Aviation biofuels:

How ICAO and industry plans for 'sustainable alternative aviation fuels' could lead to planes flying on palm oil

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biofuelwatch
biofuelwatch.org.uk · biofuelwatch@ymail.com

Contents

Report by Almuth Ernsting
Edited by Rachel Smolker
Design by Frances Howe

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biofuelwatch.org.uk
biofuelwatch@gmail.com

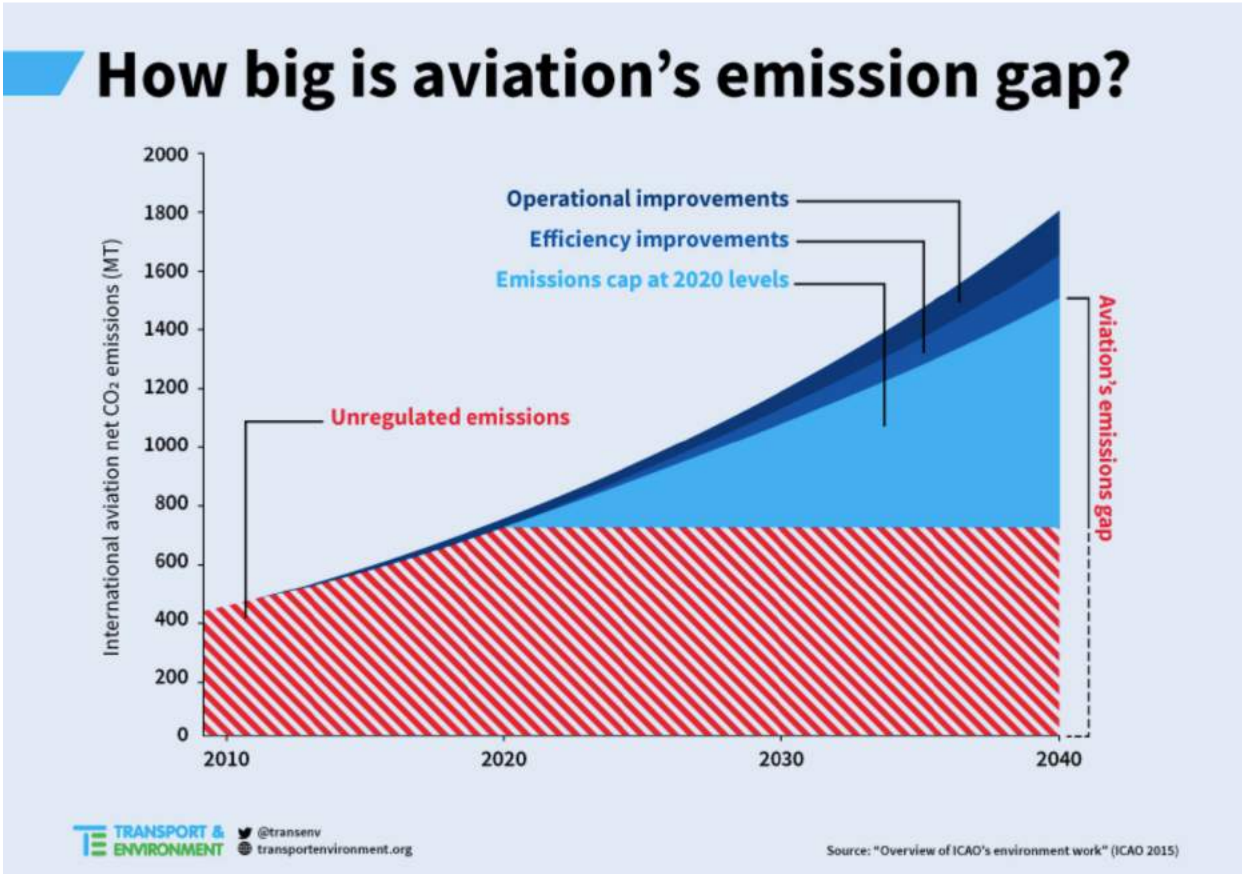
1. How do biofuels fit in with the aviation industry's and ICAO's growth strategy?

Greenhouse gas emissions from aviation are rising faster than those from almost any other sector. Between 1990 and 2014, emissions from international aviation alone grew by 87%[1]. Growth in aviation emissions is incompatible with the goal of the UN Paris Agreement to keep global warming to within 1.5°C. Under the Kyoto Protocol, international aviation has been exempt from any curbs on its emissions. In the context of the Paris Agreement, the industry can no longer rely on such a blank cheque for aviation emissions in future. At the same time, it wants to maintain its present high rates of growth to protect shareholder profits.

The aviation industry association IATA (International Air Transport Association) predicts that the number of air passengers will double over the next 20 years[2]. In addition, global air freight is rising at a rate of around 4.3% a year[3]. There are no technical means of allowing air travel to expand at such a rate without CO_2 emissions[4] also growing steeply. No alternatives to liquid fuels exist in aviation: passenger planes cannot fly with electricity, and hydrogen-fuelled planes are nowhere close to being approved, due to technical and safety problems[5].

Aircraft efficiency has been improving at a rate of just 1.1% a year[6], less than that of most other industries. Airlines have adopted voluntary efficiency goals[7] and the International Civil Aviation Organisation, ICAO, has adopted an efficiency "CO_2 standard"[8]. But even if those are implemented, efficiency gains will still lag far behind the industry's growth rate. Environmental NGOs have argued that far more could be done to improve fuel efficiency of aircraft. According to the International Council on Clean Transportation, fuel consumption of new planes could be cut by 40% by 2034[9]. Yet, even that would be nowhere close to cancelling out the increase in emissions from doubling air traffic over 20 years.

In order to avoid growth-curbing regulations, the aviation industry has adopted the concept



transportenvironment.org/sites/te/files/publications/2017_02_briefing_aviation_decarbonisation.pdf of “carbon neutral growth”. In 2016, ICAO, which is a specialised UN agency which works very closely with the industry, endorsed a plan for “carbon neutral growth” from 2020 and for a reduction in ”net carbon emissions” by 2050, of 50% compared to a 2005 baseline. ICAO plans to meet those goals primarily through a combination of carbon offsetting and biofuels. ICAO’s carbon offsetting scheme has already been denounced by more than 100 civil society organisations[10].

Ahead of its High-Level Conference on Alternative Aviation Fuels in Mexico City from 11th to 13th October, the ICAO Secretariat has published a proposal for very large-scale biofuel use[11]. The proposal would involve:

- 5 million tonnes of biofuels a year used by planes by 2025, which is 2% of projected aviation fuel use;
- 128 million tonnes a year used by 2040, which is 32% of projected aviation fuel;
- 285 million tonnes a year used by 2050, which is 50% of projected aviation.

The Secretariat proposes calling on member states to work with industry and to “set policies that strongly incentivise SAF [Sustainable Aviation Fuel] production”.

