A sustainable source for aviation fuel – the Air Fuel Synthesis approach

Biofuels, hydrogen and even electrical power have all been proposed as alternatives to the current, fossil-based fuel used in aviation. Here, David Benton *surveys these and other alternatives, concluding with a new approach – to manufacture fuel, essentially from carbon dioxide and hydrogen produced using electricity from renewables*

As with other transport sectors, aviation is having to think long and hard about the types and sources of the fuels that it is going to have to use in a future post-fossil fuel era. Even today, as peak oil approaches, with the rise in fuel prices and the pressures from environmental groups, air transport is going through a difficult period.

While future road transport may look forward to all-electric cars, or hydrogen gas as fuel for an internal combustion engine, or a fuel cell/electric motor combination, electric or hydrogen aircraft in the future are unlikely. Yes, electric light aircraft exist and photovoltaic electric drones have flown to very high altitudes and achieved long flight times. A number of hydrogen-powered aircraft have flown over the last 50 years, but neither of these options has progressed into a practical proposition.

Consequently, it is not rocket science to consider that the most likely way forward for aviation is to find a suitable liquid fuel, not too chemically different from JetA (the kerosene-type mixture of hydrocarbons that is fuel for jet engines), to replace JetA. This would allow existing aircraft to keep flying and minimise the changes to the storage and supply infrastructure.

For road transport, a number of alternative liquid fuels have been investigated and in some cases brought to market. In principle, some of these are attractive to aviation but aviation imposes additional requirements on its fuel properties, for example, the fuel has to operate at temperatures down to –50°C and to have low viscosity at these temperatures. Any new fuel will have to be chemically compatible with the elastomer seals in engines and pipelines and the fuel must not be corrosive towards the metals that it comes into contact with. The energy density of the fuel is more critical and of greater economic importance than with road or sea transport.

Further, as aviation looks to the future, it will have to play its part in reducing carbon dioxide emissions and ensure that its fuel supply is sustainable. Although aviation is currently responsible for only about 5% of the world's carbon dioxide emissions, it is often pilloried by environmental groups since it is an expanding business and, as emissions from other sectors hopefully fall, the impact of aviation will appear larger and become a bigger target for action.

Possible alternative aviation fuels

Clearly, any alternative fuel to JetA will have to fulfil the technical specifications of the aviation controlling bodies and meet the chemical compatibility issues mentioned above. Ideally, one single universal fuel, readily available at all airports, is needed. In the future, aviation fuel will also have to meet the environmental aims of being zero carbon or carbon neutral and be able to be manufactured in a sustainable manner and in any quantity that the market requires in order to avoid supply/demand pressures. It is these environmental considerations that this article will consider.

There are two basic ways forward to achieve the environmental aims. The first is to develop new fuels using sources that can be sustainably produced. This usually means biofuels. The second way is to consider the option that the best replacement for JetA is JetA and to find a way to synthesise JetA from non oil-based sources. With the elimination of hydrogen as a future fuel for aircraft, any aviation liquid fuel will realistically be made up of compounds of carbon, hydrogen and possibly oxygen. Put another way, the supply problem reduces to finding suitable carbon and hydrogen sources that are readily available in the required amounts and developing techniques to chemically work them up into a suitable fuel.

The new generation of fuels are mainly based on various forms of biomass as the initial material. The fuels are derived either from the seeds of plants or the plant material itself. Examples of the seeds that have been considered are rape, coconut, jojoba and sunflower. The seeds are crushed to extract their seed oil. The physical properties of the oils are unsuitable in their initial state so are chemically treated to produce a usable fuel.

A related fuel source that has been attracting a lot of attention in the last 2–3 years is the oil that can be extracted from algae. Algae are the fastest growing plants and so produce the largest yield per hectare. While algae can be grown on open ponds, the likely way forward is specialist growing containers on algae farms – that optimise the growing conditions by feeding in an atmosphere enriched in carbon dioxide together with nutrients, and which are designed to maximise sunlight on the plants.

