TECHNICAL BRIEFING

The reality of waste-derived fuels: up in the air

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Introduction

In light of recent promotional statements from technology providers, governments, and academic and research institutions, this report looks at the proposed application of converting municipal waste into fuel, namely for gas turbine aircraft engines. General information on the concept of plastic to fuel (PTF) can be found in other publications (Rollinson and Oladejo, 2020; Schiegel, 2020).

Jet Engine Fuel

Gas turbine aircraft engine (jet) fuel, often called 'aviation kerosene', is a mid-crude oil distillation cut between gasoline and diesel, with hydrocarbons in the C_8-C_{16} range. It has a high concentration (70-85%) of paraffins, and contains naphthalenes and aromatics. Standards, however, are based on performance rather than composition (ASTM D1655).

Acceptable aviation fuel must perform consistently and safely in extreme conditions: it must allow engine re-light at high altitude, and it must have low viscosity to ensure consistent atomisation (Blakey et al, 2011). Aviation fuel must also fulfil other functions, including **hydraulics** and balancing aircraft weight. One aerospace representative called it 'the Swiss army knife of aircraft', and warned 'don't play with our fuel quality' (Jeuland, 2019). It is also currently accepted that any proposed plastic- or waste-derived aviation fuel must be 'drop in'; meaning that it must meet the current standards exactly (Bergthorson and Thomson, 2015). This is to avoid the logistical problem of airports handling multiple fuel types, and due to the long working life of commercial jet engines. Alarmingly, therefore, some are proposing the very technologies with a track record of failure at the simpler function of municipal waste disposal (gasification and pyrolysis) for the challenging and difficult task of creating high-specification aviation fuel (Gleis, 2012; Rollinson and Oladejo, 2020). **In short: plastic- or waste-derived engine fuels have been failures in other sectors, and with aviation fuels, the bar is raised even higher.** Moreover, the expectation that new engines could work with new fuel types is unlikely to be supported by the aviation industry due to the investment required to change fleets.

hydraulics
Mechanical systems operated by pressurised fluid, e.g. brakes, undercarriage/ landing gear, and directional controls.

Status

only 0.3% of aviation fuel comes from alternatives to crude oil

A rigorous, lengthy, and very expensive testing regime stands in the way of alternative jet engine fuels (ASTMD4054). According to the International Civil Aviation Organization, only eight alternative production routes are currently permitted and municipal solid waste or plastic is not on the list (ICAO, 2020). Only one of these routes is reportedly at commercial scale, this being hydroprocessing of vegetable oils and animal fats (Bauen et al., 2020). Currently, it is estimated that only 0.3% of aviation fuel comes from alternatives to crude oil (Chiaramonti, 2019).

Thirty years after lab demonstrations, the industrial scale-up of pyrolysis has still not happened (Chiaramonti, 2019). This technology remains at 'early demonstration stage' due to its products' high viscosity, water, acidity and oxygen content, as well as chemical instability (Bauen, et al., 2020). These obstacles are well-known, in addition to unsustainability from high energy requirement (Rollinson and Oladejo, 2019).

30 years after lab demonstrations, the industrial scale-up of pyrolysis has not materialized

When it comes ot gasification of municipal waste, which is usually followed by **Fisher-Tropsch (FT) synthesis**, there are at least two commercial ventures that company websites and press releases have advertised as under development. One site was alleged to have operational difficulties by one author, although these were refuted by the company (Lane, 2020).

Approved ASTMD4054 research testing stations were contacted to seek information on whether any municipal waste-derived fuels had passed all or any of these stages, or even been submitted for testing. Of the handful which responded, none would answer, quoting reasons of confidentiality. Though the Standard specifies that there must be reports of testing, albeit not explicitely made public, none for municipal waste-derived fuels were found in the public domain.

Fisher-Tropsch (FT) synthesis

A method for making hydrocarbons from carbon monoxide and hydrogen. It occurs over a metal catalyst at temperatures around 200°C and at heightened pressure.