2. Aviation biofuels: The state of play

On 24th February 2008, Richard Branson was filmed playing with a coconut next to a Virgin Atlantic plane at Heathrow Airport as he announced the world’s first commercial flight with biofuels. This flight, he proclaimed, was “a vital breakthrough” which “will enable those of us who are serious about reducing our carbon emissions to go on developing the fuels of the future”. Virgin’s ‘biofuel’ flight was widely denounced and ridiculed as a mere publicity stunt[12]. In fact, it was neither the world’s first biofuel flight, nor a commercial one[13], and it used a mere 5% biofuels mixed with fossil fuels.

Ironically, Virgin Group has never since used biofuels on any flight, although it continues to invest in their research and development[14]. Yet growing numbers of other airlines have used biofuel blends on thousands of passenger flights since 2011, when such fuel blends were first cleared for commercial use[15].

Nonetheless, overall biofuel use in aviation remains minimal. According to Bloomberg New Energy Finance, existing refineries could produce as many as 100 million gallons of biofuels for aircraft – a fraction of the current 83 billion gallons per year of petroleum based total aviation fuels in use today.

That 100 million gallons estimate far exceeds what is being produced so far: there is just one commercial-scale refinery in the world which regularly produces small amounts of such biofuels, while focussing primarily on biofuels for road transport.

What types of biofuels can be used in planes?

Ethanol (made from starch or sugar crops) and biodiesel (made from vegetable oils and animal fats) account for 95% of all biofuels produced worldwide[16], but they cannot be used in aircraft. For safety reasons, any fuel used in aircraft has to meet jet fuel specifications, which include high energy density, low freezing point, and a specific temperature at which fuels ignite or explode. Any new type of aviation fuel must be approved by the international standards organisation ASTM. So far, five types of biofuels produced through four different methods have been approved for use in passenger flights[17]. The four methods produce:

1) A fuel made by putting plant oils or animal fats through processes commonly used in oil refining, including hydrotreating (which involves the use of hydrogen). Biofuels produced using this method are called Hydrotreated Vegetable Oil (HVO). A particular type of HVO, called HEFA, is needed for aircraft[18], produced under slightly different refining conditions than HVO diesel, which is used in road

transport. HVO is made in oil refineries – either on its own, in a converted refinery, or through co-production together with petroleum in a conventional refinery. The world's leading HVO producer is the Finnish oil company Neste, but several other companies have invested in the technology (see Chapter 5);

2) A fuel made by fermenting sugars to farnesene, which is a hydrocarbon that can be converted to jet fuel. Hydrocarbons are chemical compounds that contain only hydrogen and carbon atoms. This process was developed by a synthetic biology company, Amyris[19], which has since admitted that "sales of our fuels products have not been cost-effective given the current costs of producing farnesene and current market prices for petroleum fuels". Amyris now sells beauty products instead[20];

3) A fuel made by gasifying solid biomass such as wood and then converting it to hydrocarbon fuels using a technology called Fischer-Tropsch reforming, after its inventors. The process is discussed in more detail below. Two different types of aviation biofuels made through gasification and Fischer-Tropsch reforming have been approved. Fischer-Tropsch reforming has been in the research and development stages since the 1920s[21];

4) A fuel made by fermenting sugars to an organic compound called isobutanol, which is then upgraded to hydrocarbons contained in jet fuel[22]. The company behind this technology is Gevo.

Other methods for making aviation biofuels have been proposed, but not yet approved. This includes an application to allow the use of 15% blends of Hydrotreated Vegetable Oil (HVO) diesel, currently produced for road and rail transport. If approved by the ASTM, this would allow for far cheaper production of biofuels for aviation, as discussed in Chapter 5.

In short, four very different methods for making aviation biofuels have so far been approved. Between them, they could convert sugars and starch, solid biomass such as wood, switchgrass or straw, vegetable oils and animal fats into biofuels suitable for planes. Furthermore, a US company, Fulcrum BioEnergy, has announced plans for a Fischer-Tropsch plant using Municipal Solid Waste which, though not a biofuel, would still be classed by ICAO and airlines as a "sustainable alternative aviation fuel"[23].

The fact that a particular aviation biofuel has been approved and that companies have produced small quantities, does not prove that it can be produced in commercial quantities – something Amyris has already conceded in the case of its aviation biofuel based on farnesene.

As illustrated in Chapter 3, three of the four approved aviation biofuels do not appear to be technically and economically viable based on current knowledge and technology development.

On the other hand, HVO fuels – and specifically HVO diesel – are already being produced on a significant and fast-growing scale. If, as is widely expected, HVO diesel blends are permitted for aircraft, aviation biofuel costs will fall dramatically and may well become affordable with limited subsidies. This would create a new market for vegetable oils, likely palm oil, as discussed in Chapter 4.

How much aviation biofuel is being produced so far?

The only refinery which regularly produces aviation biofuel is AltAir's HVO refinery in Paramount, California. Most of AltAir's shares are owned by the US oil company Alon. AltAir sold 1.1 million gallons (just under 45,000 tonnes) of biofuels for aircraft in 2016[24]. Jet biofuels accounted for just 6.6% of its production in 2016[25]. Most of its sales and profits come from HVO diesel for road transport i.e. a biofuel with the same properties as conventional diesel for cars.

Otherwise, aviation biofuels have only been produced in small quantities and mostly in small pilot plants, generally as part of government-funded research and development projects, such as the EU's Itaka programme, or the Defense Advanced Research Projects Agency's (DARPA) BioFuels Program.

3. Unlikely contenders: Aviation biofuels made from anything other than vegetable oils and animals fats

Airlines have signed 12 sourcing agreements with a total of 8 biofuel companies[26]. Those include AltAir Fuels (see above) and Neste, who produce 60% of the world's HVO, albeit not routinely for aviation so far. A third company, SG Preston, has agreed to supply HVO biofuels to Jet Blue – but seems to be nowhere close to building or converting a refinery.

This leaves five companies promising to produce substantial amounts of biofuels for aircraft using a technology other than HVO. How credible are those promises?

Fulcrum Bioenergy: Turning waste into fuels for planes?

At an ICAO Seminar about aviation biofuels in February 2017[27], Fulcrum BioEnergy gave a very upbeat presentation to delegates: Fulcrum had developed a "proven" technology to turn Municipal Solid Waste into aircraft fuel, which guaranteed "low-cost production" with an "attractive environmental and sustainability profile". Municipal solid waste is certainly much cheaper than vegetable oils – and compared to palm oil, it would be a far less controversial feedstock. But by any definition, Fulcrum BioEnergy's technology is neither "proven" nor "low cost".

Fulcrum BioEnergy, founded in 2007, spent its first 6-7 years struggling to interest any private investors in its plans, and it had to abandon an attempt to float the company on the stock exchange in 2012[28]. In 2014, the company's fortunes changed: it was awarded a $70m grant under the US government's Defense Procurement Act to build a first commercial-scale refinery in Nevada[29]. On top of this, the US Department of Agriculture awarded it a $105 million public loan guarantee. That same year, Cathay Pacific Airways decided to invest in the company and to enter into a supply agreement for 10 million gallons a year over a decade[30]. Commercial production was to start in 2016/17[31]. Since then, Fulcrum has also signed an investment and supply agreement with BP and a supply agreement with United Airlines[32], and it has partnered with the oil company Andeavor (formerly Tesoro). Yet so far, Fulcrum Bioenergy has not even announced a start date for construction. It claims to have "proven" its technology in a demonstration plant in North Carolina. This is a small pilot plant on the premises of the Southern Research Institute, which has been used to test biomass and waste gasification and reforming to liquid biofuels. In the same year that the US government promised Fulcrum up to $175m in subsidies, Southern Research Institute was advising the Department of Energy that tests at the plant showed that "large scale systems have significant technical, logistics, and economic challenges"[33].