Ethanol and methanol

Alternatively, and most well known, sugar may be extracted from sugar cane and maize (corn in the US) and fermented into ethanol. Alternatively, ethanol may be made by the use of cellulosic plant material, thereby making a much larger range of plant material available. A recent development, being favoured by Virgin's Sir Richard Branson, is the production of isobutanol from sugars using a genetically modified bio-catalyst. Biomass is often regarded as being carbon neutral. However, a careful analysis has to be made to include transportation costs from growing area to production plant and the energy input to any fertiliser used.

Another front runner is methanol. Methanol is already a major feedstock for the chemical industry. It is most commonly made by steam reforming of natural gas to a mixture of carbon monoxide and hydrogen called Syn Gas. A catalytic reaction then turns the Syn Gas into methanol.

Technically, it is quite possible for these fuels to power aircraft and flight trials have been made. The factor that is likely to limit their application is the quantities that can be made from the world's resources. The UK uses about 12mn tonnes of aviation fuel a year and the world's airlines consume about 205mn tonnes. Military use will add to this. Whether the world can match these amounts from biomass sources is a very moot point. There are already serious concerns of the effect on food production; thus ethanol production for fuel (currently for road transport), took 25% of the US corn crop in 2008. However, there are many voices that claim there is spare land capacity for fuel crops.

The use of algae has been seen as a way of avoiding the difficulties arising from the use of food-growing fertile land for fuel crops. Nevertheless, algae production to meet an output of millions of tonnes will still require significant land space for the bio-reactors. Moreover, algae need fertilisers to be added and is very energy intensive. A full 1% of the world's energy consumption is used to make fertiliser. Methanol from natural gas is a well established chemical process that produces

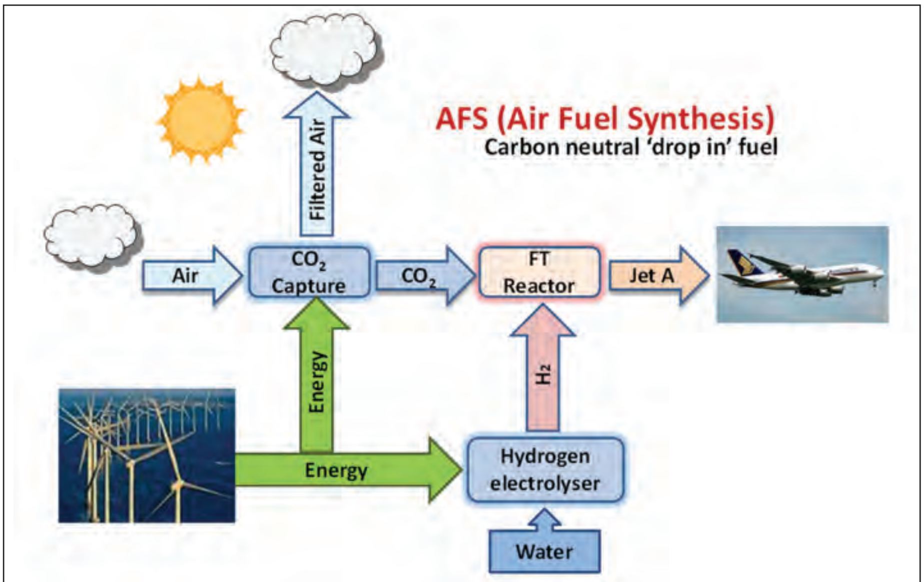

Figure 1: Schematic outline of the air fuel synthesis (AFS) route *Source: R. Monkhouse, 2009*

millions of tonnes of methanol a year. The adoption of methanol from gas as a major fuel, for air or road, would bring it into competition with other uses of methanol and put additional pressure on natural gas supplies.

Manufacture of synthetic JetA fuel

The most obvious carbon source that is readily available to make synthetic JetA is coal. In many quarters, the coal reserves of the world are so large as to be seen as a semi-sustainable supply, at least to the extent that they might tide the world over until a fully sustainable carbon source for fuel production is found.

