Flight path to alternative fuel

With some 250M gallons/year of offtake agreements for sustainable jet fuel supply, the fossil fuel alternative is no longer a concept but a pending commercial reality. *Serena Lim*

Sustainable jet fuel from a broad range of feedstocks and technologies is being commercially developed now with some 250M gallons/year of offtake agreements already in place, according to Steve Csonka, executive director of the Commercial Aviation Alternative Fuels Initiative (CAAFI), a North American public private partnership, working on behalf of the aviation industry.

Csonka says common misconceptions about sustainable jet fuel are that they are a decade away from reality, that they are unproven, unsafe or inferior, have burdensome infrastructure/handling needs, or that the low price of crude oil had stopped all development efforts.

In fact, sustainable jet fuels are a key component in meeting the aviation industry's commitments to decouple increases in carbon emissions from traffic growth. "Airlines will take all the sustainable jet fuel they can get but at parity pricing," says Csonka.

Worldwide air traffic is expected to grow by 5%/year, he adds. "In the USA, 25bn gallons/year of jet fuel are consumed. Worldwide, the figure is 87bn gallons/year." This equates to a third of the diesel used globally, or 264M tonnes of hydrocarbon output or 1.6M barrels/day of production.

"Aviation takes its environmental responsibility seriously," Csonka says, and has made progress in noise reduction and tackling pollutants from planes. "While achieving carbon neutral growth from 2020 seems feasible based on our progress, achieving 50% fewer carbon emissions by 2050 remains a huge task" given that a 460% increase in emissions is projected by 2050 if no action is taken, or 300% increase if 1.5% of annual fuel efficiency improvements continue to be introduced.

Emissions targets

Globally, there are various targets for emissions reduction and alternative fuel use in aviation. The International Air Transport Association has set ambitious targets to curb fuel consumption and mitigate emissions, in which the aviation industry has committed to an average improvement in fuel efficiency of 1.5%/year from 2010 to 2020 and a cap on aviation CO_2 emissions from 2020. By 2050, the goal is to reduce CO_2 emissions from aviation by 50%, relative to 2005 levels.

In 2016, the UN's International Civil Aviation Organization (ICAO) also agreed on a Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to reduce CO_2 emissions from international aviation with a pilot phase from 2021-2023, followed by a first phase from 2024-2026.

Participation in both of these stages will be voluntary and the next phase from 2027-2035 would see all states on board, with the exception of small developing countries or those with very low levels of international aviation activity.

Alternative fuel criteria

Alternative fuels in aviation must meet several criteria in order to be viable, according to the US Federal Aviation Administration (FAA). Their properties have to be within acceptable limits in terms of viscosity, freeze point and fluid flow at low temperatures. They must allow for engine re-light at altitude, and their compounds should not adversely impact flame stability. Compared with fossil-derived jet fuel, their energy content should be as high or higher, and their greenhouse gas (GHG) emissions lower.

Csonka says fats, oil and greases are very close in composition to aviation fuel and the conversion of tallow or used cooking oil (UCO) to Hydroprocessed Esters and Fatty Acids (HEFA) had been shown to achieve a 65% and 78% reduction in GHG emissions respectively. They feature in several of the sustainable jet fuel processes already approved or currently under review by the aviation ▶

SOURCE: CAAFI

Figure 1: Sustainable alternative jet fuel offtake agreements

industry. There are currently five approved pathways pathways to produce drop-in fuel blending components for aviation, specified by global standards body ASTM in the ASTM D7566-18 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. The five pathways are:

The **Fischer Tropsch Synthetic Paraffinic Kerosene (FT-SPK)** process converts coal, natural gas or biomass into liquid hydrocarbons through a first gasification step, followed by Fischer Tropsch synthesis. It requires blending with jet fuel at levels up to 50%. This was approved as Annex A1 in September 2009 and is planned for use by companies such as Fulcrum Bioenergy, Red Rock Biofuels and Velocys in the USA and abroad.