Fulcrum's technology involves three different processes, and there is no evidence that either of the first two has ever worked with mixed waste: the first is gasification, which involves exposing fuel to high temperatures with controlled oxygen in order to produce syngas. The syngas is then cooled down and cleaned until it contains only carbon monoxide and hydrogen. Syngas can then be burned to generate heat and/or electricity or, in theory at least, it can be converted to liquid fuels. Gasification is highly challenging even for "clean" virgin wood. There is no reliable evidence of any successful gasification plants anywhere in the world that use mixed waste[34]. The second stage, Fischer-Tropsch reforming, involves a series of catalytic reactions during which the syngas is transformed into liquid hydrocarbons. During the final stage, the hydrocarbons would be separated into different useful hydrocarbon products, using a process widely used in oil refineries. Fischer-Tropsch reforming syngas to liquid fuels has never been successfully achieved at scale with any feedstock other than coal or natural gas, as will be discussed below in relation to a proposal by Red Rock Biofuels. Two of the three technologies in Fulcrum's process are thus entirely unproven. There seems to be little to distinguish Fulcrum's promises from ones made by the now bankrupt aviation biofuels company Solena[35].

Red Rock Biofuels: Turning trees into biofuels for planes?

Red Rock Biofuels (RRB) also procured a $70m grant under the US Defense Procurement Act. Furthermore, it obtained a $4.1m Department of Defense grant and $2.1m in tax credits from the Oregon Department of Energy. It has signed supply agreements with Southwest Airlines, and FedEx.

The technology RRB wants to use is very similar to Fulcrum BioEnergy's, except that it would use trees rather than waste as a feedstock. RRB has never built any type of plant, however small. The gasifier that the developers say they will use is to be supplied by a company called TCG, who received a $20 million grant from the US Department of Energy for a demonstration gasifier. TCG's final project report, in 2010, showed that problems initially prevented any syngas from being collected whatsoever. After the plant was taken down and reassembled, TCG managed to produce some syngas, but it was too contaminated to be converted to biofuels. Eventually, after major investments, TCG succeeded in obtaining clean syngas for a total of four days[36]. According to publicly available evidence, this appears to be the total of RRB's gasification technology supplier's experience with the technology, and the basis for the company's claim that it can gasify 175,000 tonne of wood a year. The Fischer-Tropsch technology is to be supplied by Velocys, one of the companies involved in the failed Solena venture. Velocys's experience with biomass Fischer-Tropsch reforming seems to also be limited to some test runs at the same Southern Research Institute plant previously used by Fulcrum – the one whose researchers concluded in 2014 that the technology does not so far work at scale.

RRB still needs more funding before it can start building its refinery, and there are serious concerns about the location of the plant, not least because the village where it is to be built suffers from pollution levels so high that residents have been fined for using wood stoves[37].

It seems highly unlikely that RRB's or Fulcrum's plans can possibly succeed. There have been other more credible efforts to develop biomass gasification and Fischer-Tropsch refining, projects that involved years of research and development. The company which got furthest with the technology was Choren Tech GmBH. Choren first trialled the technology to produce diesel from wood in a pilot plant, which opened in 1998. In 2003, Choren then embarked on scaling up the pilot plant and attracted investment from Shell, Daimler and Volkswagen. It succeeded in producing small amounts of Fischer-Tropsch biofuels over a total period of thousands of hours, albeit with many shutdowns, repairs and modifications along the way. After years of such experimental production, Choren remained unable to achieve commercial-scale production, causing investors to pull out[38]. Choren filed for bankruptcy in 2011 and its

Solena Fuels

For several years, US company Solena Fuels captured headlines around the world about its aviation fuels-from-waste plans. In 2010, Solena entered into a partnership with British Airways to build a large refinery in the south-east of England. It teamed up with Quantas to build a similar plant in Sydney, and negotiated with Easy Jet, Ryanair and Aer Lingus about building one in Dublin, and with city authorities in Chennai India, about yet another such plant.

Like Fulcrum BioEnergy, Solena Fuels wanted to combine waste gasification with Fischer-Tropsch reforming. Neither Solena nor any of its partner companies had ever proven such a technology at any scale – not even in a small pilot plant. In October 2015, Solena Fuels filed for bankruptcy in Maryland, without ever having built or produced anything.

Remarkably, British Airways has just announced a new "partnership" with Solena's supposed technology supplier Velocys (discussed in the section about Red Rock Biofuels), for what seems to be exactly the same proposal.

Choren's biomass-to-liquids demonstration plant in Freiberg, Germany, 2011. Photo: Choren/Detlev Muller

technology has been sold to Linde, which now promotes its use to turn coal into liquid fuels.

In Europe, just one biomass Fischer-Tropsch project is now underway, supported by €33.2 million in subsidies. Unlike RRB, its operators have not promised that they will produce any fuel, let alone 19 million gallons a year – all they have committed to are four years of research followed by a "validation" report about the feasibility of the technology[39].

In the US, Fischer-Tropsch fuel research has been largely driven by the military. During the 2000s, when oil prices and energy security concerns were high, the US Air Force set itself a goal of using 50% Fischer-Tropsch "synfuel" by 2016[40]. The Air Force was most interested in coal-to-liquids synfuels, a far more mature technology. US legislation, passed in 2007, prevented any government agency, including the Air Force, from buying fuels with higher emissions than petroleum. The government therefore funded research into co-gasifying biomass with coal to produce liquid fuels, on the basis that biomass is classified as "zero carbon" (contrary to scientific evidence). Those efforts, too, proved futile and the Air Force's synfuel goal has been quietly abandoned. The Department of Energy's Fischer-Tropsch research programme now focuses entirely on coal and natural gas-to-liquids[41], a development that precedes the Trump administration.

Technical problems with biomass Fischer-Tropsch technology include:

- Challenges posed by biomass gasification: Although some biomass gasifiers which use homogenous feedstock have been made to work, this is not an off-the-shelf technology. Successful gasifiers are generally ones which operators have spent years adjusting and repairing, while the vast majority of biomass gasification projects worldwide fail. Problems include explosions, tars clogging up the equipment, chemicals in the gas causing corrosion, and problems with gas purification. Solving those problems can push up operating costs and reduce energy gains[42];

- Coal-to-liquids technology has been developed over many decades, but biomass has very different chemical properties from coal – and there are significant differences in the properties of different types of biomass, so coal cannot just be replaced with biomass. Each feedstock requires specific catalysts and technology adjustments. The US alone spent $3.6 billion on coal Fischer Tropsch conversion research & development[43]. The South African Apartheid regime heavily subsidised coal-to-liquids technology and the company they had set up in 1950 to deploy the technology, Sasol. In 2005, Sasol stated that it supplied 28% of South Africa's liquid fuels from coal[44]. Yet even coal-to-liquids technology remains expensive and cannot compete with petroleum without high subsidies to cover the capital costs.

