Australia's National Science Agency

Sustainable Aviation Fuel Roadmap

International Activity

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CSIRO acknowledges the Traditional Owners of the lands that we live and work on across Australia and pays its respect to Elders past and present. CSIRO recognises that Aboriginal and Torres Strait Islander peoples have made and will continue to make extraordinary contributions to all aspects of Australian life including culture, economy and science.

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1 International activity overview

Australia's key APAC neighbours were assessed to understand their current or likely role in a regional SAF production zone. Four key indicators were used to assess SAF development in each country.

Australia's key APAC neighbours were assessed to understand their current or likely role in a regional SAF production zone. Four key indicators were used to assess SAF development in each country.

- **Other biofuels experience**: does the country have experience in other biofuels?
- **Government SAF policy**: what measures are their government taking to encourage SAF or feedstock production?
- **Feedstock activity and plans**: are there plans to allocate or import feedstocks for SAF?
- **SAF activity and plans**: are there plans to begin SAF production?

Three rankings are provided for each criterion:

RANKING	STATUS	DESCRIPTION
●	Developed	• Established and operational, supported by strategy, investment, and outputs.
◐	Developing	• Activity is planned or under construction.
○	Undeveloped	• No to little action taken with no strategy in place.

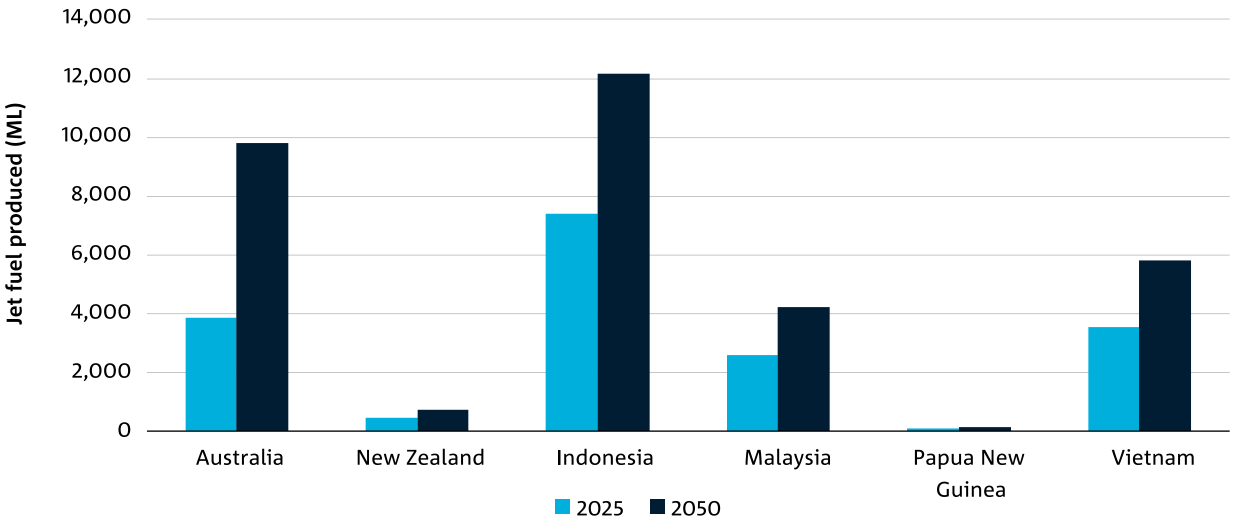
Activity summary

COUNTRY	OTHER BIOFUELS	SAF POLICY	FEEDSTOCK ACTIVITY	SAF ACTIVITY	LIKELY FEEDSTOCKS
New Zealand	◐	◐	◐	◐	Sawmill residues, tallow
China	●	◐	◐	◐	UCO, animal fat, ethanol
Fiji	◐	○	○	○	Bagasse, sawmill residues, coconut oil
India	◐	◐	◐	○	Ethanol
Indonesia	◐	◐	◐	◐	Palm oil
Japan	◐	◐	◐	◐	Ethanol from MSW imported UCO.
Malaysia	●	◐	○	◐	Palm oil, UCO
Philippines	◐	○	○	◐	MSW, ethanol
Papua New Guinea	○	○	○	○	Palm oil, agricultural residues, MSW
Singapore	●	◐	●	●	Imported UCO, animal fats
South Korea	◐	○	○	◐	Import UCO
Thailand	●	○	○	◐	Palm oil, UCO and ethanol
Vietnam	◐	○	○	○	Ethanol, agricultural residues

Feedstock potential summary

To better understand the feedstock potential of some countries of the APAC region, a high-level modelling exercise was undertaken to provide an indication of their feedstock production compared to Australia's. The countries in the figures below were chosen due to a combination of factors including likelihood to be a feedstock producer, proximity to Australia and availability of relevant data. Further research is required to better quantify the SAF potential of the whole APAC region.

