BLACK & VEATCH THOUGHT LEADERSHIP

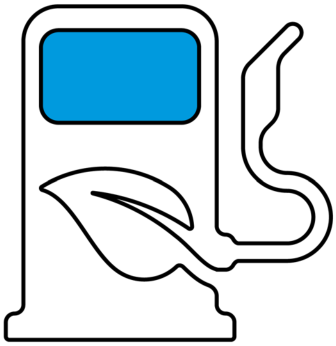
Sustainable Fuels: Challenges and Opportunities of Biomass to Liquids From MSW

2024

BLACK & VEATCH

About This Report

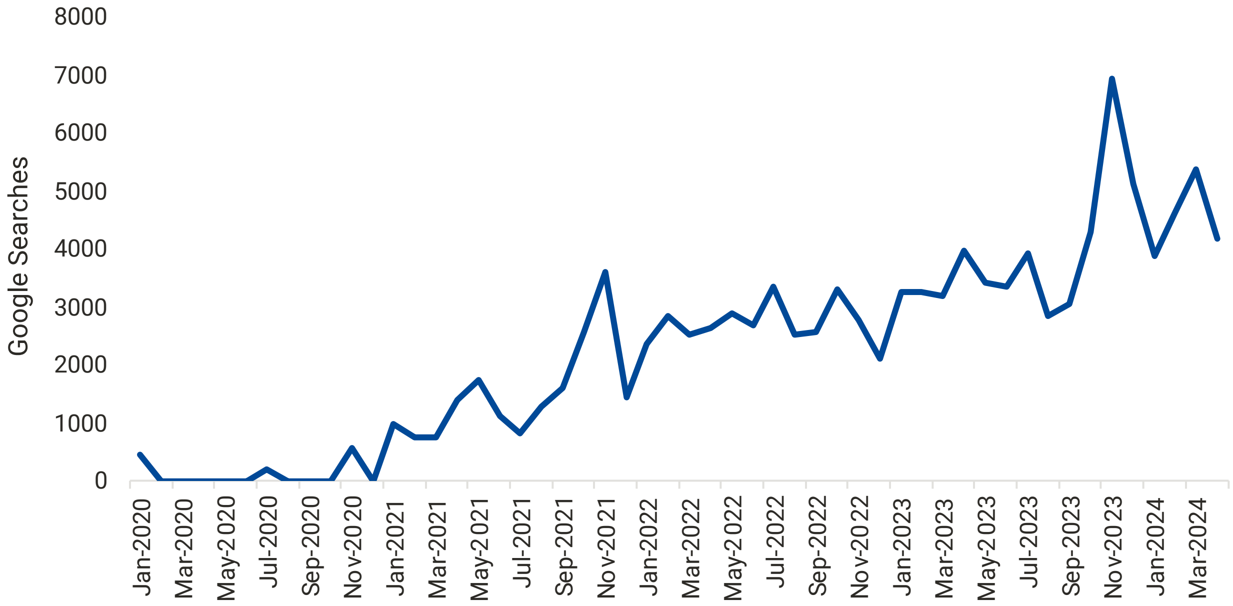
Interest in Sustainable Aviation Fuel (SAF) has been rising in the last three years, and supportive state policies worldwide continue to drive activity in the field.



This paper casts a high-level look at the issues and challenges. We review the need for aviation decarbonisation, various SAF regulations in place globally, feedstocks and routes for producing SAF, and finally, a closer look at the issues and challenges of Municipal Solid Waste (MSW) to SAF, which is seen as a large, low carbon and potentially low cost pathway (though with operational complexity and risk).

While the paper focuses on issues and challenges within an Australian context, the themes and insights apply to a wider set of countries.

Figure 1. Google Searches for the Keyword 'Sustainable Aviation Fuel'



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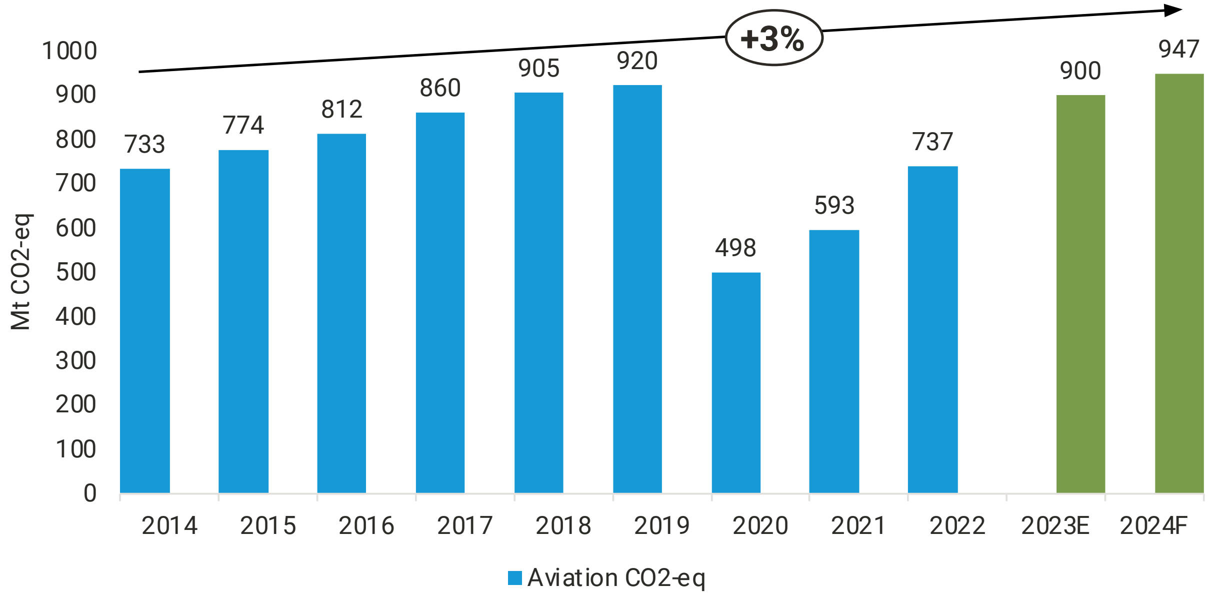
Small Scale Biomass To Liquids From MSW

The SAF Market Doubled In 2023, and Will Continue to Grow

Aviation was estimated to have emitted 1036 Mt of CO2-eq in 2019 (IEA, 2023) , amounting to 2.7% of the 38 Gt of global anthropogenic GHG emissions (IPCC, 2022)[1]. Within this, commercial airlines (i.e. excluding defence and private aviation) as estimated by the IATA emitted 920 Mt in 2019, and with global aviation recovering from the aftermath of COVID, emissions are expected to overtake the 2019 number in 2024 (IATA, 2023).