The development of biomass Fischer-Tropsch technology thus lags decades and many billions of dollars behind that of coal Fischer-Tropsch fuels, which have only been viable with a combination of generous subsidies and low coal prices. Any technical breakthrough would likely apply to one single type of biomass given the varying characteristics of different feedstocks. There is little genuine research and development into biomass Fischer-Tropsch at present and it seems highly unlikely that such fuels will be available for airlines in the next few decades.

Planes flying with fuels made from sugar?

Two technologies for turning sugar into aviation fuel have been developed, one by Amyris, the other by Gevo. Both are biotech companies using synthetic biology, i.e.

extreme geoengineering, to genetically modify microorganisms.

Amyris, as mentioned above, has given up on trying to produce biofuels. It had been selling biofuels at a cost of $7.80 per litre, which is $1,240 per barrel, but was making a loss even at such exorbitant prices[45]. Nobody else has come forward to invest in this technology.

This leaves Gevo as the only contender, using different technology.

Gevo made headlines in November 2016, when it supplied the first ever aviation biofuels made from wood to Air Alaska. Breaking down cellulose contained in wood into sugars which can then be fermented has been possible for over a century[46], but the costs and energy balances have been prohibitive. Gevo did not in fact process any wood. Instead, sugars obtained from wood were delivered by a now defunct public private research initiative[47]. Gevo has built a commercial-scale refinery in Minnesota. That refinery contains four fermenters, all of which use corn starch. Three produce ordinary corn ethanol, a fourth has been designated to produce isobutanol which is then upgraded to useful hydrocarbons, including jet fuel, in Texas. Gevo's isobutanol production has been so expensive, and so beset with problems, that the whole business continues to operate at a loss. In its 2016 Annual Report to the financial regulators in the US, Gevo admitted: "We have produced only limited quantities of isobutanol at commercial scale and we may not be successful at increasing our production"[48]. The company conceded it has had problems with contamination – i.e. the wrong type of yeast getting into the isobutanol fermenters – and with achieving the yields it had hoped for, by which it must mean the yields which it has been telling airlines and government agencies it could achieve. Gevo's losses and debts continue to mount, and the company's future seems in serious doubt.

Creating a new demand for sugar cane or cereals would mean more industrial monocultures for biofuels, grown at the expense of food and at the expense of grasslands and other biodiverse habitats. It would also mean more agrochemical use, more water and soil pollution and depletion. However, this does not appear to be a realistic threat posed by aviation biofuels.

Air Alaska's flight with isobutanol from sugars in wood appears to have been nothing but a PR stunt: there has not been a single successful ethanol refinery that uses wood in the world, despite many attempts – whereas ethanol production from sugar crops and cereals is commonplace. Given that nobody has succeeded in commercially successful

U.S. Air Force photo/Staff Sgt. Oely Santiago: First aircraft flown with Alcohol-to-Jet fuel by the US Air Force, fuel supplied by Gevo, June 2012 isobutanol production from any type of sugar, the idea that this could be done from wood in the foreseeable future seems far-fetched.

LanzaTech: Aviation biofuels without biomass?

In 2016, VirginAtlantic announced a partnership with the New Zealand/US company LanzaTech, with whom it had been collaborating since 2011. It announced that LanzaTech had produced 1,500 gallons of aviation biofuels at a demonstration plant in

Shougang Jingtang Iron and Steel Plant – at which LanzaTech's demonstration plant is situated; photo: wikimapia.org

Shougang, China[49]. The fuel is yet to be approved for use for passenger flights. LanzaTech's fuel, despite being certified by the Roundtable on Sustainable Biomass[50], is not in fact made from biomass. The company has genetically engineered gas-fermenting Clostridium bacteria, commonly found in hydrothermal vents, in order to ferment carbon monoxide from flue gases to ethanol and another chemical, butanediol[51] which can be converted to hydrocarbons, including aviation fuel.

LanzaTech's concept is attractive: Planes would eventually fly without fossil fuels or biofuels from crops or trees, which require large areas of land. Instead, smokestack gases coming out of steel mills or oil refineries would be captured and fermented to fuels. By the end of 2014, LanzaTech had attracted investment from Mitsui, Siemens, Khosla Ventures, and New Zealand Superannuation Fund, amongst others, and it had entered into Joint Ventures with two large Chinese steel producers[52]. Yet there is little evidence that LanzaTech is anywhere close to a commercial breakthrough. Between 2014 and 2015, its annual losses grew while its revenues dropped[53]. LanzaTech's website lists four pilot and demonstration plants it has built – three of which have been closed[54].

According to Robert Rapier (author a blog on energy issues), the key problem with LanzaTech's technology is energy balance[55]. Even a conventional corn ethanol refinery requires high energy inputs, much of it for distilling the ethanol, which is recovered from fermentation tanks in 12-15% solutions. The less concentrated the solution, the more energy is needed to boil off the water[56]. In March 2017, LanzaTech revealed that it had achieved less than 2% concentrations of ethanol, and less than 4% concentrations of butanediol (i.e. of the chemical which can be upgraded to aviation fuels – requiring further energy inputs)[57]. This means that LanzaTech will need at least six times more energy than a corn ethanol refinery for distillation. LanzaTech claims that it will use "low-value waste heat" from steel mills or a refinery, but, as Rapier has pointed out, waste heat is only "low-value" because it is not hot enough to boil water. With such high energy requirements for distillation, LanzaTech is clearly a very long way from being able to fuel planes.

Genetically engineered microbes for biofuels may not be commercially successful, but pose serious dangers

Amyris, Gevo and LanzaTech have all been using synthetic biology, i.e. extreme genetic engineering, to develop microorganisms which can help convert biomass into biofuels, including for planes. Amyris and Gevo have been engineering baker's yeast to ferment sugars to two different precursors of hydrocarbon fuels. LanzaTech has been engineering gas fermenting Clostridium bacteria, which metabolise carbon-rich flue gases to biofuels.

The ecological and health implications of genetically engineered microorganisms escaping or being deliberately released into the environment remain unknown and largely unassessed, but of most serious concern:

- Microorganisms play a vital role in regulating the carbon cycle and all planetary nutrient cycles, including soil nutrient cycling. Yet their ecology is poorly understood and it is estimated that only around 1% of all yeast and bacteria species have ever been isolated and identified;

- Once a GE microorganism enters the environment, it will be difficult to detect and impossible to isolate. Even if it was to proliferate to form large populations and cause harm, limited knowledge of the world's microbial diversity would make it very difficult to trace back to its source. Reversing any harm done would be virtually impossible;

- Microorganisms are capable of transferring genetic materials to other species, even to plants and animals. Such "horizontal gene transfer" has been observed in Clostrodium bacteria and in yeasts. This means that altered gene sequence may not remain limited to the intended species;

- Microorganisms have a particularly large potential for population growth and evolutionary change. Even GE microorganisms thought to be unable to survive in the natural environment could acquire the ability to do so through gene transfer and mutations[58].