Figure 1. Potential SAF production from each country's top two feedstocks (high scenario)[1]



1 The top two feedstocks for SAF production in Australia by 2025 are agricultural residues (from barley, corn (maize), grain sorghum, oats, rice, triticale, and wheat crops), and the combination of sugarcane and bagasse. By 2050, the two most potential feedstocks for SAF production come from the PtL process and agricultural residues. The two primary feedstocks available for SAF production in New Zealand up to 2050 are sawmill residues and tallow. For Indonesia, they are palm fruit and sugarcane and bagasse combined. The two most potential feedstocks for SAF production in Vietnam are agricultural residues and sugarcane and bagasse combined. For Malaysia, they are palm fruit and agricultural residues. For PNG, they are palm fruit and coconut.

1.1 New Zealand

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	◑	• Small biofuel industry for bioethanol and biodiesel (< 0.1% of transport fuels) hindered by lack of domestic production and previous policy support.
SAF policy	◑	• SAF mandate is under development, but no policy announcements have been made yet.
Feedstock activity	◑	• Forestry products and residues are the primary feedstock candidate with a history of projects evaluating the production of biofuels from them. • Exports of tallow.
SAF activity	◑	• 1.2 ML shipment of SAF imported in 2022. • Airline commitment to reach 10% SAF by 2030.

Other biofuels experience

Biofuel use in New Zealand is minimal and lacks domestic refining capacity.[2] With three processing plants, Lactanol supplies approximately 15 ML of bioethanol from whey, a dairy industry by-product, annually.[3] 0.6 ML of biodiesel was also produced in 2015, but the aim of increasing biodiesel production through Z Energy has not been realised.[4] The 20 ML per annum biodiesel plant was permanently closed due to rising tallow prices and high capital costs involved in its scaling.[5] Overall, liquid biofuels contribute less than 0.1% of total fuel sales.[6]

The Sustainable Biofuels Obligation was expected to contribute to future road transport fuel targets and strategies. However, this has recently been scrapped due to concerns over the cost-of-living and the sustainability of imported biofuels.[7]

Government SAF policy

In 2021, Cabinet agreed that a separate SAF mandate would be developed to address aviation, following the Sustainable Biofuels Obligation. Policy is under development, after facing delays from extended consultations on the Obligation. Progress is now being made on the SAF mandate, but timing has not yet been determined.

Additionally, New Zealand operates an Emissions Trading Scheme (ETS), putting a price on emissions to incentivise technology investment and improve practices to reduce them. This provides benefits to forestry participants for CO_2 removal through tree plantings and opportunities to trade emission units. To date, this has had little effect on transport fuel use as prices for emission units have been very low.

2 NZ Ministry of Business, Innovation & Employment (2022) Biofuels and the sustainable biofuel obligation. <https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-generation-and-markets/liquid-fuel-market/biofuels/> (accessed 19 May 2023).

3 Lactanol (n.d.) Lactanol - Sustainable New Zealand Ethanol. <https://www.lactanol.com/content/dam/lactanol/Lactanol%20Brochure.pdf> (accessed 19 May 2023).

4 Scion NZ (2018) New Zealand Biofuels Roadmap Summary Report. <https://www.scionresearch.com/__data/assets/pdf_file/0005/63293/Biofuels_summary_report.pdf>(accessed 19 May 2023).

5 Z (2022) Z confirms closure of Te Kora Hou biofuels plant. <https://www.z.co.nz/about-z/news/z-confirms-closure-of-te-kora-hou-biofuels-plant/> (accessed 19 May 2023)

6 Scion NZ (2018) New Zealand Biofuels Roadmap Summary Report. <https://www.scionresearch.com/__data/assets/pdf_file/0005/63293/Biofuels_summary_report.pdf> (accessed 19 May 2023).

7 Autocar NZ Magazine (2023) Government announces end to biofuels mandate. <https://www.autocar.co.nz/government-announces-end-to-biofuels-mandate/> (accessed 19 May 2023).

NZ Ministry of Business, Innovation & Employment (2022) Biofuels and the sustainable biofuel obligation <https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-generation-and-markets/liquid-fuel-market/biofuels/> (accessed 19 May 2023).

Feedstock activity and plans

Woody biomass

The New Zealand Biofuels Roadmap has identified forestry products and residues as the leading feedstock candidates, with the potential to account for 2.3 BL fuel annually by 2050 and thereby meet all South Island's demand.[8] The advantage of using forestry products from plantation forests in New Zealand is centred around the profitability and productivity of feedstock produced on lower quality, non-arable land. This includes land types that are rolling and steep, which is unsuitable for agriculture. Furthermore, the flexibility with growing practices as well as harvest schedules, and the range of forestry products offered are also significant.

However, contention exists over the sustainability of harvesting forestry products and residues for bioenergy, given the complexity of forest ecosystems and limited site-specific data. Key arguments include carbon sequestration being favourable compared to atmospheric emissions from biomass combustion, the perception that forestry activities accounting and reporting is not transparent and leads to biodiversity loss.

Conversely, there are also benefits to residue removal from forestry plantations such as reducing methane emissions, less fire risk and minimising infrastructure destruction caused by debris during storms. A Ministerial inquiry is being held to investigate land use practices and the impact of woody debris including forestry residues on the local environments following cyclone events.[9]

Forest harvest and wood processing residues are likely to provide an initial source of biofuel feedstocks based on previous availability assessments. Projections based on the National Exotic Forest Description (NEFD) data showed a consistent 10-12 million cubic metres of woody biomass produced annually from combined forest residues and pulp logs.[10] Additional residues would be produces in sawmills.