The **Hydroprocessed Esters and Fatty Acids (HEFA-SPK)** process converts vegetable oils, animal fats or waste oils into synthetic paraffinic kerosene by deoxygenation and hydroprocessing. The process was certified for blends of up to 50% in Annex A2 in July 2011 and is used by AltAir Fuels, USA and Neste, Finland.

Synthetic Iso-paraffin from Fermented Hydroprocessed Sugar (HFS-SIP) (formerly referred to as Direct-Sugar-to-Hydrocarbon) converts sugars to a pure C15 paraffin molecule using advanced fermentation. Developed by French oil and energy giant Total and US industrial bioscience company Amyris, the process converts plant sugars into a hydrocarbon molecule called farnesane. SIP was approved in Annex A3 in June 2014 for a blending ratio of up to 10% with conventional jet fuel.

The **Fischer Tropsch (FT) Synthetic Kerosene with Aromatics (FT-SKA)** process also uses coal, natural gas or biomass – such as municipal solid waste, agricultural waste and forest waste – and adds some alkylated benzenes. This has been approved as Annex A4.

The **Alcohol to Jet SPK (ATJ-SPK)** process starts from an alcohol to produce a SPK through dehydration of the alcohol to an olefinic gas, followed by oligomerisation (to obtain longer chain length liquid olefins), hydrogenation and fractionation. Isobutanol-derived jet fuel was the first ATJ-SPK to be specificed under Annex A5 in 2016, which allowed US renewable chemicals and biofuels company Gevo Inc's renewable jet fuel to be blended at up to 30% in commercial airline operations. A later revision in April 2018 lifted the blend ratio limit for ATJ-SPK fuels to 50%. In April this year, Annex A5 was revised to add ethanol as a feedstock, paving the way for renewable jet fuel from US firms such as biofuels provider Byogy Renewables, Gevo and carbon recycling company LanzaTech. LanzaTech began construction of Europe's first commercial bioethnol-from-gas facility in June 2018.

The US$150M, 80M litres/year plant is located in Belgium, at the site of leading steel maker ArcelorMittal's facility in Ghent. LanzaTech uses microbes that feed on carbon monoxide, hydrogen and carbon dioxide to produce bioethanol.

Current offtake deals

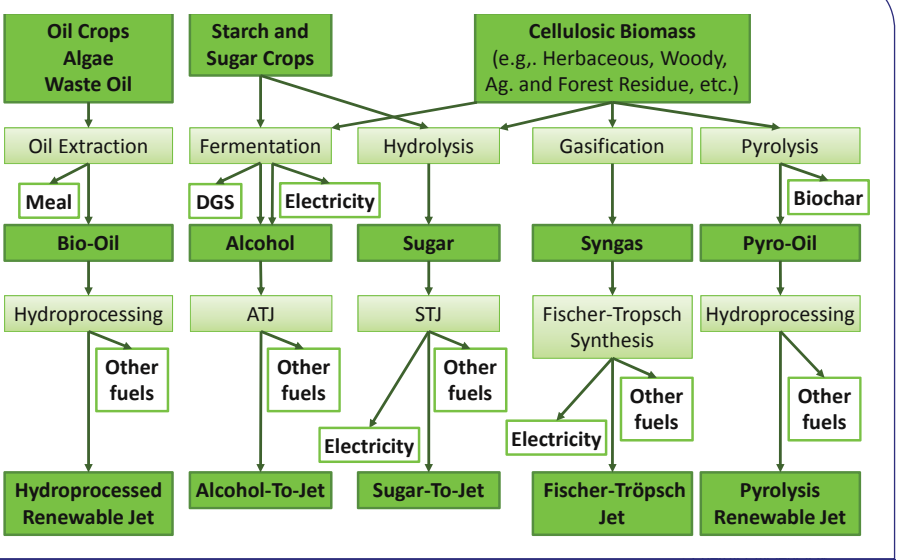
Current offtake agreements between alternative fuel producers and airlines total more than 250M gallons/year, representing the first few commercial efforts in sustainable jet fuel (*see Figure 1, above*). They include:

AltAir Fuels 2016 agreement to supply the USA's United Airlines with up to 5M gallons/year of fuel at Los Angeles Airport, in collaboration with World Fuel Services, USA. AltAir Fuels was bought by World Energy, one of the largest biofuel suppliers in North America, in March 2018 and has a 45M gallons/year renewable diesel and jet fuel production facility in Paramount, California.