In 2012, LanzaTech obtained permission for the environmental release of GE bacteria in New Zealand[59]. Gevo and Amyris claim that their use of GE yeast in refineries is 'contained'. However, Gevo has admitted to struggling with contamination of its isobutanol fermenter, i.e. with keeping other strains of yeast out of it. If it cannot prevent undesired yeast from entering that fermenter than it is difficult to imagine that the company can contain the GE yeast inside it. In 2012, the industry magazine Biofuel Digest reported about Amyris:

> *A friend of the Digest writes: "I was in Brazil last month and got an earful about that from a very high up there on [Amyris]. If their shiny high grade fermenter was not up to snuff they are really in trouble…having worked in nice university labs and clean room pharmaceuticals they did not know what was awaiting them in the down market dirty world of biofuel. You can't make biofuels with anything you got to keep that clean."*[60]

Synthetic biology research, NASA Ames, Photo: Alexander van Dijck

4. Palm oil for planes – by far the most credible feedstock for aviation biofuels

Hydrotreated vegetable oils: the world's fastest growing type of biofuel

In 2007, the Finnish oil company Neste inaugurated a completely new type of biofuel production into its oil refinery in Porvoo, near Helsinki. This biofuel – made from Hydrotreated Vegetable Oil (HVO) - was chemically identical to petroleum-derived diesel, which made it technically superior to biodiesel or ethanol.

Three years later, Neste went on to open the world's two largest biofuel refineries, in Singapore and in Rotterdam. Each produces almost 1 million tonnes of HVO fuels per year. Several, mostly oil companies, have followed suit, although Neste still accounts for 60% of global HVO production[61].

The Italian oil company Eni has converted an oil refinery near Venice to 100% HVO production and is in the process of converting a second, in Sicily. Total is converting its La Mède refinery in France. Repsol and Cepsa in Spain and Galp in Portugal are co-processing vegetable oils and animal fats with fossil fuel oil. Preem in Sweden and the paper company UPM in Finland have built HVO refineries which use a byproduct from pulp and paper production (tall oil) as a feedstock.

In the US, AltAir, Diamond Green Diesel and REG are operating HVO biofuel refineries, and Emerald Biofuels and SG Preston have plans for future ones.

Three Chinese refiners, Yangzhou Jianyuan Biotechnology Co Ltd, ECO Biochemical Technology Co Ltd and Hainan Huanyu New Energy Co Ltd have been certified as producing HVO diesel which meets the EU biofuel standards set out in the Renewable Energy Directive[62]. Furthermore, China Petrochemical Corporation (Sinopec) has announced plans to build an HVO refinery with the stated aim of producing fuel for aircraft[63].

HVO refineries have also been announced in United Arab Emirates, Indonesia and Mexico, although the status of those plans is uncertain.

Altogether, 5.2 million tonnes of HVO were produced in 2016. HVO accounts for 4% of biofuels worldwide, but is growing at over ten times the rate of biofuels overall[64]. With two new HVO refineries due to open in 2017/18, and with Neste expanding its capacity, HVO production will continue to grow steeply.

Eni's Porto Marghera refinery near Venice which has been converted to HVO production from palm oil, Source: panoramio.com/photo/40482299

What exactly is HVO?

HVO is made from the same feedstocks as biodiesel: vegetable oils (including rapeseed, palm and soybean oil) and animal fats (mainly tallow, a residue from slaughterhouses). It consists entirely of hydrocarbons, i.e. compounds of hydrogen and carbon.

Hydrotreating, used to produce HVO, is a process widely used in fossil fuel oil refining, which oil companies have adapted to vegetable oils and animal fats. It involves reacting oils and fats with hydrogen, which is usually produced from natural gas[65]. Reactions take place under high pressure and at temperatures of 300- 400^{o}C.

HVO fuels can be produced in existing, possibly retrofitted oil refineries, or in purpose-built ones. They can also be processed together with fossil fuels in a refinery. Biodiesel refineries, on the other hand, cannot be converted to HVO fuels.

There are two important differences between HVO and biodiesel:

Firstly, HVO products are chemically identical or near identical to petroleum-derived products. This means that there is no limit on the amount of HVO that can be blended with diesel. On the other hand, most diesel engines can only burn limited amounts of biodiesel. The EU's legal standard for diesel permits a maximum of 7% biodiesel blends[66]. HVO is thus essential to meeting biofuel targets of more than 7%. And, because HVO products can be used in aircraft in up to 50% blends, whereas biodiesel is unsuitable for aviation[67].

Secondly, the properties of biodiesel vary depending on the feedstock, but those of HVO vary only according to the refining conditions[68]. Biodiesel made from some types of vegetable oil – most importantly palm oil – solidifies during normal winter temperatures in temperature climates, which strictly limits the amount of palm oil that can be used for biodiesel.

HVO fuels for planes: Still an expensive niche market

At present, the vast majority of HVO fuels are

HVO diesel, used in road transport. The fact that HVO diesel can be used in higher blends makes it competitive with biodiesel, even though it is more expensive to produce. Like most biofuels, it depends on subsidies, including blending mandates and quotas in order to compete with fossil fuels[69].

HVO diesel is cheaper to produce than HVO fuel for aircraft, called HEFA. This is because HEFA refining requires more severe processing, which reduces biofuel yields per tonne of feedstock by 5-10%.

AltAir, the world's only regular producer of HEFA, appears to be selling it as a "loss leader", one which has gained them a lot of interest and publicity, while making most of its income from selling HVO diesel and getting federal and state subsidies[70] for that.

According to several estimates, the production cost of HVO aviation fuel is above $1,000 per tonne[71]. By comparison, the highest monthly global jet fuel price during the year ending 31.8.17 was around $426 per tonne[72]. Jet fuel prices are on average only slightly above those of diesel. This means that even extending the subsidies available for road transport biofuels to aviation biofuels would not make HEFA competitive with HVO used in cars.

Far cheaper HVO for airplanes on the horizon

Aviation biofuels will have to become significantly cheaper to produce before airlines can use them on a large scale. This could happen very soon if an application made by Neste and Boeing to the standards agency ASTM is approved.

In 2014, the two companies tested a blend with 15% HVO diesel (i.e. the HVO fuel normally only used for road transport) in a jet engine[73]. They argue that the overall blend met all of the technical specifications for jet fuel and should therefore be approved. Approval of this application would immediately lower the production cost of aviation biofuels to that of HVO diesel. Except where subsidies favour biofuels for cars, HVO could become even more profitable when sold to airlines rather than for road transport, because jet fuel prices are slightly higher than those for diesel.

15% of current global jet fuel use translates to 43.3 million tonnes. This is equivalent to 3 times the volume of the EU's entire biofuel market - or 1.6 times the world's entire biodiesel production[74].

In 2011, a High-Level Panel of Experts warned[75]: "Biofuel support policies in the United States and the European Union have created a demand shock that is widely considered to be one of the major causes of the international food price rise of 2007/08." It pointed out that the growth in global vegetable oil markets would have slowed down had it not been for the major growth in European biofuel use between 2000 and 2010. This was happening at a time when global and EU vegetable oil use for biofuels was significantly smaller than today. Creating a new biofuel market for vegetable oils 1.6 times as big as the one that exists today would have very dramatic effects indeed.

