions of dollars and take years to complete, we can all sleep better on those long flights knowing it is a rigorous and thorough process.

Once approved, the specification requirements for all new types of SAF are incorporated into an annex of the ASTM D7566 standard: Standard Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons. Importantly, D7566 specifies the maximum blend rate at which each type of SAF can be used. Currently, no types of SAF can be commercially used at blending rates higher than 50%, and some have limits as low as 10%.

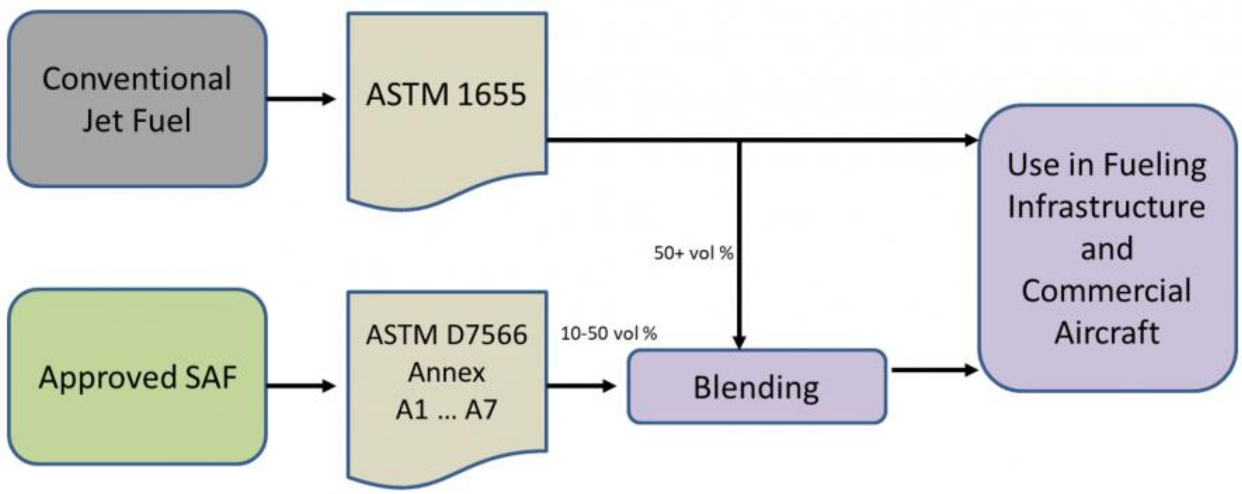


Figure 3. ASTM SAF and Conventional Jet Fuel Requirements. Source: ASTM

SAF Production Processes

Several technologies exist to produce RD — and SAF — but a general design typically reacts a renewable feedstock (such as vegetable oil) with hydrogen (H_2) at high pressure over a reactor filled with catalyst (blue step in **Figure 4** flow diagram). After the reactor, the liquid hydrocarbons are separated (from unreacted hydrogen and water; gray step) and then fed into a lower-pressure fractionation system (orange step) and distilled into refinery intermediates.

This basic design can be modified to maximize production of SAF. One way this can be accomplished is by incorporating a "dewaxing" catalyst to satisfy the cold-flow properties required for jet fuel. However, dewaxing tends to lower the cetane number of the fuel, which could be a bit of a headwind for a renewable fuel manufacturer seeking optionality to sell either RD or SAF (or both), depending on market conditions.