AltAir is also producing its 30% renewable/70% petroleum jet fuel as part of a three-year contract that US business jet aircraft manufacturer Gulfstream Aerospace Corporation signed with World Fuel Services in 2015 for the purchase of up to 1.3bn litres/year of renewable fuels for daily operations in Savannah, Georgia.

In another agreement, KLM Royal Dutch Airlines and German airline Lufthansa signed three-year deals in 2016 to buy fuel produced by AltAir and supplied by Amsterdam-based sustainable jet fuel supplier SkyNRG for flights departing from Los Angeles airport.

Air BP, the aviation division of British oil and gas giant BP, announced in January 2016 that Norway's Oslo Airport would become the first in the world to make bio jet fuel available to all airlines, with Air BP providing a minimum of 1.25M litres of the fuel. The announcement was made together with Norwegian airport operator Avinor and SkyNRG, with Lufthansa, KLM and Swedish national carrier SAS confirming they would be buying the fuel. The bio jet fuel – produced from



SOURCE: US DEPARTMENT OF ENERGY

Figure 2: Co-products in the bio-aviation fuel pathways

camelina oil – was sourced from the Porvoo refinery of Finnish oil refiner and renewable diesel producer Neste. Air BP is one of the world's largest suppliers of aviation fuel products and currently supplies over 7bn gallons/year of jet kerosene and aviation gasoline.

Fulcrum Bioenergy converts municipal solid waste (MSW) into fuels through gasification of the organic material in MSW feedstock into a synthesis gas, which is purified and processed through the Fischer-Tropsch process to produce a syncrude product that is then upgraded to jet fuel or diesel.

In 2014, Hong Kong carrier Cathay Pacific Airways announced it was investing in Fulcrum and had also negotiated a long-term supply agreement for 375.M gallons/year over 10 years.

In June 2015, United Airlines announced it was investing US$30M in Fulcrum, with a supply agreement for 90M gallons/year of fuel through long-term fuel offtake agreements.

In November 2016, BP announced it would invest US$30M in Fulcrum and secured a 10-year offtake agreement for 50M gallons/year, which Air BP would distribute and supply at key hubs across North America.

Fulcrum's first plant is under construction in Nevada and is expected to process approximately 175,000 tonnes/year of MSW, creating 10.5M gallons/year of syncrude. It is expected to begin operations in 2020. Its second plant will reportedly be in Chicago and its third on the US west coast in or near California.

Colorado-based **Red Rock Biofuels** announced an agreement in July 2015 to produce approximately 3M gallons/year of jet fuel from 2017-2024 for FedEx Express, a subsidiary of US courier service FedEx Corp. FedEx joins Southwest Airlines in purchasing Red Rock's total available volume of jet fuel from its first commercial plant in Lakeview, Oregon – which broke ground in July – and will convert approximately 140,000 dry tonnes of woody biomass into 40% jet fuel, 40% diesel and 20% naphtha, or 6M, 6M and 3M gallons respectively. The Southwest Airlines offtake agreement of 3M gallons/year for seven years was signed in September 2014.

Red Rock gasifies woody biomass to produce synthesis gas, which is cleaned and sent through the Fischer-Tropsch process to produce a liquid hydrocarbon that is hydroprocessed to produce jet, diesel, and naptha fuels.

US industrial bioscience company **Amyris** began a two-year programme in May 2016 with Cathay Pacific, in which its 10% blended sugarcane-derived fuel would be used on all Airbus A350 delivery flights from Toulose to Hong Kong. The Amyris/Total process converts plant sugars (sugarcane) into a hydrocarbon molecule called farnesane, with the fuel produced at the Amyris biorefinery in southeastern Brazil. Airbus recently announced this programme will continue with A350-1000 delivery flights that commenced in June 2018.