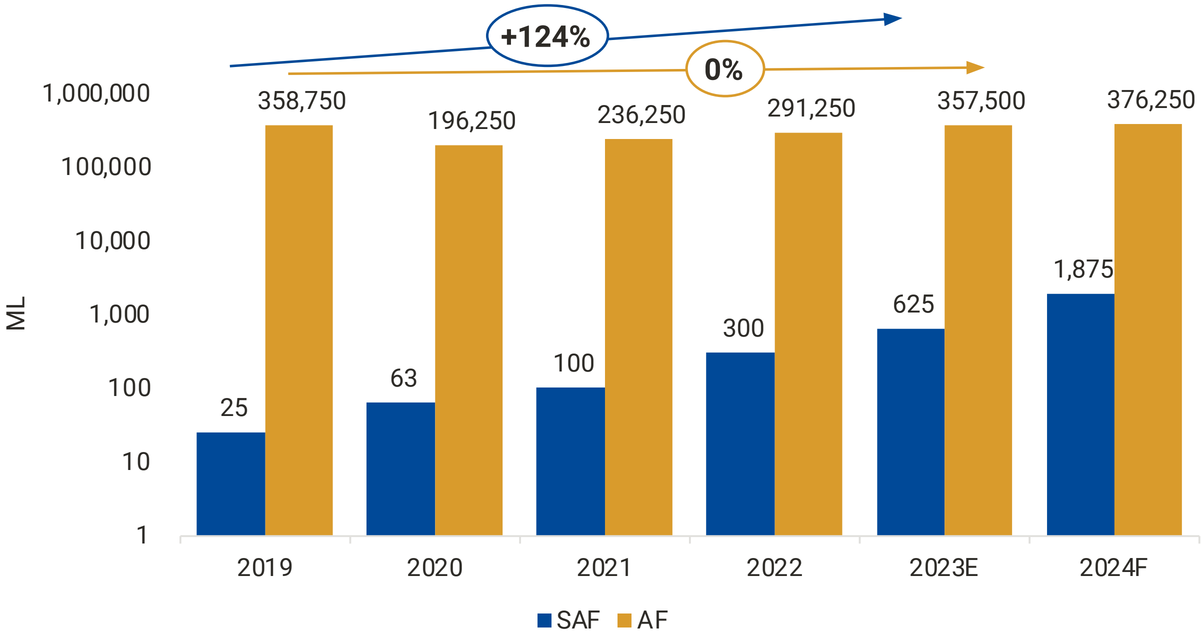
Figure 2. GHG Emissions From Aviation — Past and Future (IATA, 2023)



Sustainable Aviation Fuel (SAF) has emerged as a means to curb carbon emissions from the aviation sector, with various government and voluntary airline targets and mandates in place (EU 6% by 2030, UK 10% by 2030, Canada (BC) 3% by 2030, Japan 10% target by 2030, Qantas 10% target by 2030, etc.).

The SAF market has been growing at 124% CAGR over 2019-23, with consumption in 2023 expected to have been 625 ML (Figure 3). Though a doubling over the demand in 2022, it would still have been only 0.17% of the 357 GL (fossil) aviation fuel market.

Figure 3. SAF and Fossil AF Supply (Mistry, IATA)



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[1] Aviation emissions estimated by the IEA for 2019 were 1036 Mt CO2-eq. This corresponds to only the fuel burned, and not the warming effect of contrails. Total anthropogenic GHG emissions in 2019 were 59 Gt CO2-eq, of which 38 Gt CO2-eq was from fossil fuel combustion.

SAF Mandates Are Coming Into Force, and the Market Will Grow by More Than 3300% by 2030

There were 37 SAF policies around the world as of 2023, targeting demand and supply side factors (Watson, et al., 2024). See for a summary of these in Table 1.

Blending mandates have been in force since 2020 (Norway), and got a significant boost in October 2023 with the EU ReFuelEU Aviation initiative. Continental Europe and the UK leads the way in demand-side legislation to support SAF, while the US continues to support decarbonisation through supply side incentives. In Asia, Singapore has mandated 1% SAF blending from 2026, while other jurisdictions are planning similar programmes.

Table 1. SAF Mandates and Policy Support in Key Regions

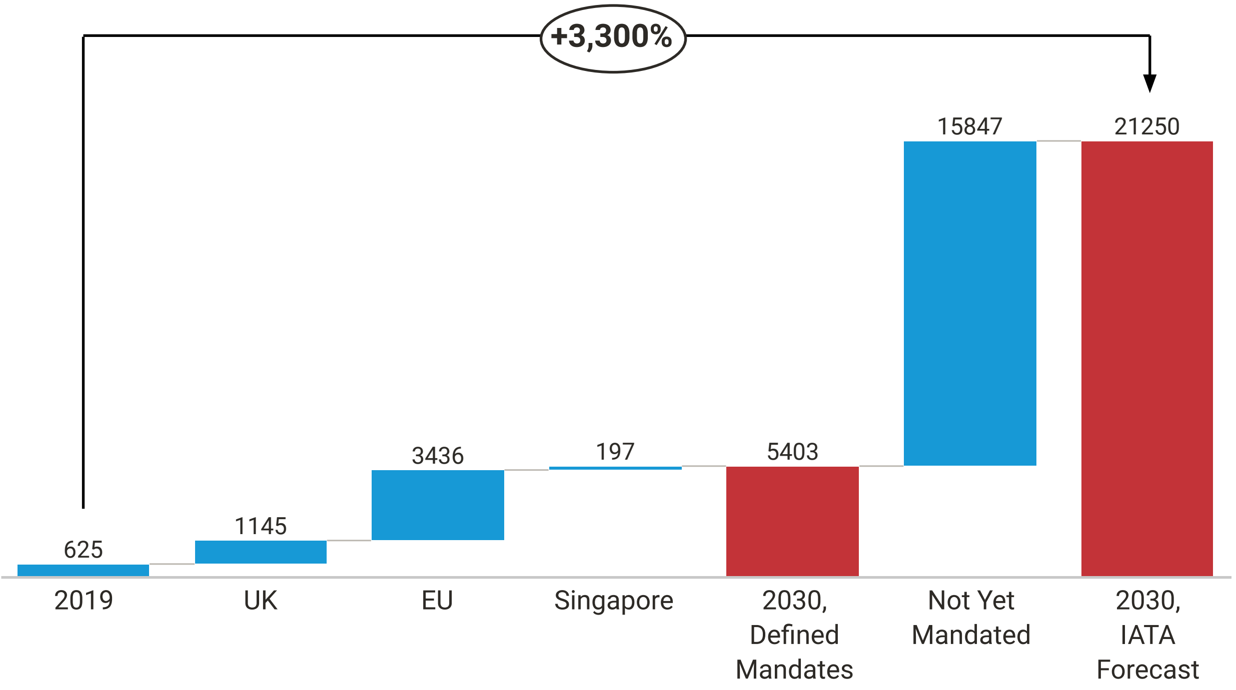
Jurisdiction	Name/Type of Regulation	Status	Enforced From	Details
Norway	Blending mandate	In force	2020	Starting at 0.5% in 2020 and increasing to 30% by 2030
Sweden	Blending mandate	In force	2021	Starting at 1% in 2021 and increasing to 30% by 2030
France	Blending mandate	In force	2022	Starting at 1% in 2022 and increasing to 2% in 2025. 5% by 2030 and 50% by 2050
California	Low Carbon Fuel Standard (LCFS)	In force, with SAF opt in	2022	The Low Carbon Fuel Standard (LCFS) requires the carbon intensity of all types of transport fuel (including electricity sold for EV charging by utilities) produced or imported into the state to be reduced by 20% by 2030, and 80% by 2050. Notably, however, aviation fuel for intra-state flights is exempted until 2028. The California Air Resources Board (CARB), which issued the LCFS, has limited power to influence inter-state flights, as it is a Federal matter. Separately, bill AB 1322 to mandate the use of SAF for intra state flights in California that was tabled in 2022 and passed by the assembly and senate, was vetoed by Governor Newsom in 2024.
Washington and Oregon	LCFS (Washington and Oregon); SAF price incentive (Washington)	In force, with SAF opt in	2021, 2023	SAF generates credits if opted in under the LCFS as in California and Oregon. Additionally, a Washington State SAF price incentive operates, which can give up to a US$2/gallon incentive for SAF
USA (Federal)	IRA (price support)	In force	2022 (revised 2024)	SAF credit of US$1.25 per gallon. SAF must have at least a 50% reduction in lifecycle GHG emissions over fossil jet fuel. Supplemental credit of one cent for each percent that the reduction exceeds 50%.
EU	RefuelEU Aviation	In force	2024	SAF supply in blend to increase from 2% in 2025 to 6% by 2030 and 70% by 2050. From 2030, 1.2% SAF must be synthetic fuels, rising to 35% by 2050. Biofuels from food and feed crops excluded.