There is an opportunity to convert residues and low-cost products like small, exported pulp logs to higher-value products like SAF. This could increase the price paid for residues, improving the viability of sawmills and existing wood processing plants, while also displacing fossil carbon and generating greater liquid fuel security for New Zealand.

The Biofuels Roadmap contended that considerations which are thought to limit their feedstock potential for large-scale biofuel application are the low available volumes compared to expected fuel demand, high costs from competing existing uses and lacking technical or economic feasibility to collect geographically dispersed forest residues. Therefore, the ability to secure woody biomass will be driven by its location and SAF producers' willingness to pay. Based on this, New Zealand's forestry industry, starting with sawmill residues, is the most promising feedstocks for domestic SAF production.

Sawmill residues

As per the approach of Australian feedstocks, sawmill residues were assessed to understand the potential for New Zealand. Firstly, historical data was used to calculate average growth since 2010. Using this trajectory, two growth scenarios (low and high) were applied to forecast production through 2050. It was assumed that residues would be converted to SAF using gasification and FT.

Assuming a maximised SAF yield, a small-scale FT plant, capable of producing 50 ML of SAF per year would require 5% of New Zealand's projected sawmill residues in 2025. A large-scale plant producing 300 ML of SAF per year would require 31% of collected sawmill residues in 2025.

To understand how feedstock allocation can impact fuel production, the proportion of annual feedstock production was varied (20% and 40%), assuming high growth projections and high SAF yields. Sawmill residues could supply large quantities of jet fuel over time. As per the figure below, utilising 20% of residues through to 2050 could meet 10-12% of fuel demand, whereas utilising 40% of projected available residues could produce 21-24% of fuel demand.

8 Scion NZ (2018) New Zealand Biofuels Roadmap Summary Report. <https://www.scionresearch.com/__data/assets/pdf_file/0005/63293/Biofuels_summary_report.pdf> (accessed 19 May 2023).

9 NZ Government (2023) Inquiry to investigate forestry slash and land use after cyclone. <https://www.beehive.govt.nz/release/inquiry-investigate-forestry-slash-and-land-use-after-cyclone> (accessed 19 May 2023).

10 Bio Pacific Partners (2020) Wood Fibre Futures. https://mpi.govt.nz/dmsdocument/41824/direct> (accessed 19 May 2023).

Figure 2. New Zealand sawmill residue growth projections and FT feedstock requirements based on plant size

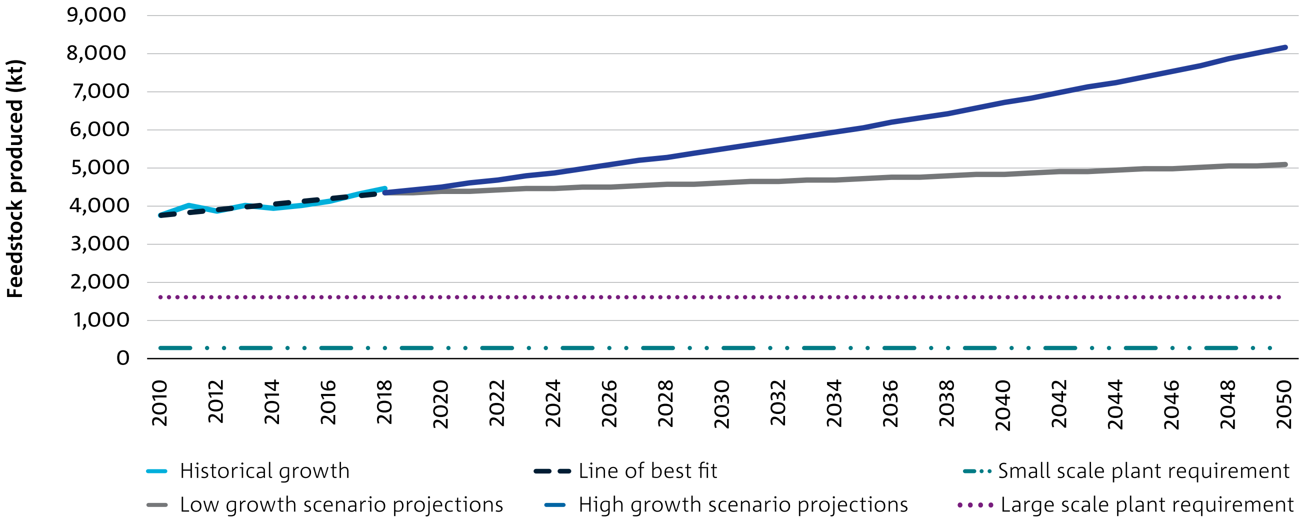
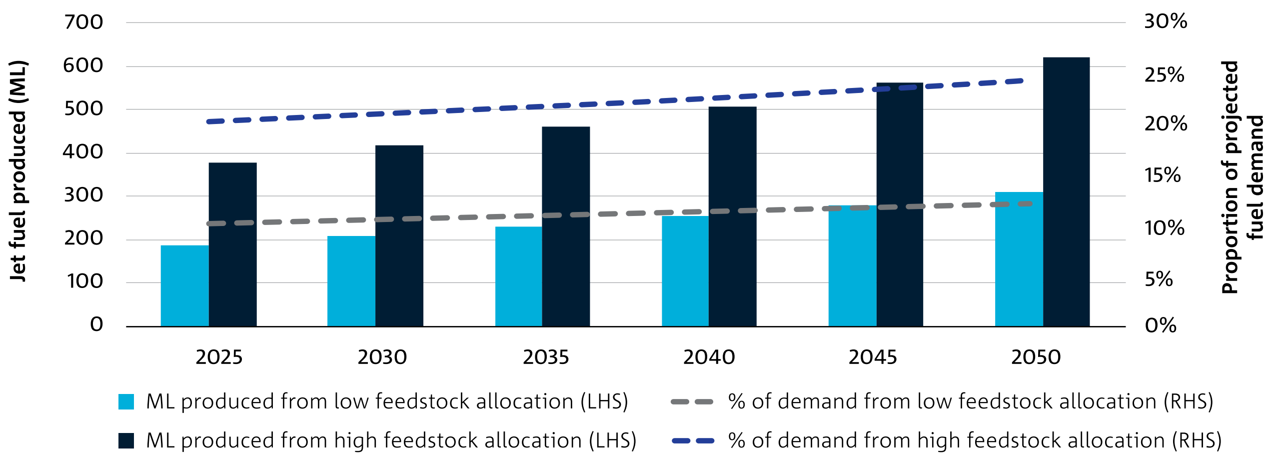