Can we really expect 43 million tonnes of HVO diesel burned in planes in the near future?

There can be no doubt that approval for 15% blends of HVO diesel in commercial aircraft would be a very significant breakthrough.

However, HVO diesel is more expensive than biodiesel and far more expensive than fossil fuel diesel[76]. HVO "cost parity" with petroleum-based jet fuel would thus require new subsidies to bridge the remaining gap.

At present, far more generous subsidies are available for road transport biofuels than for aviation biofuels:

In the EU, subsidies mainly take the form of blending mandates. Such mandates have been introduced by Member States seeking to meet a 10% renewable energy target for road and rail transport by 2020, set by the EU Renewable Energy Directive, as well as a related target contained in the Fuel Quality Directive. Aviation biofuels can be counted towards meeting Renewable Energy Directive Targets, but no EU member state requires airlines to use any biofuels.

The only country in the world with a biofuel mandate for aviation is Indonesia, which has

Felled rainforest on a Korindo oil palm concession in Papua, Photo: Mighty Earth, farmlandgrab.org/post/view/27387-samsung-get-out-of-conflict-palm-oil

mandated 2% from 2018, 3% from 2020, and 5% from 2025. However, the 2% mandate was to originally have started in 2016, and there are doubts as to whether it will be enforced in future[77].

The question of whether aviation fuel made from HVO diesel will be adopted on a large scale thus comes down to policy decisions: will ICAO members decide to make funds raised from aviation carbon offsets available to help airlines bridge the price gap between petroleum-based jet fuel and biofuels, as the Brazilian Biojetfuel Platform proposes[78]? Will the EU and governments around the world extend existing biofuel subsidies to aviation and perhaps introduce new ones?

The outcome will largely depend on whether governments and ICAO are prepared to create and subsidise a new market for palm oil.

Why palm oil is essential for large-scale HVO use

So far, airlines have been careful to avoid biofuels made from palm oil. The high level of public awareness about rainforest and peatland destruction and landgrabbing associated with oil palm plantations would make it a PR disaster for companies promising “greener” aviation. It looks far better for airlines to source the still tiny amounts of biofuels used so far from wastes and residues. Yet it is difficult to see how biofuel use for flights could be scaled up without resorting to palm oil.

Technically, HVO can be made from any vegetable oil as well as from animal fats. Feedstock accounts for 60-80% of production costs[79]. The second biggest cost is for hydrogen. Hydrogen requirements and thus costs can be reduced by choosing feedstocks which are rich in saturated fats, such as palm oil or tallow, as opposed to soybean, rapeseed or camelina oil.

EU support for aviation biofuels

The European Commission has endorsed aviation biofuels for many years. In 2011, it published a White Paper calling for 50% “sustainable low carbon aviation fuel” use by 2050. In the same year, it partnered with industry to set up the European Advanced Biofuels Flight Path Initiative, which aims for 2 million tonnes of aviation biofuels to be produced annually by 2020. There has been significant EU funding for research and development into aviation biofuels biofuelstp.eu/aviation-biofuels.html. Aviation biofuels which meet the - albeit very weak – EU biofuels standards are classified as “zero carbon” under the European Emissions Trading Scheme (ETS). In practice, this has not yet made a difference because the ETS carbon price has been far too low to compensate airlines for the higher cost of such fuels.

The European Commission’s proposal for a new, post-2020 Renewable Energy Directive includes a progressively tightening cap on food-based biofuels, including ones from virgin vegetable oil, the abolition of a separate renewable energy target for transport, but a new mandatory target for “advanced biofuels”.

As the new legislation is debated, crucial decisions will be made about incentivising aviation biofuels in general (by counting them higher towards renewable energy targets, and about deciding which types of biofuels (regardless of where they are used) are defined and incentivised as “advanced biofuels”. Companies such as Neste want to get HVO classified as “advanced”.

Bridging the price gap between jet fuels made from fossil fuels and those made from biofuels requires keeping feedstock and other operating costs as low as possible. This would still be the case even if existing subsidies for biofuels for road transport were extended to aviation.

According to a 2011 report by one of the leading technology developers for HVO biofuels, Honeywell-UOP[80], tallow was the cheapest HVO feedstock at the time. But tallow and other suitable wastes and residues, namely Used Cooking Oil, are in limited supply. Tallow and Used Cooking Oil are popular biodiesel feedstocks, and some types of tallow are in high demand for animal feed, soap, cosmetics, rubber and plastic production.

For example, Total is converting an oil refinery in La Mède, France to HVO and will require 650,000 tonnes of vegetable oils and animal fats per year in order to operate the plant at full capacity. Total claims that it will use 100,000 tonnes of Used Cooking Oil, but has only succeeded in signing a sourcing contract for one-fifth of that amount. A specialist trader in waste vegetable oils and fats, Greenea, estimates that Used Cooking Oil collections could at most be increased by 50,000 tonnes a year across France. All of Total's other feedstock – ranging from 550,000 to 630,000 tonnes a year - is expected to be palm oil[81].

Not surprisingly, given the cost considerations discussed above, the vast majority of HVO produced worldwide is made – completely or partly – from palm oil:

- Finnish oil company Neste, the world's leading HVO producer, states that its use of crude Palm Oil dropped from 31% in 2015 to 19% in 2016, and that wastes and residues accounted for 78% of its feedstock that year[82]. 19% of palm oil translates into half a million tonnes, still a very substantial amount. However, Neste's so-called residues include an undisclosed proportion of a constituent of Crude Palm Oil called PFAD[83], which many believe should not be classified as a residue at all (see below);

- Italian oil company ENI runs its HVO refinery near Venice, Italy, entirely on palm oil[84], which is also the expected feedstock for the HVO refinery it is currently converting in Sicily;

- Portuguese oil company Galp started co-processing 3% of palm oil in its Sines oil refinery in Portugal in September 2017[85]. Galp has set up its own oil palm plantations in Brazil[86];

Even jet fuel from tallow could be bad news for forests and climate

Tallow is a residue from slaughter houses. It comprises animal fats which can be used in food, and ones which are not safe for human consumption. In the EU, tallow which is not edible for humans is divided into three categories, only one of which (category 3) can be used for soap, cosmetics and industrial products. In 2016, the European Commission published a commissioned study about indirect impacts associated with biofuels made from tallow (ec.europa.eu/energy/sites/ener/files/documents/Annex%20II%20Case%20study%202.pdf). It concluded that "an increased used of animal fats by the biodiesel industry would lead to indirect effects through ILUC [indirect land use change] and fossil fuel combustion". The livestock industry itself was responding to the new tallow demand for biofuels by selling tallow which it would otherwise have burned for on-site heat and power and switching to fossil fuels instead. The oleochemical industry (soap, cosmetics and various industrial products) was particularly dependent on tallow, but the competition for tallow from the biofuels sector helped producers that could most easily and cheaply switch to palm oil by partnering with Southeast Asian plantation companies. Those companies could easily switch from tallow to palm oil. The animal feed industry, on the other hand, could replace tallow with palm or rapeseed oil. A new tallow market for HVO for aircraft would also compete with biodiesel producers, who might have to switch to palm oil or other virgin vegetable oils. Flying aircraft on blends with biofuels made from tallow could thus have much the same overall impacts as flying them with HVO from palm oil.