Jurisdiction	Name/Type of Regulation	Status	Enforced From	Details
Canada (British Columbia)	Low Carbon Fuel Standard (LCFS)	In force	2024	Original 2008 LCFS revised in 2023 to include SAF. SAF to increase from 1% in 2028 to 2% in 2029 and 3% in 2030 and stay at 3%
UK	Blending mandate	Pending Parliamentary approval	2025	Starting at 2% in 2025, increasing linearly to 10% by 2030, and to 22% by 2040, then staying flat. HEFA limited to 71% in 2030 and 33% in 2040. PtL mandate from 2028, increasing to 3.5% by 2040
India	Blending mandate	Planned	2025	1% SAF blending
Germany	Blending mandate (PtL)	In force	2026	Aiming for 0.5% of AF to be SAF via PtL by 2026
Turkey	Blending mandate	Planned	2026	Starting at 1% in 2026 and increasing to 5% by 2030
Singapore	Blending mandate	In force	2026	1% SAF blending by 2026, rising to 3-5% by 2030
Japan	Blending mandate	Planned	2030	10% SAF blending

The demand from The EU, UK, and Singapore mandates — which are in force at present — means that 2030 SAF demand will be 5.4 GL, even if the underlying aviation traffic remains at its pre-COVID peak.

The IATA expects that SAF demand will rise to 17 Mt (21 GL) in 2030 (Mistry), meaning that an additional 15.8 GL of SAF will have to be supplied over the mandated minima. This represents a 3,300% increase over pre COVID levels.

Figure 4. SAF Demand (Ml) From Defined Mandates and Voluntary/Supply Side Subsidies In 2030 (Assuming No Organic Growth of Underlying Aviation Market) (Assumed Singapore Will Have 3% SAF by 2030)



MSW and Fischer Tropsch Offering Attractive GHG Savings Amongst the SAF Pathways

Conventional fossil aviation fuel (AF), like other petroleum distillates, is a complex mix of various straight chain and cyclic hydrocarbons. There are various points of difference between SAF and AF, such as:

- The distribution of hydrocarbons of various chain lengths
- The percentage of aromatics (low in all of the currently certified SAF production pathways)
- The percentage of olefins
- The physical properties, such as viscosity, freezing point, flash point, etc. — which are dependent on the above differences in chemical composition

The above differences limit the blending of SAF with AF to a maximum of 50% at present.[1]

More generally, SAF can be defined as an engineered mix of hydrocarbons, with the carbon and hydrogen units coming from a variety of sources and processes. These can be summarized as:

- Pure e-Fuels, where the carbon units are supplied from CO_2 in the air through Direct Air Capture, and Hydrogen from electrolysis ("Power to Liquids")
- Fuels where the hydrogen and carbon come from biogenic sources. Some supplemental hydrogen is required for these pathways, whether provided externally by reacting the syngas produced from the feedstock with steam. These are:
  - More HEFA from different types of vegetable oils and waste oils as the feedstock, or from third generational oleaginous feedstocks such as algae and genetically modified crops.
  - SAF synthesized from alcohol resulting from the fermentation of carbohydrates ('alcohol to jet'). Sugarcane, corn, and a variety of carbohydrate rich crops such as sorghum are possible candidates. Enzymes have also been developed to ferment cellulosic biomass such as bagasse (second generation ethanol). The basic route follows a fermentation to alcohol, after which several different pathways to a hydrocarbon is possible.
  - SAF synthesized from the gasification of waste biomass to produce syngas, followed by Fischer Tropsch (FT) synthesis and product upgrading. Further details on the FT synthesis pathway are provided in **Box 1: The Syngas and FT pathway**.

As of July 2023, there were 11 ASTM certified feedstocks and production pathways for SAF under two standards: ASTM D7566 and ASTM D1655. Another 11 were under evaluation.

Although HEFA using waste oils and greases like tallow, UCO, PFAD are currently in use, they are difficult to scale up. With tallow, scaling up would entail disrupting existing supply chains as tallow is a feedstock for other materials that may end up sourcing high carbon feedstock from elsewhere). With UCO, the barriers are increasing collection rates in the major edible oil consuming countries, and guarding against fraud i.e. diverting virgin oil into the UCO market with minimal use. Collection rates are already at 60-80% of potential in China ((Kristiana, Baldino, & Searle, 2022), which is the largest source of supply accounting for nearly 70% of the 3.7 billion gallon global UCO market in 2022 (Global Data, 2023). With PFAD, the challenge is that high demand would make it a co-product rather than a byproduct of palm oil production, an argument that led to its exclusion from the ReFuelEU policy.

Looking further afield, we have crop based carbohydrates (Ethanol from sugarcane and corn are the largest inputs into biofuels today. In addition, palm oil into biodiesel, though a major industry in Indonesia, is associated with deforestation and high ILUC carbon impact. The latter is excluded from the ReFuelEU initiative and wouldn't qualify for credits under the United States Inflation Reduction Act for its high carbon impact). Crop based carbohydrates take the alcohol to jet route into SAF (though they could also take the gasification and FT route). These feedstocks are significant — particularly sugarcane, which has a relatively low carbon footprint — on account of the volumes currently going into biofuel mandates around the world, and which may get diverted into SAF as the road transport sector increasingly switches to electric vehicles.

The environmental credentials of ATJ are further improved with the fermentation into alcohols of cellulosic biomass (second generation ethanol) and the cultivation of crops on degraded or marginal land. As the fermentation to alcohol is a low temperature, low capex process compared to gasification and syngas cleanup, the ATJ route holds promise, particularly for small lots of feedstock.

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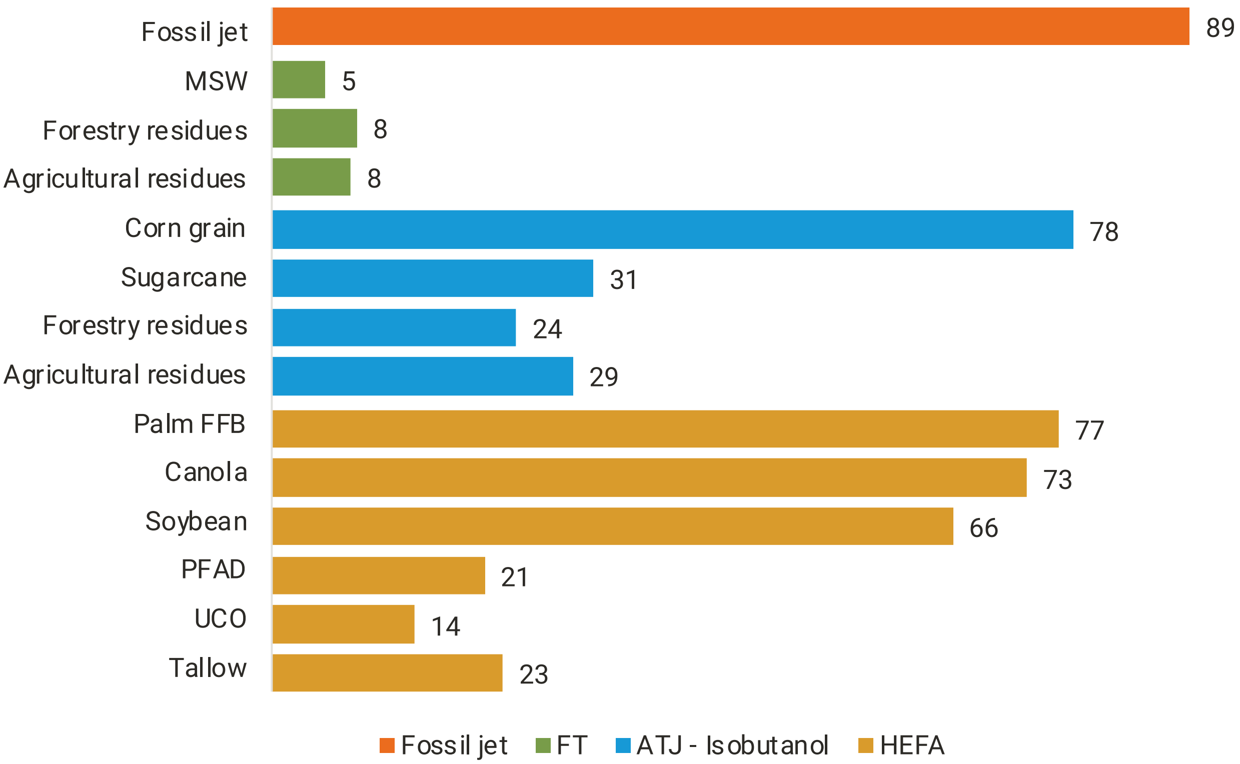
[1] Flights with 100% SAF have been test run successfully. Virgin's "Flight100" from London to New York in November 2023 ran on 100% SAF, as did a United Airlines flight in Oct 2021 from Chicago to Washington DC . Both flights used a blend of HEFA derived SAF with Synthetic Aromatic Kerosene (SAK). SAK is one of the feedstock-process pathways under evaluation by ASTM at present,