US bioenergy company **SG Preston** announced a 10-year agreement in September 2016 with New York airline jetBlue in which it would supply 33M gallons/year of fuel for at least 10 years at John F Kennedy Airport, New York. The fuel will consist of 30% renewable jet fuel blended with 70% traditional Jet-A fuel. In October 2017, Australian airline Qantas also announced it would be buying 8M gallons/year of renewable jet fuel from SG Preston over the next 10 years to fuel its Los Angeles-to-Australia aircraft.

In a 10-year agreement announced in November 2013, top aircraft engine supplier GE Aviation said it would be buying 500,000 gallons/year of cellulosic synthetic biofuel from Washington-based **D'Arcinoff Group** (DG) for the testing of its jet engines at is primary engine test facility in Peebles, Ohio. The fuel will be produced via gasification of biomass to produce syngas, followed by Fischer-Tropsch conversion.

These deals represent 250M gallons/year of offtake agreements, says Csonka, but other recent announcements also represent further expansion.

Recent announcements

In July, SAS and Sweden's largest fuel company, Preem, announed that they would be collaborating to produce renewable jet fuel at Preem's planned capacity expansion at its Gothenburg refinery, with total ethylene capacity for biofuels of 1Mm^3 and an estimated start-up date of 2022.

US renewable chemicals and biofuels firm **Gevo** announced in June that it had struck its first long-term commercial deal for its alcohol-to-jet fuel (ATJ), and will supply Avfuel Corporation, a leading US supplier of aviation fuel and services.

In the first phase of the deal, Gevo will supply Avfuel from its smaller-scale hydrocarbon processing facility in Silsbee, Texas, which can produce 70,000 gallons/year of renewable hydrocarbon products (50% ATJ and 50% isooctane). Gevo plans to build a larger scale hydrocarbon plant at is existing ethanol and isobutanol facility in Luverne, Minnesota. At its completion, phase 2 of the five-year Avfuel agreement would begin, comprising larger volumes of up to 1M gallons/year of unblended ATJ. In addition, Gevo announced in October 2017 that it would supply Virgin Australia Group with ATJ for flights departing from Brisbane Airport.

US renewable fuel company **Velocys** announced in September 2017 that it is partnering with British Airways to prepare the case for a commercial waste-to-renewable-jet fuel plant in the UK, with the aim of reaching a final investment decision in 2019. Velocys converts residues from forestry operations into fuel and its first US biorefinery is being built in Natchez, Adams County, Mississippi.

Neste announced a collaboration with American Airlines in November 2017 to explore opportunities for renewable fuel use, including acceptance and commercialisation of high freeze point

HEFA (HFP-HEFA) renewable jet fuel, which ASTM is considering for approval. Neste also said in June that it would work with Dallas Fort Worth International Airport to explore renewable fuel use.

Canadian biotech firm **Agrisoma Biosciences** has a partnership with Qantas that will see it provide Qantas with a regular supply of aviation biofuel by 2020. The two firms will work with Australian farmers to grow carinata on 400,000ha of land, enough to produce more than 200M litres/year of biofuel and fulfil up to 50% of Qantas' annual fuel needs. On 28 January, its 10% blend jet fuel was used by Qantas on a 15-hour flight from Los Angeles to Melbourne.

Dubai-based **Petrixo Oil & Gas** announced in 2014 that it would produce biojet fuel and renewable diesel at a new refinery to be built in Fujairah, UAE. Petrixo will use Honeywell UOP technology to process around 500,000 tonnes/year of renewable feedstocks into biojet fuel and renewable diesel.

More pathways to fuel

Although there are currently five approved pathways to produce drop-in bio jet fuel, the aviation industry is also reviewing various additional jet fuel production processes, including:

Catalytic Hydrothermolysis (CH) combined with hydroprocessing, which can convert vegetable oils and animal fats and greases, including waste oils and industrial oil crops, into a drop-in jet fuel without blending with conventional fuel (the final product contains both paraffins and aromatics). This pathway is being developed by Applied Research Associates (ARA), and approval is expected by early 2019. ARA, along with its partner Chevron-Lummus Global, expect to license the technology to commercial developers, several of which are progressing through front-end engineering for facilities in the USA and Japan.