Despite this lack of public evidence, one technology provider claims that their fuel (Fulcrum Bioenergy Fuels, no date): '...has been tested, certified and approved for commercial and military aviation worldwide.' If this claim refers only to biomass-derived fuel, great caution is urged not to conflate this with a product derived from mixed waste, for the problems with gasification as a mixed-waste-to-fuel process have been known for a century. The technology destabilises with non-standard (woody biomass) feedstocks and it has inherent problems with scale-up, while gas clean-up is extremely difficult and needs non-standard technology (Rollinson, 2018). Simply put, the challenge will be getting a gas of sufficient (and consistent) quality to satisfy the secondary catalytic FT processing stage, where impurities (nitrogen, chlorine, sulfur, tar and soot) will deactivate the catalyst, and higher oxygen and unsuitable H_2/CO ratios will necessitate complex gas cleaning stages on top of other additional processing (Dry, 2002).

A Fulcrum Bioenergy press release states that it will use **Johnson Matthey** FT components. It is interesting therefore that a very recent publication in the same company's journal reports that (Bauen et al., 2020): 'The integrated application of biomass gasification to FT [Fischer-Tropsch] fuel has yet to be demonstrated at scale'.

Alternative Technology Viability

Solvent-based technologies target plastic rather than mixed waste as a feedstock. The argument against these concepts is that they are too far away from technological readiness, produce large quantities of toxic spent solvent, and are pursued not because of their merits but because of the failures of gasification and pyrolysis (Rollinson and Oladejo, 2020). One other important factor is that plentiful academic funding is currently available for their research and this perpetuates the idea of technological viability, however impractical in real terms. Fundamental technical issues include low yield, long processing times, high temperature and high energy demand, and the inability to tune the product distribution – in other words, poor product quality (Liu et al., 2021).

At the time of writing, two academic studies currently dominate internet search engine results, namely Jia et al. (2020) and Liu et al. (2021), though it is likely that these will soon be yesterday's news. Results include many press releases containing the same information over different sites, a PR-driven practise known as 'churnalism'.

Johnson Matthey

Multinational company specialising in, among other things, chemicals and catalysts.

Jia et al. (2021) accept that their process 'requires very high energy input'. No energy balance is provided but the process uses supercritical hydrogen (H_2) at pressures of 60 bar and 200°C temperatures, along with the need to shred and clean the plastic. Pure hydrogen H_2 is created by steam reforming of (fossil fuel) natural gas, and at industrial scale the infrastructure required for use of 60 bar H_2 will be prohibitive. An even more impractical aspect is the use of ruthenium (Ru) in high relative quantities at 0.5 g of catalyst (containing 5% Ru) per 1 g of high-density polyethylene (HDPE) processed. Ru is one of the rarest elements on Earth. Extrapolating to a modest scale of an economically feasible commercial plant at say 100,000 tonnes per year, this means 50,000 tonnes of catalyst (i.e. 2500 tonnes of ruthenium (Ru)), while the total annual global production of ruthenium (Ru) is only 30 tonnes! Catalysts cannot be reused repeatedly, even after energy-intensive treatment. Such catalyst deactivation is clear from the tables and figures, though the text downplays this by claims that the degeneration stabilised after two runs — an insufficient duration. Spent solvent is perhaps the greatest obstacle and has been the reason for the collapse of previous attempts at commercial scale-up for this type of technology since both toxins from the plastic and newly created but unwanted molecules carry-over into the solvent (Sherwood, 2020). With the ratios required, for the same modest 100,000 tonne-per-year HDPE plant, this creates 2.5 million m^3 of post-processing **n-hexane**.

> “ For a commercial waste-derived jet fuel plant with a capacity of 100,000 tonnes per year, 2500 tonnes of ruthenium (Ru), one of the rarest elements on Earth, is needed, while the total annual global production of Ru is only 30 tonnes.