However, where it can be deployed at scale, gasification and FT has the lowest life cycle carbon impact, as it can handle dry biomass and MSW with relatively high carbon recoveries (depending on the cost of green hydrogen, virtually all of the biomass can be recovered into fuel).

Figure 5. Life Cycle Emission Factor (LCEF) of Various Feedstocks and Pathways (gCO2eq/MJ) (ICAO, 2024) – Includes ILUC



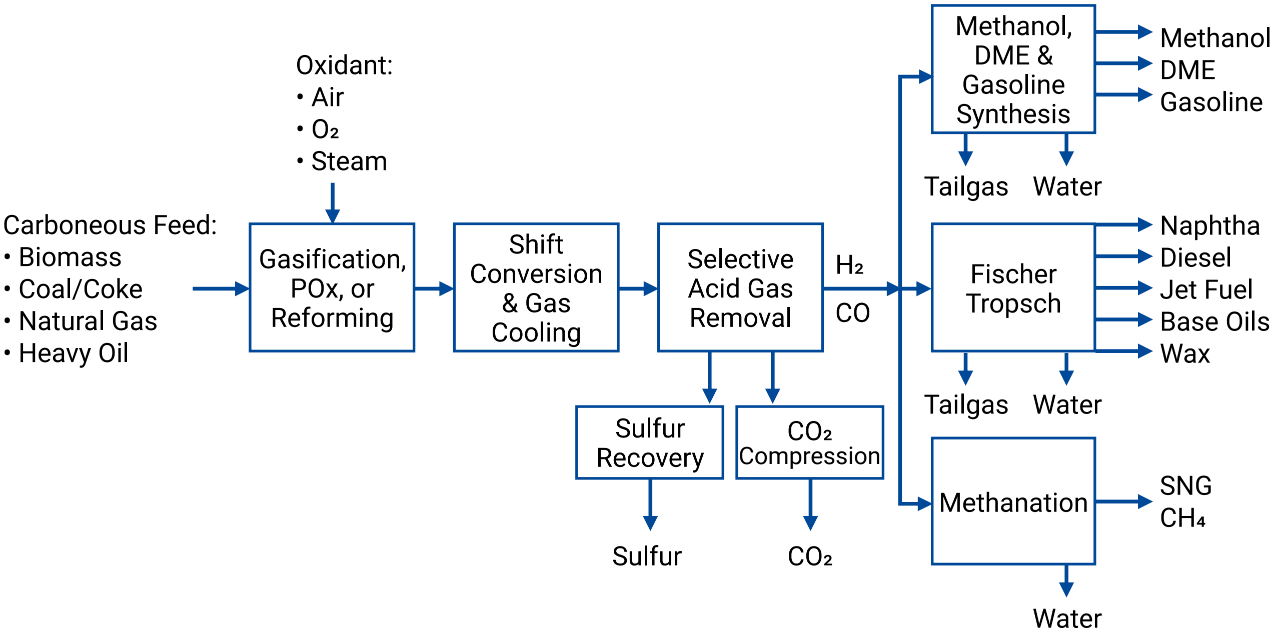
*Global default CORSIA values for all except Sugarcane, which corresponds to Brazil.

Box 1: The Syngas and FT Pathway

The Fischer Tropsch (FT) pathway to produce SAF first begins with the production of synthesis gas (syngas), which consists of a mixture of primarily hydrogen and carbon monoxide. Syngas represents the molecular building blocks to produce higher value liquid fuels products in the FT reactor.

Note that alternative pathways exist that use syngas to produce other hydrocarbons such as Dimethyl Ether (DME), gasoline, and methane, called in this instance Renewable Natural Gas (RNG) (Figure 6).

Figure 6. Thermochemical Processes for SAF Production, Including Fischer Tropsch



The process starts with preparing the (solid) feedstock to go into the gasifier. With MSW, the feedstock is sorted and separated to eliminate tramp metals and other items that shouldn't go into the gasifier. The treated waste then goes into the gasifier where it is reacted with a medium such as air, oxygen, and/or steam, to produce syngas.

If the feedstock is in the gaseous phase, such as landfill gas or biogas from wastewater treatment, then it goes directly into a reformer to produce syngas, followed by the steps below.

The raw syngas from gasifiers typically does not have sufficient hydrogen to achieve the desired hydrogen to carbon monoxide ratio needed for liquid fuel production, and thus undergoes a water gas shift reaction to convert some of the carbon monoxide (and water) to hydrogen (and CO_2). Depending on economics, green hydrogen can be used to supply the extra hydrogen units and to maintain an optimal H2:CO molar ratio of 2:1.

An additional common treatment step is acid gas removal to remove the CO_2 and sulphur contaminants.

Syngas is fed to the FT reactor to produce a crude liquid fuel product, which is then refined and upgraded using conventional refinery processes to selectively produce the desired liquid fuels. Commonly a range of liquid fuels is produced, such as gasoline, diesel, and jet fuel; the upgrading process can be designed to prioritize production of a specific liquid fuel depending on the commercial prospects of the offtake.

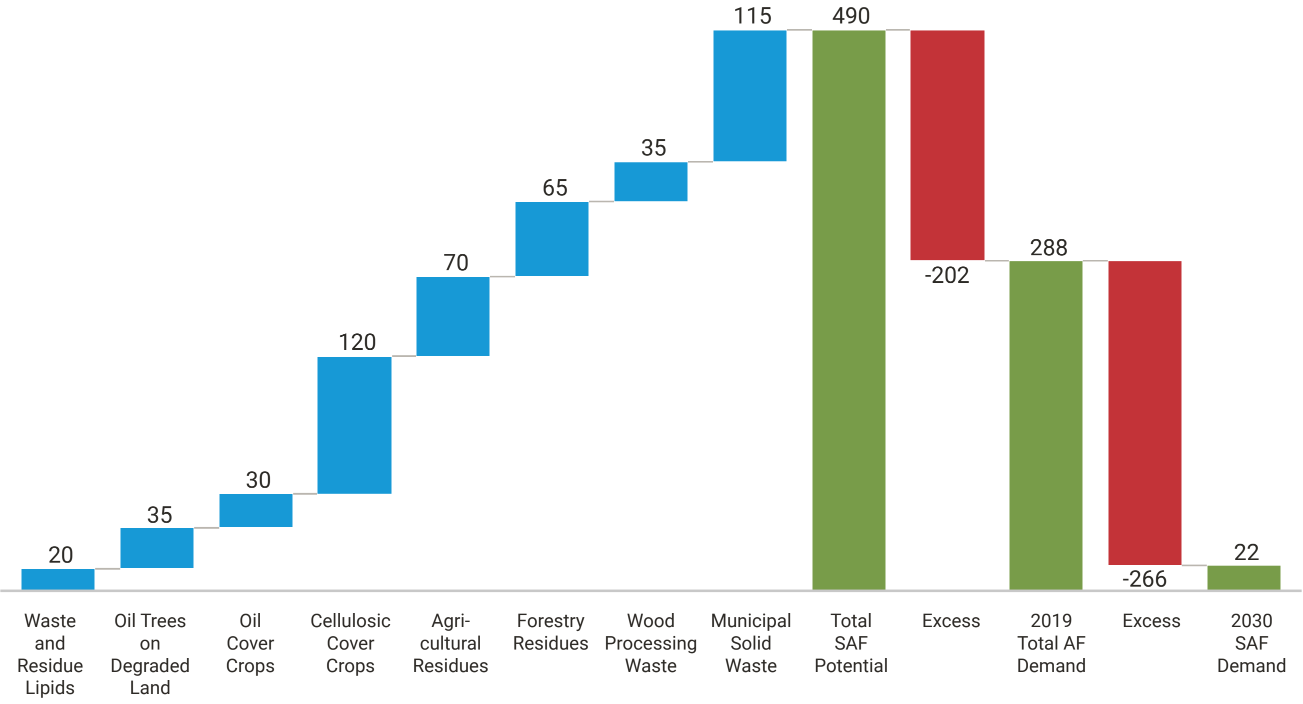
A point to note is that the FT reaction is highly exothermic. The heat is used to produce steam to meet process requirements, power production, or potentially integrated with solid oxide electrolyzers to produce hydrogen. Solid oxide electrolysers are capable of achieving higher efficiencies than room temperature alkaline or PEM electrolysers for the generation of hydrogen.