Figure 3. Potential SAF production from New Zealand sawmill residues and contribution toward domestic fuel demand



Tallow

New Zealand produces around 150 kt of tallow per year. A large volume of this is currently exported while the remaining 20% is consumed in domestic markets for animal feed, soap and margarine.[11] The NZ Biofuels Roadmap outlined the competition for existing use and tallow often being too costly as a factor limiting their potential as a feedstock.[12] This is supported by the closure of Z Energy's biodiesel plant.

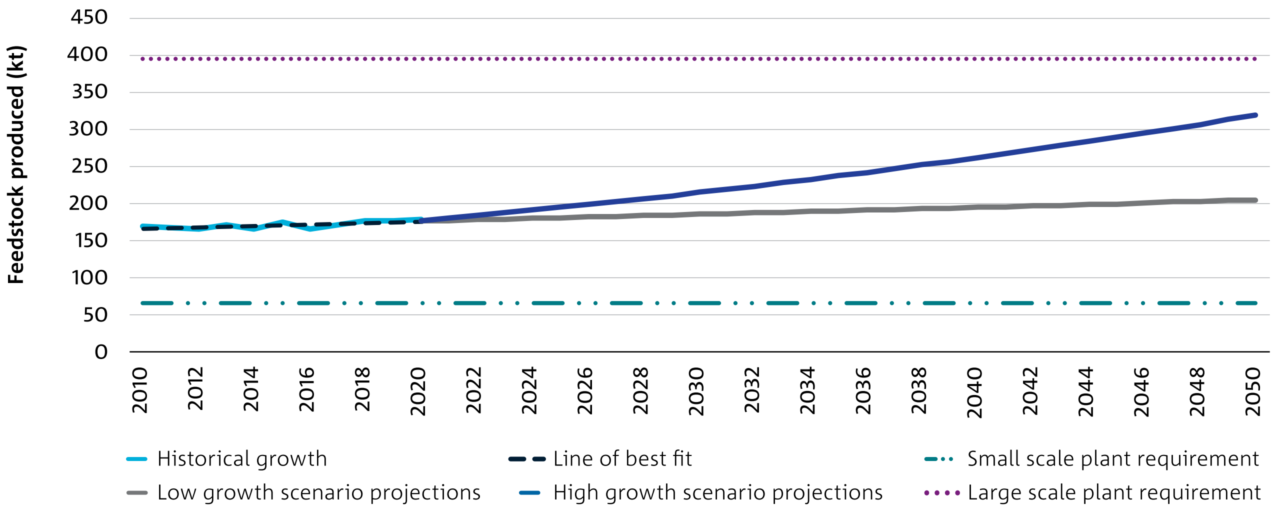
Assuming a maximised SAF yield a small-scale HEFA plant, capable of producing 50 ML of SAF per year, would require 34% of New Zealand's projected tallow production in 2025. Whereas a large-scale plant producing 300 ML of SAF per year could not be sufficiently supplied by tallow alone. This shows that tallow is unlikely to be a suitable feedstock for SAF in New Zealand.

SAF activity and plans

Currently, there is no SAF available in New Zealand. However, this has not deterred Air New Zealand from SAF-related activity. In 2008, a successful test flight was conducted using a 50% SAF blend in a Boeing 747.[13] More recently, the first SAF import was received into New Zealand fuel infrastructure for use in commercial flights. The 1.2 ML of UCO-derived SAF was purchased and delivered in 2022 and is equivalent to fuelling 400 flights between Auckland and Wellington, operating at 100% SAF.[14]

As a member of the Clean Skies for Tomorrow Coalition, Air New Zealand has committed to helping accelerate the supply and use of SAF to reach the goal of 10% by 2030. Despite there being no more local refining, the airline and the Ministry of Business, Innovation and Employment issued a request for proposal for feasibility demonstrations of operating commercial SAF plants in New Zealand.[15] The study is still underway.