- In Spain, Cepsa (owned by International Petroleum Investment Company) and Repsol jointly produced 140,000 tonnes of HVO in the first half of 2016 (i.e. 280,000 tonnes throughout 2016, assuming that the rate of production remained the same all year). Together, they are co-processing palm oil with fossil fuels in 7 or 8 refineries[87];

- BP produces HVO from palm oil in its Rotterdam refineries and in two refineries in Spain;

- Chinese HVO producers Hainan Huanyu New Energy Co Ltd and ECO Biochemical Technology Co Ltd use PFAD (see below) in their mix;

- In Indonesia, an HVO refinery has been proposed by the state-owned oil and gas company Pertamina in collaboration with a palm oil company, PT Perkebunam Nusantara.

Hiding palm oil amongst residues: Why Palm Fatty Acid Distillate (a PFAD) matters in the debate about aviation biofuels

Companies hoping to become aviation biofuel producers face an obvious dilemma: on the one hand, the economics of HVO production strongly favour palm oil. On the other hand, palm oil fuels would pose a reputational risk to airlines and undermine efforts too "green" the industry's image.

HVO refiners have found a partial answer to this dilemma: Palm Fatty Acid Distillates (PFAD), which companies like Neste controversially class as a 'residue'. When crude palm oil is refined, free fatty acids are removed because they turn palm oil rancid and thus unsuitable for food. PFAD, which contains those concentrated fatty acids, is used by the oleochemical industry in soap, cosmetics, candles, rubber and plastic, for animal feed, and to extract compounds for nutraceuticals[88].The UK Government advises:

> *"The treatment of PFAD in the RED [Renewable Energy Directive] GHG [greenhouse gas] calculations indicates that it is to be treated as a product. PFAD has a significant economic value in relation to the main product (palm oil) and a variety of productive uses."*[89]

This seems sensible, given the high demand for PFAD and the fact that none would be wasted in the absence of a demand for biofuels. Biofuel guidance in Sweden, Finland and Norway also states that PFAD should not be classified as a "waste or residue"[90]. Italy on the other hand classifies PFAD as a residue and counts it double towards its biofuels targets.

Such a debate about classifications may sound academic, but it has major implications for palm oil use in biofuels:

In the EU, biofuels made from residues are exempt from most sustainability standards, and count double towards renewable energy targets, which gives them a significant price premium. Furthermore, from the beginning of 2018, palm oil processed in mills without methane capture will no longer meet the EU's greenhouse gas standards for biofuels[91], yet this will not affect any palm oil "residues". And the European Commission's proposal for a post-2020 Renewable Energy Directive would provide yet more incentives to biofuels made from residues and wastes as opposed to virgin vegetable oil, sugar crops and cereals. In short, classifying PFAD as a residue allows companies such as Neste to make more profit (through double-counting of its biofuels), and to protect itself against any future regulations that may limit palm oil use.

Getting PFAD classed as a residue by ICAO would allow airlines to source HVO made from palm oil, without having to declare it as such. The same could happen if ICAO was to classify PFAD as a by-product whilst treating those in a similarly favourable way as the EU treats wastes and residues for biofuel.

That could contribute significantly towards making HVO use in aircraft commercially viable, albeit not at the scale proposed by the ICAO Secretariat. Right now, PFAD production worldwide is just 2.5 – 3 million tonnes a year. A multi-million tonne demand for aviation biofuels would have dramatic, though difficult to predict, impacts on palm oil markets.

There are two main ways in which PFAD use in aviation biofuels could lead to new and larger oil palm plantations:

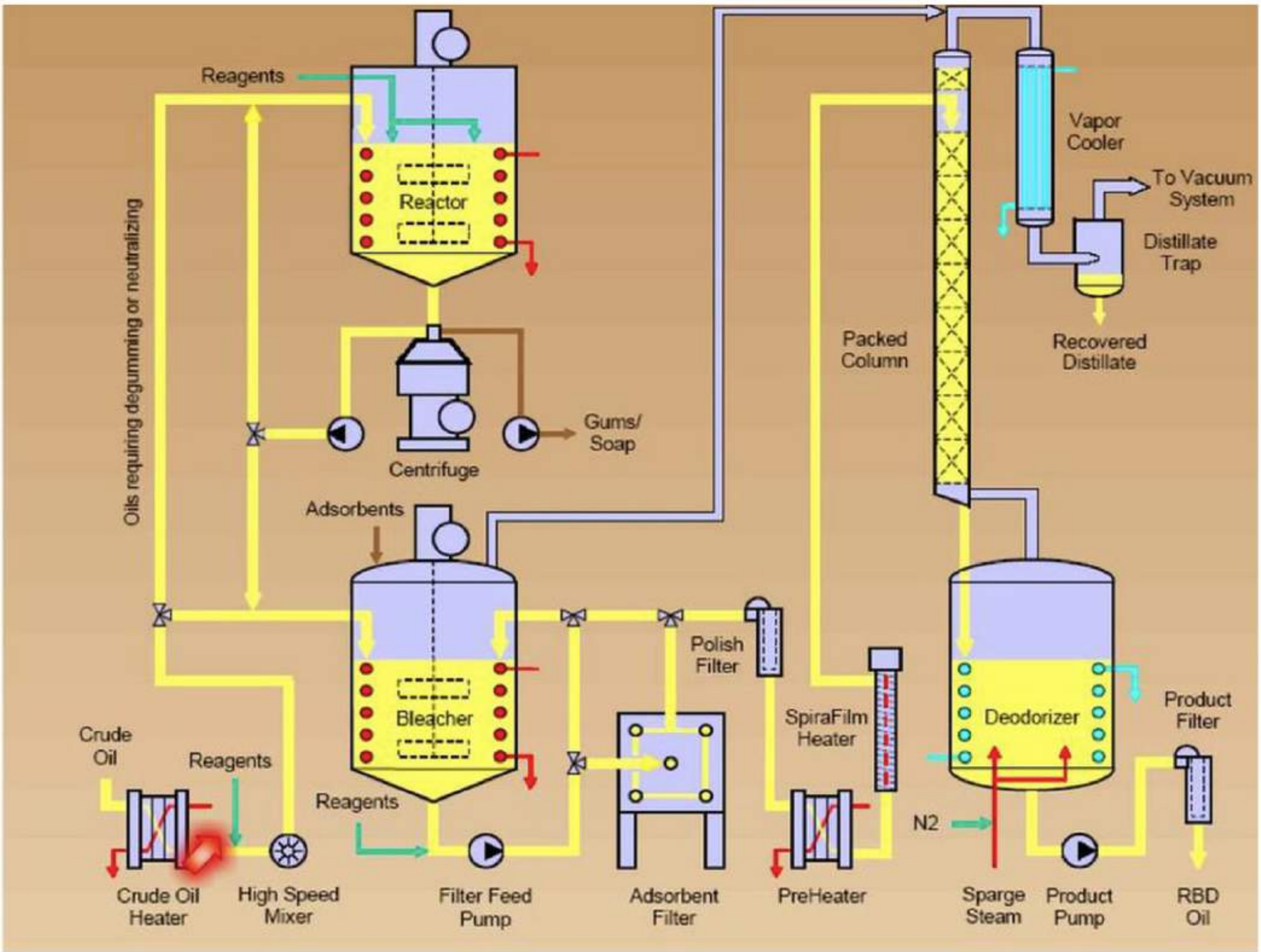


Diagram of a Crude Palm Oil refinery (Note: Recovered Distillate is PFAD), Source: Abd Karim Alias, vimeo.com/34329405

The most obvious one will be for animal feed producers and oleochemical companies to replace PFAD with crude or refined palm oil, particularly since the other attractive alternative, tallow, is also increasingly used for biofuels.