There is a well understood technology available today to turn coal into JetA (and indeed other hydrocarbon fuels for road transport). The technology is the steam gasification of coal into a mixture of carbon monoxide and hydrogen, called Syn Gas. The Syn Gas is reacted via the Fischer-Tropsch (FT) reaction to combine the carbon monoxide and hydrogen into hydrocarbons and water. The Fischer-Tropsch reaction is some 90 years old, previously used in war-time Germany and also in South Africa for petrol production. Together with various standard oil refining processes such as cracking and hydrogenation, FT can make a wide range of hydrocarbons.

For aviation specifically, the SASOL company in South Africa has been the leader of recent FT development and has achieved certification for its FT aviation fuels. The USAF has flown a B52 bomber on fuel derived from coal.

The advantage of using coal and FT reaction is that it very much a today solution with potentially large reserves known and ready to be exploited. Further research into new catalysts and reactors will improve the economics. The weakness of this approach is that coal supplies are not evenly distributed over the world and a new 'OPEC' for coal might lead to geopolitical pressures on the supply chain. Such coal use would do nothing for the environment as carbon dioxide emissions would continue at the present level and indeed increase as aviation expanded. Unlike coal-powered electricity generating stations, direct carbon capture and sequestration (CCS) from aircraft is not possible. However, indirect CCS maybe possible in the long term using a worldwide array of carbon dioxide capture devices as suggested by a leading CCS expert Klaus Lackner.

In many ways, the use of coal to make aviation fuel is a business-as-usual approach, merely involving a shift in the raw material from crude oil to coal, which would draw upon the existing technologies already employed in the oil and industrial chemical sectors. However, true sustainability would not be achieved. Supply would be dependent on the coal supplies released by the coal producing countries and would have to be over and above their needs for electricity generation; a situation that might lead to a difficult supply/demand position at times.

The second synthetic route retains the existing technology of gasification but applies it to biomass as the source material to produce Syn Gas followed by the FT reaction to produce JetA. The type of biomass that can be used is wide ranging and could include algae. The gasification of a wet product such as recently-harvested plants is more difficult than using coal, but is possible.

A new option for sustainable JetA

A new company, Air Fuel Synthesis Ltd, has been developing a novel route to alternative transport fuels. The company is chaired by Prof Tony Marmont, a long-term proponent of renewable energy, who in January 2010 received an Energy Institute individual achievement award. Prof Marmont funded the creation of the Centre for Renewable Energy Systems Technology (CREST) at Loughborough University from the sale of his business interests. Around three years ago, he published a cooperative study with BA, Rolls Royce and Imperial College, investigating the potential for biomass-based aviation fuels in the UK.

The Air Fuel Synthesis approach is to capture carbon dioxide from the air for use as a carbon source, generate hydrogen by electrolysis of water and react the two together to synthesise JetA fuel. The resulting JetA will be a straight replacement for fossil-fuel derived JetA and so be able enter directly into the current infrastructure and market.

Over the last five years or so, a number of groups around the world have been exploring the possibility of using carbon dioxide captured from the air as a carbon feedstock for fuel production and many patent applications have been made. The carbon dioxide-sourced fuel synthesis concept may be seen as allied to and synergistic with other programmes aimed at capturing carbon dioxide from the atmosphere or combustion streams for carbon sequestration purposes. Most carbon dioxide-sourced fuel synthesis schemes aim to produce hydrocarbon fuels but at least two groups have concentrated on methanol production.

The Air Fuel Synthesis Ltd approach is called, not surprisingly, Air Fuel Synthesis or AFS. A schematic description of the steps is shown in **Figure 1**. The capture of carbon dioxide is achieved by the use of a tower arrangement based on the work of Professor Keith at Calgary University, who has demonstrated a large laboratory apparatus. Micron-sized droplets of a sodium hydroxide solution are sprayed down a tower while air is blown up the tower. Sodium hydroxide readily reacts to absorb the carbon dioxide in the air to form a sodium carbonate solution, thereby concentrating the carbon dioxide.