Figure 4 . New Zealand tallow growth projections and HEFA feedstock requirements based on plant size



11 Bioenergy NZ (2015) What and how much is being made in New Zealand? <https://www.liquidbiofuels.org.nz/documents/resource/WLB01_LiquidBiofuels-biodiesel-bioethanol-sources-details.pdf

12 Scion NZ (2018) New Zealand Biofuels Roadmap Summary Report. <https://www.scionresearch.com/__data/assets/pdf_file/0005/63293/Biofuels_summary_report.pdf > (accessed 19 May 2023).

13 Air New Zealand (2023) Sustainable Aviation Fuel. <https://flightnz0.airnewzealand.co.nz/initiatives/sustainable-aviation-fuel> (accessed May 19 2023).

14 Neste (2022) Air New Zealand welcomes first shipment of Neste MY Sustainable Aviation Fuel into New Zealand <https://www.neste.com/releases-and-news/renewable-solutions/air-new-zealand-welcomes-first-shipment-neste-my-sustainable-aviation-fuel-new-zealand> (accessed May 19 2023).

Air New Zealand (2022) Air New Zealand to welcome first shipment of Sustainable Aviation Fuel into Aotearoa. https://www.airnewzealand.com/press-release-2022-airnz-air-new-zealand-to-welcome-first-shipment-of-sustainable-aviation-fuel-into-nz> (accessed May 19 2023).

15 Air New Zealand (2023) Sustainable Aviation Fuel. <https://flightnz0.airnewzealand.co.nz/initiatives/sustainable-aviation-fuel> (accessed May 19 2023)

RNZ (2021) Refining NZ confirms Marsden Point switch to import-only terminal from April 2022. <https://www.rnz.co.nz/news/business/456277/refining-nz-confirms-marsden-point-switch-to-import-only-terminal-from-april-2022> (accessed May 19 2023).

1.2 China

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	●	• Established bioethanol economy (forecast 3.4bL in 2021) supported by blending mandate. • Approximately 1bL of biodiesel produced and exported.
SAF policy	◑	• Aviation emissions reduction targets set • Target of 25 ML by 2025
Feedstock activity	◑	• Used cooking oil and animal fat are likely feedstocks, potential for ethanol as a feedstock • No official vision of matching feedstock with SAF production
SAF activity	◑	• Small HEFA amounts produced but concerns about UCO availability

Other biofuels experience

China has an established bioethanol economy strengthened by a nationwide E10 mandate of 10% ethanol blending in gasoline from 2020, with production estimated to be 3.8 billion litres in 2022.[16] Production was initially driven by the motivation to reduce maize supply surplus, utilising it as a feedstock for bioethanol production. Regarding biodiesel, B5 and B10 standards, requiring a 5% and 10% biodiesel blending, respectively, have existed in China for over a decade.[17] However, high transportation and processing costs of biodiesel throughout Asia (due to limited feed palm oil availability) have meant there is no incentive for domestic fuel makers to purchase biodiesel. Therefore, most of China's biodiesel is exported, over 1bL in 2020, of which 97% was exported to the EU.[18] However, this trend is likely to change with increasing emphasis on the importance of bioenergy in Chinese policy.

Government SAF policy

China's 2021-2025 plan outlines their energy intensity and carbon emissions targets for the aviation industry with the aim of (1) reducing CO_2 emissions per ton km by 4.5% by 2025 compared to 2020 levels; (2) achieving negative emissions growth by 2030 and (3) reaching net zero by 2060. The environment ministry aims to incorporate the aviation sector into the national carbon market by 2025 by introducing carbon pricing mechanisms and running pilots for SAF production and use in aviation for short-duration flights. Regarding SAF, the plan has set the target of total SAF consumption of 25 ML by 2025.[19]

16 United States Department of Agriculture (2021) Biofuels Annual China. <https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Beijing_China%20-%20People%27s%20Republic%20of_CH2022-0089.pdf> (accessed 19 May 2023).

17 United States Department of Agriculture (2021) Biofuels Annual China. Foreign Agricultural Services, Beijing. <https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Beijing_China%20-%20People%27s%20Republic%20of_08-16-2021.pdf> (accessed 10 January 2023).