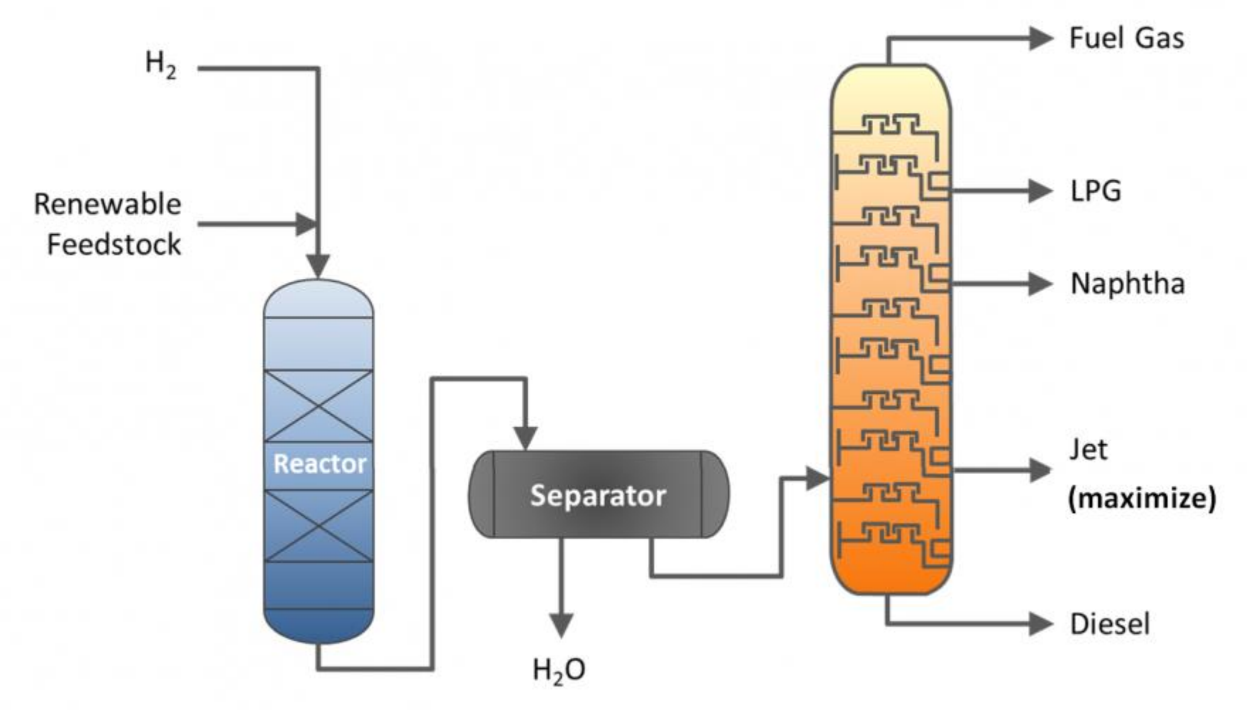


Figure 4. RD/SAF Manufacturing Process Utilizing Hydrotreating Technology. Source: Baker & O'Brien

Additionally, the catalyst formulation used can be adjusted to "hydrocrack" the heavier, diesel hydrocarbons in an effort to boost the yield of jet fuel. However, as the verb suggests, this involves "cracking" open the larger diesel molecules into smaller molecules. So, in addition to producing jet fuel, this also yields less valuable co-products like fuel gas, LPG, and naphtha, and therefore less revenue is earned. From what we have discussed so far, RD would appear to have an edge over SAF on profitability because it generally requires less hydrocracking and dewaxing during processing, allowing for a higher yield of the desired fuel product. Note that historically, before COVID, conventional jet fuel prices often demanded a premium over ultra-low sulfur diesel (ULSD), depending on the specific market.

SAF Policies and Manufacturer Incentives

In Part 1, we discussed various policies aimed at reducing the CI of transportation fuels. Some policies include jet fuel, while others do not. Consider California's LCFS program, for example. Currently, jet fuel is exempt from the program, and the production of conventional jet fuel does not generate deficits for refiners. However, production of SAF can generate credits under California's LCFS program and thereby offset deficits generated from conventional gasoline and diesel production. Similarly, while renewable blending is not required for jet fuel under the U.S. Renewable Fuel Standard (RFS), it does generate RINs (Renewable Identification Numbers) when blended, which can then be sold to "obligated parties" under the RFS program.

There are certain voluntary programs that we should note, such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA was developed by the International Civil Aviation Organization (ICAO), an agency of the United Nations, and the program is currently in a voluntary, pilot phase with an aspirational goal of achieving carbon-neutral growth from 2020

onwards. Although CORSIA is voluntary, there is a credit trading scheme currently in place for SAF. That means, if you're utilizing SAF (in California, for example), there is a potential opportunity to layer on credit opportunities under the U.S. RFS, the California LCFS, and CORSIA.

Given that many policies in support of SAF use are currently voluntary, and the technologies and pathways to its production are still evolving, commercial volumes of SAF are miniscule today. The Environmental Protection Agency (EPA) reported that just over 2.4 million gallons of neat (100%) SAF were produced in the U.S. in 2019 (the latest numbers available). Compared to the 21.5 billion gallons of conventional jet fuel produced the same year, SAF accounted for a paltry 0.01% of the total. The disproportionately negative impact on jet fuel demand from COVID certainly hasn't helped. However, given the compositional similarities between RD and SAF, if we assume that at least half of all RD produced in 2019 (or approximately 500 million gallons) had instead been produced and sold to SAF specifications, it would have represented just over 2% of U.S. jet fuel supply that year.

Looking ahead (as noted in Part 5), projections for RD capacity in 2025 are approaching 500 Mb/d (7.7 billion gallons per year). If we assume that at least half of this could instead be produced and sold to SAF specifications, it would represent over 17% of 2019's U.S. jet fuel supply. Considering the "headwinds" faced by SAF relative to RD — regulatory hurdles, narrower specifications, and fewer economic incentives — SAF will likely require more demand "pull" and/or economic incentives to encourage increased SAF production in the coming years. However, given the relatively smaller market for jet fuel relative to diesel, the projected capacities for renewable distillate production could offer volumes that would make up a fairly substantial fraction of future jet fuel consumption.

In the next blog in this series, we'll look at hydrogen as a potential transportation fuel under the various LCFS programs.

Note: The article was authored by Aaron Imrie of Baker & O'Brien and published on RBN Energy's Daily Energy Post on August 10, 2021.

"Come Clean" was written by Kara DioGuardi and John Shanks and in January 2004 was the second single released from Hilary Duff's second studio album, Metamorphosis. Produced by John Shanks, the song peaked at #35 on the Billboard Hot 100 Singles chart in the U.S., but broke into the Top 20 in the UK and Australia.