Another consideration — as previously noted is that if green hydrogen were to become sufficiently cheap in the future, then a greater portion of the carbon in the biomass could be recovered to the liquid by means of a reverse water gas shift reaction, converting more of the CO_2 in the waste gas stream to CO.

There Is Enough Waste Biomass Globally — Including MSW — To Supply Low LCEF SAF

Several studies exist that point to the adequacy of waste biomass feedstocks around the world to meet SAF demand. The 2020 report “Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation” by McKinsey & Co. estimated 490 Mt of SAF that could be produced from global annual production of waste biomass. This is a number far in excess of the requirement for SAF in 2030 or indeed the total quantity of aviation fuel consumed around the world. However, as the above study and several others have noted, the economics of gathering widely scattered resources, the carbon footprint of doing that, and the effect of disrupting existing end use supply chains in certain cases (as with tallow), impose practical limits.

Figure 7. SAF Potential (MT) From Global Waste Biomass Availability Alone (WEF, McKinsey & Co., 2020)

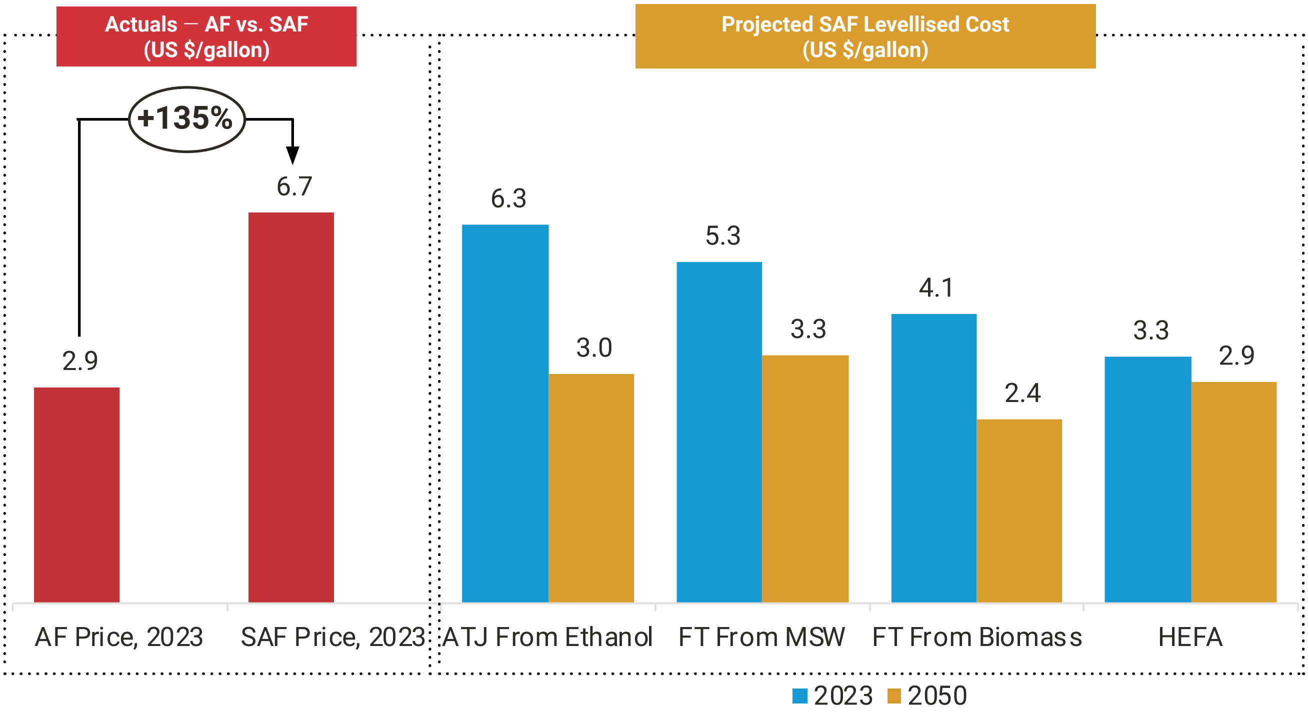


MSW and cellulosic cover crops are the largest potential sources of waste biomass. MSW has the advantage that:

- An existing garbage collection supply chain is already in place
- As cities expand, landfills take up a scarce resource (land), and the waste has to be diverted anyway, with energy or material recovery being the two options.
- Existing landfills generate methane from the garbage inventory, which needs to be tapped anyway for environmental considerations. Again, this methane can be used for energy or material recovery.

Provided that there is sufficient feedstock to build a plant at a viable scale, SAF based on MSW may come closer to parity with jet fuel in the future, without subsidies. Figure 8 shows the current and projected future levelized cost of SAF from the FT process using MSW and dry biomass. While 2-2.3x the price of fossil jet fuel today (and comparable with the price of SAF from HEFA), the technology learning curve can bring the cost down in future to within less than a dollar of the current fossil jet fuel price.

Figure 8. Current Price Vs. Current and Future Levelized Cost of SAF Vs. Fossil Based AF (US $/gallon at AUD:USD of 0.7, ex Australia, Without Subsidies) (CSIRO, 2023) (Reuters, 2023)



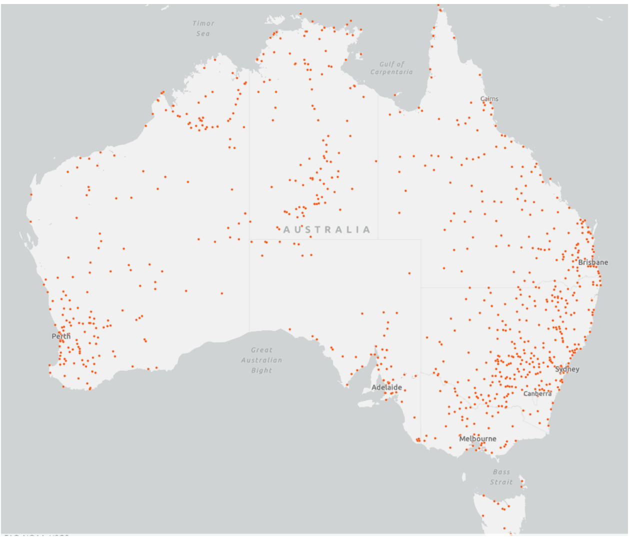
MSW Supply In Australia Is Both Declining and In Competition With Other End Uses

There were 1,035 putrescible landfills in Australia as of 2022 (Blue Environment Pty Ltd, 2022) (Map 1), although only a fraction of these continue to take organic household rubbish (the publicly available database includes closed facilities and those that no longer take household rubbish).