18 Independent Commodity Intelligence Services (2021) Corrected: China's biodiesel growth lacks policy support, cost advantage. Viewed 10 January 2023, https://www.icis.com/explore/resources/news/2021/06/24/10655566/china-s-biodiesel-growth-lacks-policy-support-cost-advantage/#:~:text=China%20exported%20911%2C344%20tonnes%20of%20biodiesel%20last%20year%2C,97%25%20was%20sold%20to%20Europe%2C%20the%20data%20showed

19 4S&P Global (2022) China's Sinopec Zhenhai to start producing biojet fuel in May. Viewed 15 December 2022, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/oil/042922-chinas-sinopec-zhenhai-to-start-producing-biojet-fuel-in-may#:~:text=Chinese%20company%20Sinopec%27s%20flagship%20refinery%20Zhenhai%20Refining%20%26,email%20alerts%2C%20subscriber%20notes%20%26%20personalize%20your%20experience

Feedstock activity and plans

Used cooking oil and fat are the major feedstocks for SAF production in China to repurpose waste cooking oil that is illegally collected and reused, creating food safety and health risks. The State Council ordered better management of used cooking oil and avenues for commercial reuse to be explored as biofuel feedstock. Industry estimates China generates more than 10 million tonnes of used cooking oil per year, of which 1 million tonnes is used to make biodiesel.[20] Cooking oil and 'gutter oil' is currently used to power over 100 buses in Shanghai using a B5/B10 blended biodiesel. Additionally, efforts have been made to extend its use to aviation, with refiner China Petrochemical Corp (Sinopec) beginning largescale production of SAF from waste cooking oil in 2022-projected to process 100 kt of used cooking oil annually.[21]

More broadly, MotionECO, a Chinese consultancy and trading company, has partnered with the RSB in 2020 to develop a roadmap of SAF in China, advising on sustainability, feedstock, technical and policy pathways to support the sustainable growth of the Chinese aviation sector.[22]

SAF activity and plans

In 2017, a Hainan Airlines flight marked the first use of SAF in China, utilising a 15% blend of biodiesel refined from recycled cooking oil.[23]

In October 2022, China developed its first aviation plant to make SAF from used cooking oil. The plant can process roughly 100 kt of used cooking oil and fats to produce 50-63 ML of SAF per year.[24]

However, according to an industry source, the supply of used cooking oil and 'gutter oil' is unstable, with demand outweighing supply. If biodiesel was adopted nationwide, it is predicted there would be demand for 7-8 Mt of biodiesel annually, far more significant than the current supply capacity.[25] Additionally, biodiesel created from used cooking oil and fats is double the cost of gasoil refined from crude, therefore, no large-scale production of SAF currently exists in China. However, as net-zero targets are realised, SAF production is projected to grow steadily over the next few decades.

20 China Dialogue (2022) The place of biodiesel as China eyes carbon neutrality. Viewed 15 December 2022, https://chinadialogue.net/en/energy/the-place-of-biodiesel-as-china-eyes-carbon-neutrality/

21 China Daily (2022) Secondhand cooking oil takes to skies. Viewed 10 January 2023, http://www.china.org.cn/business/2022-09/21/content_78430820.htm#:~:text=China%27s%20large-scale%20production%20of%20aviation%20fuel%20derived%20from,be%20supplied%20to%20Airbus%27%20Tianjin%20plant%20this%20month.

22 MotionECO, Our Approach [Online]. Viewed 15 December 2022, http://www.motioneco.com/

23 Global Times (2022) Chinese researchers develop country's first industrial plant to make aviation fuel from gutter oil. Viewed 15 December 2022, https://www.globaltimes.cn/page/202210/1278243.shtml

24 Global Times (2022) Chinese researchers develop country's first industrial plant to make aviation fuel from gutter oil. Viewed 15 December 2022, https://www.globaltimes.cn/page/202210/1278243.shtml

25 China Dialogue (2022) The place of biodiesel as China eyes carbon neutrality. Viewed 15 December 2022, https://chinadialogue.net/en/energy/the-place-of-biodiesel-as-china-eyes-carbon-neutrality/

1.3 Fiji

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	◐	• Sufficient biofuel production from local bagasse and sawmill residues. • Established Biofuel Development Unit to implement biofuel projects.
SAF policy	○	• No national policy standard or targets exist for SAF.
Feedstock activity	○	• Coconut oil and ethanol from sugar have the most potential to meet biofuel demand.
SAF activity	○	• No current activity or plan.

Other biofuels experience

Fiji is producing enough feedstock to meet all its E10 and B5 requirements for petrol and diesel engines.[26] Fiji's local biofuel feedstocks include bagasse and sawmill residues, both of which are used for power generation.[27] The nation is also making use of the large quantities of copra (white flesh of coconut from which oil is extracted) to produce 'coco-diesel'.[28] As of 2011, 1.5 ML of biofuel was produced annually which accounted for 0.5% of the demand.[29]

In 2005, the Biofuel Development Unit was established with support from the United Nation Development Project.[30] Their responsibilities include implementing a biofuel industry by coordinating government and private sector, conducting trials and developing biofuel standards and wider policy frameworks and legislation. Successful biofuel implementation projects include 7 mills installed on the islands of Fiji which are locally managed and produce biodiesel from copra.[31]

Government SAF policy

No national policy standard or targets exist for SAF.