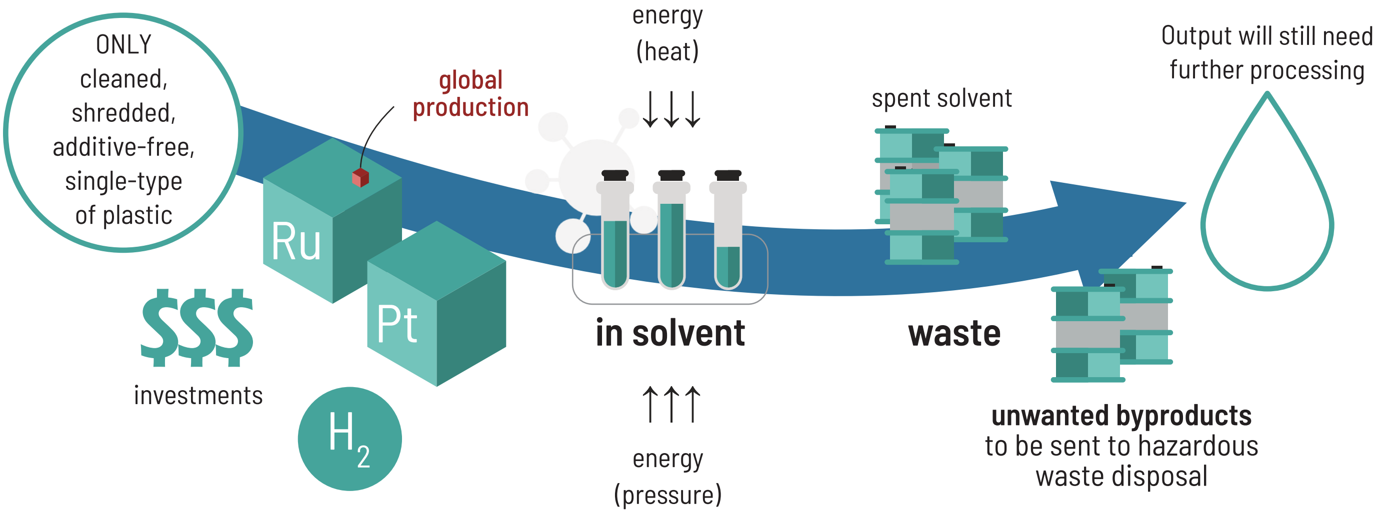
Liu et al. (2021) use platinum (Pt) catalysts for between 2 to 12 hours, at a temperature between 225 and 300 °C, and at a pressure of 30 bar. An energy balance is provided, but it is incomplete and misrepresentative for it only considers 'heating'; such that when it finds pyrolysis at a temperature between 500 and 550 °C to be roughly 10 to 11 times more energy-intensive it does so by it excluding the energy needed to produce H_2, maintain this H_2 at supercritical conditions of 30 bar and discounts Pt production. It also assumes that the process uses virgin catalyst on its first

n-hexane

Normal (n-) hexane is a volatile, flammable and explosive hydrocarbon. Health effects include neurotoxity, respiratory disease and skin irritation. It should not be released to water courses due to its chronic hazard to aquatic life.

run; while the catalyst degenerates rapidly after the first batch with 30% more solid waste produced on the second run and then nearer to 40% on the third run. Despite this, the authors call their process 'a promising energy-saving approach toward plastic waste-to-fuels conversion'.

It is easy to be accused of being a 'naysayer' when faced with such concepts, but sound practical engineering common sense must prevail. These technologies also have the same problems that come with handling mixed plastic, for waste does not come readily cleaned, shredded, and separated with its dyes, stabilisers and other additives and contaminants removed. Liu et al (2021) experimented with mixed plastics and the reaction time had to be multiplied by 4 in contrast to the unrealistic reagent grade low-density polyethylene (LDPE).



Sustainability

Jet engine aircraft combust large quantities of fuel and their impact on climate change is estimated to be around 3.5% of all global warming (Lee et al., 2021). The environmental impact is however greater than CO_2 emissions alone, with the high-altitude release of H_2O, NO_x, soot particulates, sulphur dioxides, and other hydrocarbons (Lee et al., 2020; Blakey et al., 2011). But, it should always be remembered that one unit of engine thrust must release similar quantities of CO_2 and H_2O into the atmosphere irrespective of the fuels' origin, for this is the only way to release energy. So, drop-in fuels will perform identically when burned (Blakey et al., 2011). Any differences in CO_2 and H_2O emissions must then come from the production routes, but the manufacture of plastic from gas or crude oil has an enormous carbon footprint of its own (see Zheng and Suh, 2019).