Historically, 38 landfills have taken 75% of Australia's waste (Blue Environment Pty Ltd, 2013)[2], and the generation of waste is more concentrated today than before, as more people live in cities, particularly the capital cities, than ever before (Centre for Population, Australian Government, 2024).

This implies that a majority of Australia's nearly 6 Mtpa (wet) of organic waste that is disposed of in landfills (Figure 9 and Figure 10) can be consolidated for energy or materials recovery[3]. Even otherwise, it is not unusual for waste in Australia to be carried long distances. For instance, Veolia's Woodlawn bioreactor, the largest landfill in Australia, receives waste railed 240 km from Sydney to Tarago NSW.

Map 1. Australian Putrescible Landfills, 2022 (Based on Blue Environment Pty Ltd, 2022)



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[2] This number comes from a 2013 report that was based on surveys conducted in 2008 and 2010. No publicly available data (or better and more granular data) exists for the current situation, and various laws prohibit the public disclosure of landfill-specific information by the EPAs of various states.

[3] Note that this is the organic fraction alone, as the overall quantity of waste going to landfills in Australia for final disposal was 21.3 Mt for AFY 2021.

Figure 9. Organic[4] Waste Disposed of In Landfills, Without Recovery (Wet Mt) (Australian Government, 2022) – Split by Stream

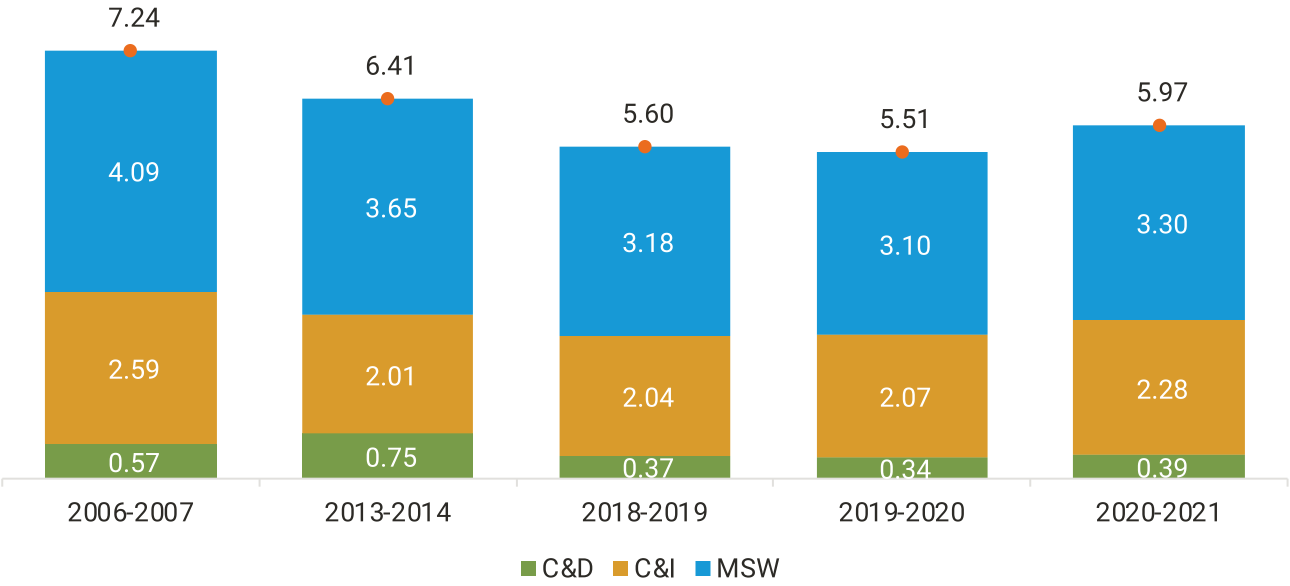
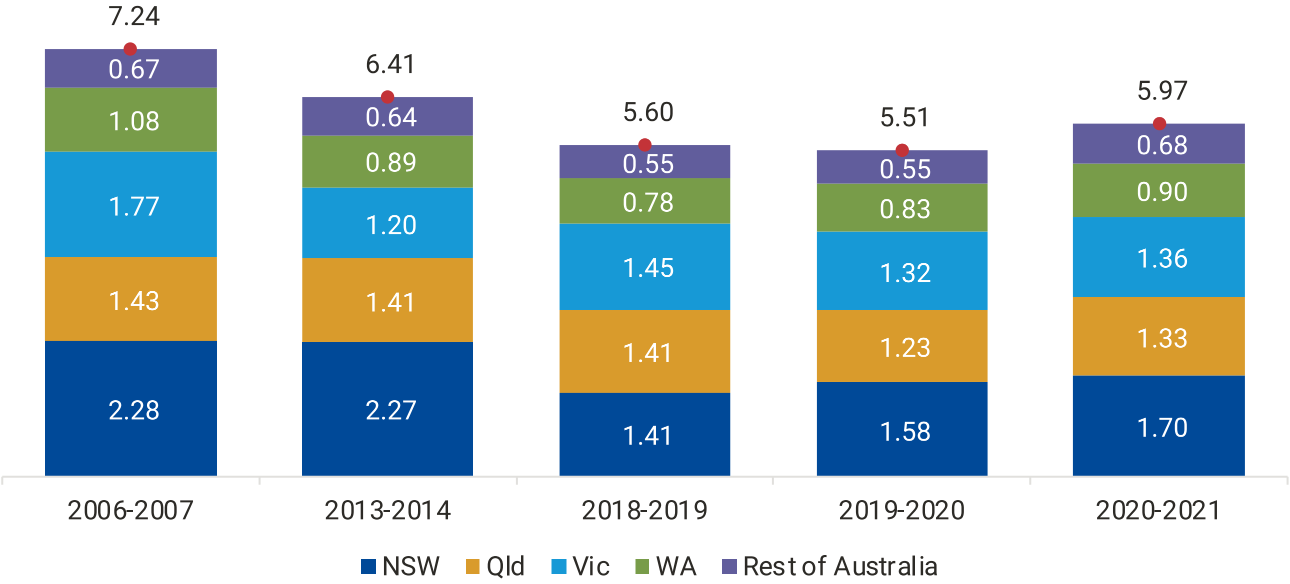


Figure 10. Organic Waste Disposed of In Landfills, Without Recovery (Wet Mt) (Australian Government, 2022) – Split by Jurisdiction



Other trends to note from Figure 9 and Figure 10 are:

- Though smaller than MSW, C&I organic waste is also a significant stream going to landfills. For the rest of this paper, 'MSW' is taken to include C&I and C&D organic waste going to landfills.
- The total quantity of organic waste going to landfills has declined in the 14 years from AFY 2007 to AFY 2021, mainly on account of greater recycling/composting of garden organics and food waste. Food waste is now collected separately from MSW at nearly half of Australia's councils, and this will further reduce tonnes going to landfill in the future.
- NSW, VIC, QLD, and WA account for 88% of organic waste sent to landfills. These are all large agrarian states where biomass to SAF routes can incorporate agricultural residue as a complementary feedstock to MSW.

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[4] Includes organics, biosolids, paper, and textile, leather and rubber (excluding tyres).

Having a Portfolio of Feedstocks Will Be Important

For SAF, future 'competition' for MSW will come from composting and Waste to Energy demand. Although SAF is a better end use for MSW than direct energy recovery in a rapidly decarbonising grid, a Waste to Energy plant will typically have an exclusivity arrangement with local councils, even under a 'waste arising' contract (which doesn't restrict recycling or waste reduction efforts by councils or tie them to fixed volumes of waste supply).