The release of the carbon dioxide from the sodium carbonate solution is achieved by an electrochemical step that is based on a US patent that produces carbon dioxide gas as a side product during the production of sodium hydroxide. Hydrogen is produced by the electrolysis of water, a standard industrial method.

Once hydrogen and carbon dioxide have been made, they can be reacted in a number of ways to produce fuels. The current AFS concept is to react the carbon dioxide with hydrogen to convert it to carbon monoxide using the catalytic reverse-water-gas-shift reaction and then reacting the carbon monoxide with additional hydrogen to produce hydrocarbon fuels using the FT reaction. Looking to the future, a likely alternative route is to react the carbon dioxide and hydrogen directly to methanol and use a modified catalyst to convert the methanol to JetA using the Mobil methanol-to-gasoline reaction.

A key feature of the fully integrated AFS route being proposed by Air Fuel Synthesis is the use of renewable energy to drive the processes. Then, the whole JetA production route and the fuel's use would be carbon neutral as the carbon dioxide was cycled around. AFS fuel production uses existing processes and so will be able to reach the market in the near-term. Apart from the carbon dioxide and hydrogen, the other input is electricity and the cost of this electricity will determine the economic viability of the scheme. The Air Fuel Synthesis studies to date predict that the electrical input for AFS synthesis is 3 kWh to make JetA containing 1 kWh of energy, or put another way requires 30 kWh to make 1 litre of JetA.

The cost of electricity at the full domestic price does not lead to economically viable fuel. However, Air Fuel Synthesis has shown that a fully integrated company, using its own renewable electricity generation (in the UK most probably wind turbines), aided by the support mechanisms available to renewable energy generation in the UK, can produce fuel at a lower cost than current fuel prices. Moreover, as the price of the raw materials will not increase, the price of AFS fuels should remain constant in real terms.

AFS fuels will have to take their place in the market alongside and in competition with the other alternatives that are now being developed. AFS fuels would not be limited in the amount that could be produced due to the readily availability of carbon dioxide and water, but would require extensive building of renewable energy devoted solely to JetA manufacture. Thus, Air Fuel Synthesis has calculated that, to meet all the 12mn tonnes per year for UK aviation would require 33,000 5 MW-rated wind turbines, or the equivalent energy produced by other renewable sources.

A single wind turbine array in the North Sea of 85 miles square would be required to meet all the UK's aviation fuel needs. A 10-year programme of wind turbine construction, with the wind turbines placed either on the sea bed or on floating platforms would solve the UK's aviation transport fuel needs once and for all.

Nuclear reactors could, of course, power AFS JetA production and may even be economically viable as fossil fuels rise in price. However, Air Fuel Synthesis Ltd is committed to a renewably-driven AFS process. The company believes this to be the best path to lead the UK to a sustainable, carbon-neutral aviation fuel in quantities limited only by the amount of renewable electricity that that is devoted to AFS aviation fuel production.

The AFS scheme is believed to be unique in the UK but there are others across the world who are working on similar programmes. The Los Alamos laboratory, which helped develop the first nuclear weapons, has a scheme called 'Green Freedom' and the US Navy has recently revealed a very similar process in which carbon dioxide is recovered from sea water, enabling aircraft carriers to make their aircrafts' fuel whilst at sea.

So, to summarise, the AFS fuel process is a 'new kid on the block'. The most important consequences arising from AFS aviation fuel are:

- The raw materials are available indigenously to the UK, and available in unlimited amounts, so that the AFS aviation fuel supplies will not be resource limited. Similar conditions will apply to most, if not all, countries.
- When driven by renewable energy, the AFS fuels can be made in a fully carbon-neutral manner.
- Is not necessary to be an oil company to make AFS aviation fuels.
- AFS aviation fuel production will not place pressure on land space currently used for food. ●

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