One will find bold claims in corporate press releases and websites about the environmental benefits of waste-derived aviation fuel. One video claims that the fuel will have a 'negative carbon score', and even that 'Every gallon consumed removes carbon from the atmosphere' (Fulcrum Bioenergy, no date). Others claim that their product, for example (Velocys, 2019): 'enables a net 70% reduction in greenhouse gas emissions [and] improves air quality, with up to 90% reduction in particulate matter (soot) from aircraft engine exhausts and almost 100% reduction in sulphur oxides; and the technology offers a lower emissions route to process UK waste than incineration or landfill.' How this can be true for a drop-in fuel with such rigid specifications is not explained.

The peer reviewed literature is far more conservative, with sober estimates that alternative aviation fuels may only offer between 15% to 24% CO_2 savings by 2050 (Blakey et al., 2011). Indeed, it is not a given that there must be a positive outcome at all. As stated (European Union Aviation Safety Agency, 2019): **'the emissions of a bio-based aviation fuel as compared to the emissions from the production and combustion of conventional aviation fuel can be lower, comparable or even higher.'**

The issue of particulate emissions for different fuels is still unresolved. For pyrolysis and gasification-based technologies, this is due to the presence of aromatic molecules which do not oxidise easily (Tang et al. 2021); these are precursors to soot formation thus increasing emissions and reducing combustion efficiency (Kathrotia and Riedel, 2020).

For alternative aviation fuels, any possible environmental impact is minimised by the standards allowing only between 10% and up to 50% blending; the remainder being conventional crude oil distillate (ASTMD7566).

The technology provider website and media claims quoted above were unsupported by references. Their source was investigated and found to be elusive; the companies were contacted but did not respond to requests for substantiation. The matter is as stated by Blakey et al. (2011):

> **'Too many numbers are bandied about around media sites that have not been through the peer review process. Methodologies of obtaining the lifecycle assessment (LCA) need to be scrutinised and standardised.'**

Alternatives

It is estimated that a third of all aviation fuel use comes from domestic flights (Chiaramonti, 2019). So, displacing domestic flights with train travel is one alternative option. The government of France has recently taken the lead here by announcing that it would implement such a ban on domestic flights where rail travel exists (Picheta and Wojazer, 2021). Other, less dramatic, alternatives are to implement better, more coordinated and fuel-saving air traffic control management, for example to minimise time spent both circling to land and waiting to take off (Williams, 2007). Improving engine technology to increase efficiency and reduce emissions may be the immediate or near future of aviation transportation. But, ironically, such 'advanced low-emissions gas turbine engines' operate with **lean pre-mixed ignition**, and because of this, any MSW-derived alternative fuel may become immediately redundant because these systems will require more exacting fuel standards" (Bergthorson and Thomson, 2015).

lean pre-mixed ignition

This involves thoroughly mixing fuel with more air (i.e. oxygen) than is necessary (defined as 'lean' conditions), and prior to combustion.

Replacing domestic flights with train travel

Fuel-saving air traffic control management

Improving engine technology

In Conclusion

There are no easy paths to sustainability for aviation. Greater efficiency in engines and operations would be an improvement, but the industry will still remain locked into its reliance on fossil fuels. Proposing to make alternative fuel from municipal waste is not, however, the answer. When one takes away the vacuous claims of 'proof', the PR-driven media narrative control, the churnalism, and the projections based on unsubstantiated life cycle analysis, all that remains is speculation in terms of potential viability, environmental impact, and sustainability. Such proposed solutions tend to facilitate a façade which outwardly supports corporate and governmental responsibility in the short term, but in the long term, provide a distracting diversion from the need to reduce waste production, ban single-use plastic, and leave fossil fuels in the ground.

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