Another possibility is that a spiralling demand for PFAD could push up its price to match or move beyond that of refined, edible palm oil. If that were to happen, palm oil processors and growers might start producing crude palm oil with a greater fatty acid content, i.e. deliberately increasing the proportion of PFAD compared to refined palm oil. This is technically possible and would directly couple PFAD demand to oil palm expansion[92].
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5. Why sustainability and greenhouse gas standards for aviation biofuels are not the answer

Whether or not sustainability (including greenhouse gas) standards can guarantee that biofuels and other forms of bioenergy are sustainable and low-carbon has been debated for many years. Biofuelwatch has long argued that they are inherently ineffective as a tool for addressing negative impacts of bioenergy[93] because:

- standards cannot address “sustainability of demand”: for example, excessive demand for agricultural products and wood has long been the primary underlying driver of deforestation and forest degradation. Driving this demand up further can only make the situation worse;

- there are no credible ways of addressing the major indirect impacts of bioenergy through standards;
- there is no regulatory mechanism for monitoring and enforcing compliance with standards;
- the World Trade Organisation and bi- and multilateral trade agreements exert strong pressures against genuinely meaningful standards.

Standards cannot make the ICAO Secretariat's aviation biofuels "Vision" sustainable. Firstly, the scale of the additional biofuel demand would be highly unsustainable. Secondly, there is no real alternative to using palm oil for large-scale aviation biofuels no matter what standards might say. Suitable wastes and genuine residues are in limited supply. And there is no good argument for taking scarce wastes and residues away from road transport biofuels as long as mandates for those remain in place – doing so would simply lead to more palm and soybean oil being used for cars.

Finally, ICAO itself is drawing up standards through its Committee on Aviation Environmental Protection, yet it is heavily dominated by the aviation industry and not known for its expertise in protecting forests or community rights.

Nonetheless, if standards were to explicitly prohibit the use of palm oil – including PFAD – this would go a very long way towards preventing serious harm from aviation biofuels. It would almost certainly prevent large-scale uptake of biofuels for planes altogether. Whether such standards would be permissible under World Trade Organisation regulation is highly questionable. It would be far safer for governments to refuse to subsidise aviation biofuels altogether.

6. The dangers of hype about palm oil for planes

Even if large-scale aviation biofuels do not become a reality – perhaps because palm oil use is politically too sensitive – there is a serious risk that plantation companies will profit from mere expectations generated by an ICAO "vision" such as that proposed by the Secretariat.

2006 landgrab by UK company Sun Biofuels in Tanzania, 2008 Photo: Tom Pietrazik, ActionAid – 11 villages lost 20,000 acres of land, no biofuels were ever produced, Sun Biofuels went bankrupt but the land went to a cattle ranching company, rather than being returned to the communities

In 2013, ActionAid reported that 98 European investors had taken control over 6 million hectares of land in Sub-Saharan Africa between 2009 and May 2013 with the stated aim of producing biofuels, especially for the EU market[94]. Yet figures published in the same year showed that virtually no African feedstock had been used for EU biofuels by 2013[95]. The mere expectation of a major new demand for vegetable oils and other agricultural products from Africa was enough to facilitate one of the biggest land-grabs in history. It helped persuade state authorities to lease or sell land to investors, and to attract finance – even if the real intention behind many of those acquisitions may have been to acquire land for different purposes, or to simply profiteer from land speculation.

There is a risk that an ICAO "vision" for large-scale aviation biofuels could fuel land-grabs in a similar manner, regardless of whether it is ever realised.

7. Conclusions

ICAO's support for large-scale biofuels stems from the aviation industry's quest to protect its high growth rates, something which would be impossible if it was forced to genuinely reduce its greenhouse gas emissions.

The only mature technology for producing aviation biofuels is hydrotreating of vegetable oils and animal fats (HVO). Even HVO aviation fuels are currently so expensive that they can only be produced in small quantities. However, Neste and Boeing have applied to the international standards agency ASTM to permit up to 15% blends of HVO diesel in planes. HVO diesel – currently used for road and rail transport only - is the fastest growing type of biofuel worldwide. Approval of HVO diesel blends with jet fuel would dramatically lower the price of aviation biofuels.

Nonetheless, HVO diesel costs significantly more than petroleum-based jet fuels. Even with subsidies, there would be pressure on producers to keep costs down. The cheapest feedstock by far which is available on a large scale is palm oil. HVO production for road transport is already heavily dependent on palm oil, and it is difficult to see how the same could be avoided for aviation biofuels.

Whether planes will in future fly with fuels from palm oil in their tanks will largely depend on political decisions, made by ICAO and by governments. Awareness of the serious negative impacts of palm oil has grown over the past decade. In April, the European Parliament adopted a resolution which calls on the European Commission to "take measures to phase out the use of vegetable oils that drive deforestation, including palm oil, as a component of biofuels, preferably by 2020"[96]. In the US, the Environmental Protection Agency has so far refused to accredit palm oil as a biofuel feedstock eligible for federal subsidies (i.e. for the Renewable Fuel Standard). It will be vital for civil society groups to oppose subsidies for aviation biofuels, which would translate into new subsidies for palm oil.

Plane Stupid Scotland scale the Scottish Parliament building in protest against plans for airport expansion. Photo by Alice Myers

At the same time, it is important to debate about aviation biofuels in the wider context of aviation. Greenhouse gas emissions from aircraft today – let alone in future, at the projected growth rates – are incompatible with stabilising global warming at 1.5^{o}C or even 2^{o}C. The only credible way of tackling those emissions is through policies which stem and reverse the growth in aviation – including better investment in and support for rail and bus services and abolishing subsidies for aircraft, including tax exemptions.

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65. It is possible to make the hydrogen from one of the byproducts of HVO production, propane, but the propane is commonly sold as "renewable" LPG instead.

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68. However, very impure waste feedstocks can cause damage to the hydrotreating equipment, and some feedstocks are easier to refine than others.

69. There is no consensus as to whether consumption mandates, such as those for biofuels, should be defined as a subsidy. The International Energy Agency and the Global Subsidies Initiatives regard them as subsidies, because they drive up market prices, set a demand floor and thus make biofuel production more competitive. We use this definition (see Biofuels — At What Cost? A review of costs and benefits of EU biofuel policies, Global Subsidies Initiative, April 2013, iisd.org/gsi/sites/default/files/biofuels_subsidies_eu_review.pdf)

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