A brief and non-exhaustive description of Waste to Energy projects and policies is provided below:

- NSW:
  - Greater Sydney has been identified as needing an additional >500 ktpa putrescible landfill capacity, and one large scale energy recovery facility by 2030, with another >1.1 Mtpa putrescible waste facility will be required by 2040 (Department of Planning, Industry and Environment NSW, 2021).
  - Waste to energy plants are banned within the Greater Sydney area, and the eligible precincts are the Parkes Activation precinct, the Richmond Valley Regional Jobs Precinct, the Southern Goulburn Mulwaree Precinct and the West Lithgow Precinct. The above changes were ushered in under the Energy from Waste Infrastructure Plan 2021, and pushed back the timeline for the development of a 500 ktpa waste to energy plant that Cleanaway was planning for Western Sydney.
- WA:
  - WA leads the eastern states in implementing waste to energy projects.
  - Waste to energy plants are under construction at Kwinana (400 ktpa) and East Rockingham (300 ktpa).
- VIC
  - Under its waste to energy framework, VIC has a cap of 1 Mtpa for thermal disposal of 'permitted waste' (which includes the non-recyclable portion of MSW, C&I, and C&D waste). The cap includes fuels produced via thermochemical routes, but not fuels produced biochemically via microbes. Agricultural and forest residues and wastes, and residues from pulp and paper manufacturing are amongst those that are exempt from the ban. There is also a goal of reducing organics sent to landfills by 50% by 2030.
  - VIC government has issued four licences for waste to energy plants as under:
    - Paper Australia — a consortium including Opal paper (Paper Australia), Veolia, and Masdar Tribe are looking at developing a 325 ktpa waste to energy plant in the Latrobe valley.
    - Visy Industries — a major paper producer, Visy has an existing cogen plant in Coolaroo and is looking to build a waste to energy plant.
    - Great Southern Waste Technologies — a 100 ktpa facility in Dandenong South using MSW and C&I waste. GWST also plans a 200 ktpa facility in Epping, Mebourne.
    - Recovered Energy Laverton Ltd — a 240 ktpa MSW gasification to energy facility in Laverton North.
    - Cleanaway is also looking at a 380 ktpa waste to energy plant in Wollert.
  - A number of waste to energy plants are also being planned in South Australia and Queensland. The latter state's 2020 Energy from Waste Policy priorities higher value added materials, including fuels, over purely thermal energy recovery.

A factor in waste to energy projects is community opposition. As an example, NSW has had significant community opposition to such plants, which is seen as a case of 'Sydney dumping its rubbish on the regions'. Similar concerns would arise for MSW-FT plants.

The developers of the East Rockingham Waste to Energy plant in WA have noted that engagement with the community during the whole project life, transparency, and particularly, going with waste arising contracts makes a project more acceptable.

The uncertainty in long term feed supply means that other biomass based feedstocks, such as bagasse, might need to be blended with MSW. Here, blend performance should be studied beforehand. Parameters such as reactivity, activation energy, ash characteristics, etc. for a blend can vary non-linearly from those of its constituent elements.

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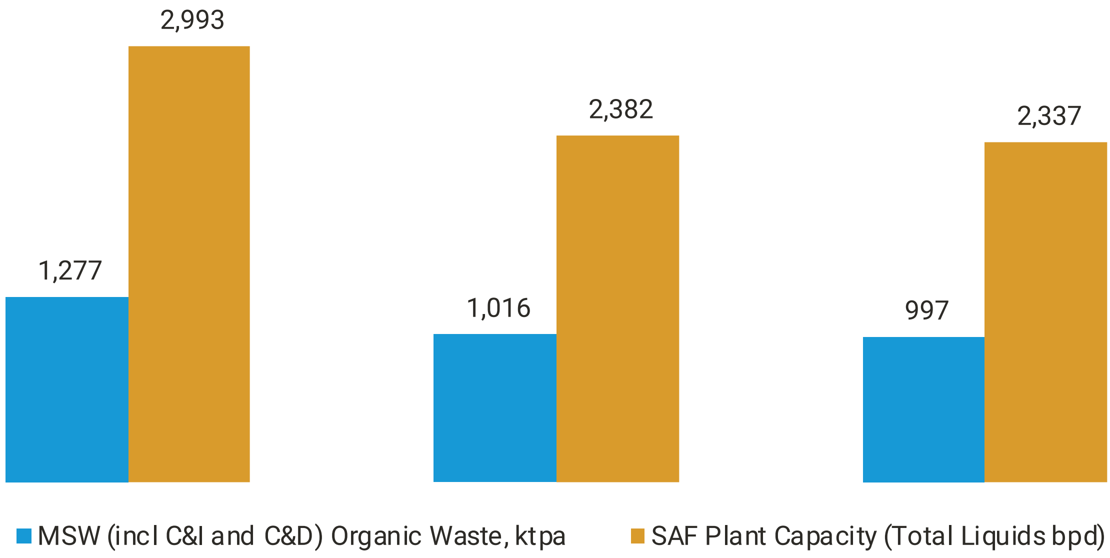
[5] Assumed: 1) Wet waste has 50% total moisture content 2) Carbon (ultimate analysis) 52.8% db 3) FT recovery 35% to liquids. Conversion of litres per annum to barrels per day assume 365 days of operation.

At AFY 2021 Levels of Collection, There Can Be One MSW-FT Plant in NSW, VIC, and QLD Each

In AFY 2021, the top 3 states (NSW, QLD, VIC) produced 4.3 Mt of organic waste that went to landfills for final disposal. If we assume that 75% of these quantities in each state can be recovered and sent to a centralized facility — this is ignoring other demands on the feedstock such as from Waste to Energy projects — then we have input quantities of wet waste of 1.27 Mtpa for NSW, 1.01Mtpa for VIC and 997 ktpa for QLD. These correspond to a plant capacity of 2,337 to 2,993 bpd of total liquids (SAF, renewable petrol, and renewable diesel) (Figure 11).

Figure 11. Inputs and Outputs of a Single MSW-FT Plant In Each State Taking 75% of Organic Waste Going to Landfills In That State



These plants would clear the threshold of a minimum desirable size of 2,000 bpd. At this scale, it is possible to build in a degree of redundancy in the gasification and material handling systems, which are crucial for maintaining plant uptime.

Fulcrum Bioenergy's 717 bpd Sierra plant near Reno, Nevada was the world's first commercial scale MSW to SAF plant when it opened in 2022. The Fulcrum plant carried out the final steps of hydrocracking and fractionating in a Marathon Petroleum biorefinery, where it shipped syncrude. Fulcrum had targeted its next two projects at 3x the capacity of the Sierra plant, going above the 2,000 bpd mark, but their future is uncertain.

(Fulcrum experienced significant operational difficulties at the Sierra plant, and at the time of writing is reportedly on the verge of bankruptcy. See the section *A note – the risks and rewards of MSW* at the end of this paper for details.)

Note that biogas/landfill gas based Gas-to-Liquids (GTL) plants, which do not require a material handling or gasification kit, are capable of going down to smaller sizes, down to the level of 100 bpd (Emerging Fuels Technology, 2024).

It is worthwhile to note that even 2,000 bpd is small in the overall scheme of things. The DG Fuels biomass to SAF plant in Louisiana, using corn stover as feedstock, is at a size of over 7,000 bpd. Even this represents a significant scaling down compared to fossil fuel based GTL plants, the smallest of which (Shell's Bintulu) is at 14,700 bpd, and goes all the way up to Shell's Pearl in Qatar at 140,000 bpd.

How Small Can We Go – And What Are The Alternatives?