Hydro-Deoxygenated Synthesised Kerosene (HDO-SK) consisting of C9-C16 paraffins and napthenes and **Hydrodeoxygenated Synthesised Aromatic Kerosene (HDO-AK)** consisting of C9-11 aromatics. The process is specific to US renewables firm Virent Inc and a 50% blending ratio with conventional jet fuel is targeted for approval. It can convert starch, sugar and lignocellulose into a hydrocarbon fuel through aqueous phase reforming, condensation and hydrotreating.

Virent – which was acquired by US petroleum refiner Tesoro Corp in 2016

US renewable fuel company Velocys has a pilot plant in Ohio, USA (pictured above) and is building a biorefinery in Natchez, Mississippi

– is working with Japanese chemical group Toray Industries, global speciality chemicals firm Johnson Matthey and The Coca-Cola Company to scale up its technology and build a commercial scale plant. Global oil and gas multinational Royal Dutch Shell is also a long-term collaborator with Virent, announcing in 2012 that it had built a pilot plant at its Westhollow Technology Center in Houston utilising Virent's technology.

Shell also completed construction in 2017 of a five tonne/day pilot plant in Bangalore, India, demonstrating IH2 technology, which turns wood, algae and municipal waste into fuel. It also signed a deal with Canada's SBI BioEnergy giving it exclusive development and licensing rights for SBI's continuous catalytic process to convert waste oils, greases and vegetable oils into drop-in diesel, jet fuel and petrol. SBI has a demonstration facility in Edmonton that was due to produce 10M litres/year by the end of 2017, with a 240M litres/year commercial scale facility was due to be online.

USA is leader

The USA is the leader when it comes to players and processes for sustainable jet fuel development. Some major expansion plans in the pipeline for sustainable jet fuel or HDRD production include:

In a joint venture called **Diamond Green Diesel**, Diamond Alternative Energy LLC – a subsidiary of Valero Energy Corporation – has partnered with renderer Darling Ingredients to build a 10,000 barrel/day renewable diesel refinery near the Valero St Charles Refinery in Norco, to process recycled animal fat, used cooking oil and other feedstocks into renewable diesel.

In March 2017, it was announced that the Diamond Green diesel facility in Norco would increase its annual capacity from 10,000 barrels/day to 18,000 barrels/day (275M gallons/year). It has also announced plans to expand further once current capacity increases are completed.

Renewable Energy Group (REG) has a commercial-scale renewable hydrocarbon diesel production facility in Geismar, Louisiana. The multi-feedstock production facility can utilise a variety of lower cost feedstocks to manufacture approximately 75M gallons of renewable hydrocarbon diesel, renewable naphtha and renewable LPG. REG acquired the facility in 2014 and, in August 2017, completed its US$20M acquisition of land at Geismar, creating opportunities for expansion. The company said then that the plant was operating at 103% capacity utilisation.

In March 2018, World Energy acquired **AltAir Fuels** and its 25ha refinery in Paramount, California for US$72M. AltAir Fuel produces more than 40M gallons/year of renewable fuels including diesel, jet, and petrol blending components using fat, oil and grease feedstocks. The acquisition creates World Energy's fifth renewable fuel manufacturing plant and provides the opportunity to expand the Paramount facility's renewable fuel production by using hydrotreating and other refinery infrastructure at the site.

Along with **SG Preston** doubling its planned capacity to 240M gallons/year facility, **ARA** licensing out activities that can tap into the brown grease market and **UOP** licensing for refinery retrofits, expansion in the USA could represent more than 1bn gallons/year of capacity by 2021. These expansions would need to be met from purpose grown feedstocks including pongamia in southern USA; winter carinata grown as a winter cash cover crop in the southeast USA; pennycress which can withstand hard frosts and fits in the soya/corn rotation; tall oil from the pulp and paper industry; white grease, poultry fat, tallow, used cooking oil, yellow grease and brown grease. Going forward, additional sustainable feedstocks of significant volume such as the offgases from steel mills, MSW, and direct air capture of CO_2 are waiting to be utilised. ●