Feedstock activity and plans

The Fiji Department of Energy recognises that coconut oil and ethanol from sugar are feedstocks with the most potential to meet biofuel demand.[32] It is estimated that at least 27 ML of coconut oil can be produced from Fiji's 15,000 ha of coconut plantation.[33] Fiji's sugarcane industry has been declining in the past two decades with an annual production of 1.6 Mt in 2019.[34] To increase profitability, the Fiji Government announced the plan to build an ethanol plant in 2023.[35] Other vegetable oil fuel feedstocks for diesel engines being considered in Fiji are jatropha, pongamia and castor oil.[36]

Ensuring sufficient feedstock supply is a key challenge for biofuel projects in Fiji. This is because only 19% of Fiji's 1.8 million ha of land is suitable for farming.[37]

26 Singh A (2014) Biofuels and Fiji's roadmap to energy self-sufficiency. Biofuels.

27 Biofuels International (2011) Fiji's biofuel potential is enormous. <https://biofuels-news.com/news/fijis-biofuel-potential-is-enormous/> (accessed 17 May 2023).

28 Fiji Department of Energy (2023) Biofuels <https://www.energy.gov.fj/biofuel/> (accessed 17 May 2023).

29 Fiji Department of Energy (2023) Biofuel implementation projects <https://www.energy.gov.fj/biofuel-implementation-projects/> (accessed 17 May 2023).

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31 Singh A (2014) Biofuels and Fiji's roadmap to energy self-sufficiency. Biofuels.

32 Dean, MRU (2022) The Fiji Sugar Industry: Sustainability Challenges and the Way Forward. Sugar Tech.

33 Silaitoga, S (2023) Ethanol plant plans. <https://www.fijitimes.com/ethanol-plant-plans/> (accessed 19 May 2023).

34 Singh A (2014) Biofuels and Fiji's roadmap to energy self-sufficiency. Biofules 3(2), 269–284.

35 Civil Aviation Authority of Fiji (2021) Fiji's state action plan for the reduction of aviation greenhouse gas emissions. <https://caaf.org.fj/sites/default/files/2021-04/fijis_state_action_plan_on_reduction_of_aviation_greenhouse_gas_emissions.pdf> (accessed 19 May 2023).

36 oneworld (2021) oneworld aspires to reach 10% sustainable aviation fuel target by 2030. <https://www.oneworld.com/news/2021-10-04-oneworld-aspires-to-reach-10percent-sustainable-aviation-fuel-target-by-2030> (accessed 19 May 2023).

37 SimpliFlying (n.d.) How Fiji Airways is preparing for a sustainable future. <https://podcasts.apple.com/us/podcast/how-fiji-airways-is-preparing-for-a-sustainable-future/id1620281360?i=1000582511054> (accessed 19 may 2023).<https://podcasts.apple.com/us/podcast/how-fiji-airways-is-preparing-for-a-sustainable-future/id1620281360?i=1000582511054> (accessed 19 may 2023); CAPA (2022) Aviation Sustainability and the Environment, CAPA 23-Sep-2022. <https://centreforaviation.com/analysis/reports/aviation-sustainability-and-the-environment-capa-23-sep-2022-623703> (accessed 19 May 2023).

SAF activity and plans

There has been no activity or plan for SAF usage and production in Fiji. In 2015, the Fiji Government put together a State Action Plan for the reduction of aviation GHG emissions, detailing quantifying methods to meet international standards and outlining actions to improve operation.[38] The use of alternative fuels was "still in exploratory stage".

As an associate member of the oneworld Alliance, Fiji Airways is also part of the alliance's joint-procurement program on SAF. The oneworld Alliance commits to the World Economic Forum's Clean Skies for Tomorrow initiative by setting a collective target of 10% SAF use across its member airlines by 2030.[39] While Fiji Airways currently does not have the capacity to contribute to SAF research and development, many of its executives have advocated for the global aviation industry to work together to address sustainability.[40]

1.4 India

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	◑	• Biofuel blending programs for ethanol and biodiesel.
SAF policy	◑	• The Indian Ministry of Civil Aviation and the Ministry of Petroleum and Natural Gas are working to develop a blending mandate, likely 1%. • Goal of flying 100 million passengers on 10% blend by 2030.
Feedstock activity	◑	• Currently, large production of ethanol from agricultural residues, sugarcane, and molasses.
SAF activity	○	• Statement of intent has been signed with Lanzajet, but little investment or strategy beyond this. • ATJ likely given the ethanol industry.

Other biofuels experience

For the past two decades, India has promoted a biofuel blending program. Currently, the 2018 National Biofuels Policy proposes targets of 20% ethanol blending in petrol and 5% biodiesel in diesel by 2030. This policy is driven by the motivation to increase India's energy security and promote inclusive rural development. The Indian government incentivises the policy through tax rebates and infrastructure support for advanced second-generation biofuel development. This policy includes research and development measures for advanced conversion technologies and biofuel feedstock utilisation of by-products.[41] Aemetis India's biodiesel plant in Kakinada has an installed capacity of producing 176 ML of biodiesel annually from various feedstocks such as vegetable oil, animal oils and waste oils.[42]

38 Civil Aviation Authority of Fiji (2021) Fiji's state action plan for the reduction of aviation greenhouse gas emissions. <https://caaf.org.fj/sites/default/files/2021-04/fijis_state_action_plan_on_reduction_of_aviation_greenhouse_gas_emissions.pdf> (accessed 19 May 2023).

39 oneworld (2021) oneworld aspires to reach 10% sustainable aviation fuel target by 2030. <https://www.oneworld.com/news/2021-10-04-oneworld-aspires-to-reach-10percent-sustainable-aviation-fuel-target-by-2030> (accessed 19 May 2023).