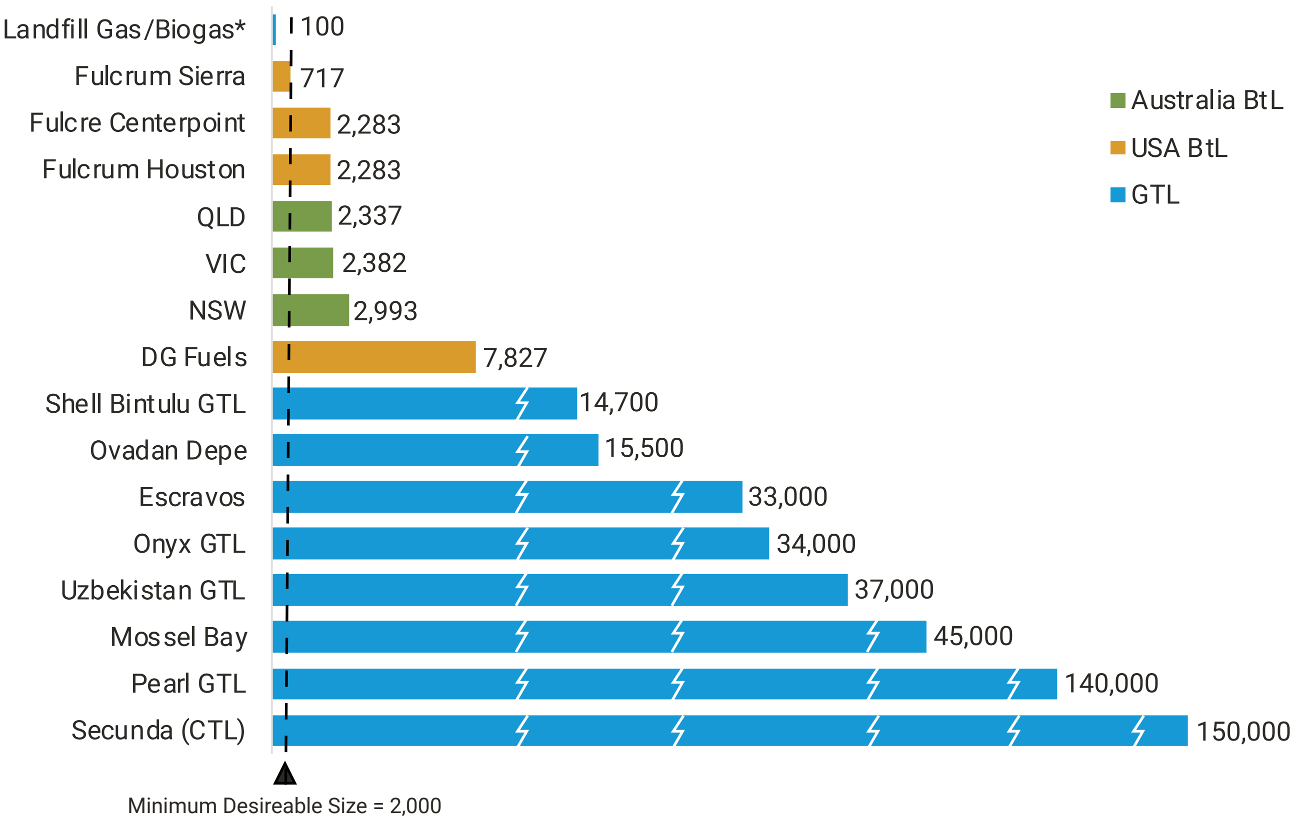
The benefit of small biomass-to-liquid plants is that they can be located closer to the source. However, as we have seen, once we have gasification and material handling in the picture, redundancy and minimum viable size considerations arise, where a minimum desirable size in a country like Australia or the US would be 2,000 bpd (Figure 12).

A few other challenges in 'going small' are as under:

- Heat integration to increase energy efficiency becomes less cost effective at small scales, as the cost of the added equipment can be difficult to justify the marginal efficiency gains. When considering natural gas as the feedstock, the reforming step can also be challenging to cost-effectively perform at small scales. SMR, and to a lesser extent, ATR processes require a high amount of heat input to drive the endothermic reforming reaction, which requires high-cost heat recovery equipment.
- Biomass has a low H:C molar ratio in the feedstock that produces syngas with a H2:CO molar ratio of 0.9-1.3. This needs to be increased to a 2:1 ratio for the FT process to work effectively, and this requires either supplying green hydrogen units through an electrolyser, or supplying more steam for the water gas shift reaction to generate H2, and losing more carbon units in the form of inert CO2. While the first option increases capex, the second eats into an already small stock of carbon units.
- ATR (a reformer used in landfill gas to liquids systems) and POx (sometimes used downstream from the gasifier to partially oxidise effluent hydrocarbon and recycled tail gas) processes require a high-purity oxygen input stream. At large scales, the oxygen is typically produced in an air separation unit (ASU), which is a large capital investment and power-intensive process that cannot be justified for a small scale facility. Thus, oxygen must be delivered for use in the process, shifting the capital cost of oxygen supply to an operating cost. Some of this can be defrayed from the byproduct oxygen of electrolysis.
- The core process equipment for a gasification based FT plant is 55-60% of the overall capex, the remainder consisting of balance of plant costs such as utilities, pipe racks, water treatment plant, etc. These balance of plant costs for a small unit are proportionately higher than for a large unit, which increases specific capex. Going small is helped where centralized, common user facilities for certain steps of the process already exist. For instance, green hydrogen production or FT syncrude hydrocracking and fractionating.

Therefore, the above challenges impose a limit on how small one can go and remain viable. The envelope of viability will vary by country (construction and operating labour costs, and equipment source), and over time, as technological learning curve effects kick in.

Figure 12. Sizes of Various BTL and GTL Plants (in BPD)



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* Biogas based SAF can operate at smaller scales than MSW based SAF.

A Note – The Risks and Rewards of MSW

At the time of writing, the news is that Fulcrum Bioenergy, the developers of the Nevada biofuels plant, is on the verge of bankruptcy (Rischar, 2024). The plant had suffered a number of technical setbacks since starting up in 2022, including nitric acid generation that corroded equipment, and fouling in the plant's gasification system.

While MSW is a free resource with an existing supply chain in place, and with the lowest LCEF values amongst candidate feedstocks for SAF, its heterogenous nature, variable chemical composition, and the need to integrate several complex systems (gasification, syngas cleanup, Fischer Tropsch, and fractionation together with various recirculation loops) makes it technically challenging. It is too early to tell whether the technology is facing teething troubles, or will remain challenging to master at scale.

Increasingly sophisticated simulation models and digital twins of existing gasification operations may help address some of this risk.

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Glossary

AF	Aviation Fuel	HEFA	Hydroprocessed Esters and Fatty Acids
AFY	Australian Financial Year	ILUC	Indirect Land Use Change
ASU	Air Separation Unit	ktpa	Kilo Tonnes per Annum
ATJ	Alcohol to Jet	LCEF	Life Cycle Emission Factor
ATR	Auto Thermal Reforming	LCFS	Low Carbon Fuel Standard
ASU	Air Separation Unit	MSW	Municipal Solid Waste
BtL/BTL	Biomass to Liquids	Mtpa	Million Tonnes per Annum
bpd	Barrells per day	NSW	New South Wales
CCS	Carbon Capture & Storage	PFAD	Palm Fatty Acid Distillate
C&D	Construction & Demolition (Waste)	POx	Pressure Oxidation
C&I	Commercial & Industrial (Waste)	PtL	Power to Liquids
CO, CO_2	Carbon Monoxide, Carbon Dioxide	QLD	Queensland
CTL	Coal to Liquids	RNG	Renewable Natural Gas
DME	Dimethyl Ether	RWGS	Reverse Water Gas Shift
EPA	Environmental Protection Authority	SA	South Australia
ETJ	Ethanol to Jet	SAF	Sustainable Aviation Fuel
FFB	Fresh Fruit Bunches	SMR	Steam Methane Reformation
FT	Fischer Tropsch	Syngas	Synthetic gas
GHG	Green House Gas	UCO	Used cooking oil
GJ/MJ	Giga Joule / Mega Joule	VIC	Victoria
G(L or t)/ M(Lor t)	Giga Litres or Tonnes/ Million Litres or Tonnes	WA	Western Australia
GTL	Gas to Liquids	WGS	Water Gas Shift
H_2	Hydrogen (molecule)	WtE	Waste to Energy

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