40 SimpliFlying (n.d.) How Fiji Airways is preparing for a sustainable future. <https://podcasts.apple.com/us/podcast/how-fiji-airways-is-preparing-for-a-sustainable-future/id1620281360?i=1000582511054> (accessed 19 may 2023).<https://podcasts.apple.com/us/podcast/how-fiji-airways-is-preparing-for-a-sustainable-future/id1620281360?i=1000582511054> (accessed 19 may 2023); CAPA (2022) Aviation Sustainability and the Environment, CAPA 23-Sep-2022. <https://centreforaviation.com/analysis/reports/aviation-sustainability-and-the-environment-capa-23-sep-2022-623703> (accessed 19 May 2023).

41 Das S (2020) The National Policy of biofuels of India – A perspective. Energy Policy 143(111595).

42 Biofuels Central (2022) Aemetis India to Acquire Site for Biodiesel and Sustainable Aviation Fuel Feedstock Refining Facility. <https://biofuelscentral.com/aemetis-india-acquire-site-biodiesel-sustainable-aviation-fuel-feedstock-refining-facility> (accessed 19 May 2023).

Government SAF policy

The Indian Ministry of Civil Aviation and the Ministry of Petroleum and Natural Gas announced at the IATA Aviation Energy Forum in November 2022 that they are collaborating to mandate a percentage of blending SAF with jet fuel.[43] While there is no firm commitment, the Honeywell India Technology Centre Director posited a potential 1% blending mandate of SAF.[44] India aims to fly 100 M passengers on SAF at a 10% blend by 2030. Additionally, India is expected to become a party to the CORSIA by 2027, meaning a commitment to 10% SAF use by 2030.[45]

Feedstock activity and plans

India's Roadmap for Ethanol Blending 2025, combined with experienced and integrated ethanol value chains, makes ethanol an attractive potential feedstock for SAF production. The roadmap aims to produce 13,500 ML of ethanol by 2025-26 to achieve 20% blending in gasoline, of which India is on track, having already achieved 10% blending in 2022.[46]

Analysis by World Economic Forum posits that agricultural residues can provide over 30 billion litres of sustainable ethanol per year, in addition to solid waste and industrial off-gases. Harnessing just 5% of the 30 billion litres of sustainable ethanol with ATJ can meet India's 10% fuel blending target in SAF.[47]

SAF activity and plans

Indian airlines have begun to trial SAF, with SpiceJet operating the first flight on 25% biofuel made from the Jatropha plant in 2018.[48] Since then, Lanzajet has signed a statement of intent to explore producing ATJ aviation fuel in India in 2022, however, commercial use of SAF is yet to occur. Moving forward, supportive policies and regulations from the Indian government will bolster commercial production of SAF from current development and research projects.

43 Argus Media (2022) India committed to SAF mandate. <https://www.argusmedia.com/en/news/2391536-india-committed-to-saf-mandate?backToResults=true> (accessed 19 May 2023).

44 Simple Flying (2022) Indian Airlines Could Start With 1% Blending of SAF With Regular Fuel. <https://www.msn.com/en-us/travel/news/indian-airlines-could-start-with-1percent-blending-of-saf-with-regular-fuel/ar-AA15JCvc> (accessed 19 May 2023).

45 Simple Flying (2022) Indian Ministries to Issue Sustainable Aviation Fuel Roadmap. <https://simpleflying.com/india-sustainable-aviation-fuel-roadmap/> (accessed 19 May 2023).

46 Simple Flying (2022) Indian Ministries to Issue Sustainable Aviation Fuel Roadmap. <https://simpleflying.com/india-sustainable-aviation-fuel-roadmap/> (accessed 19 May 2023).

47 World Economic Forum (2022) Sustainable aviation fuel could bring India's industry to net-zero. <https://www.weforum.org/agenda/2022/07/sustainable-aviation-fuel-can-bring-indias-industry-to-net-zero-with-this-one-final-step> (accessed 19 May 2023).

48 Simple Flying (2022) Indian Ministries to issue sustainable aviation fuel roadmap. <https://simpleflying.com/india-sustainable-aviation-fuel-roadmap/> (accessed 19 May 2023)

1.5 Indonesia

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	◑	• Focus on biodiesel production from palm oil supported by ambitious blending mandates.
SAF policy	◑	• SAF blending mandate of 2% has existed since 2016, increasing to 5% by 2025. • Despite a dedicate taskforce, the target is not enforced and failed to be met thus far.
Feedstock activity	◑	• Largest palm oil producer and exporter, producing 40 million tonnes per year since 2020. • Refined, bleached & deodorised palm kernel oil (RBDPKO) is currently used in SAF with plans to process crude palm oil (CPO) by 2024.
SAF activity	◑	• Pertamina produces Bio-Avtur from 2.4% palm kernel oil with plans to increase capacity by 2024 • Flight tests have been successful but SAF is not operational.

Other biofuel experience

As one of the world's largest GHG emitters, Indonesia has begun to shift its policy focus towards domestic biodiesel production and consumption, incorporating palm-based fuels. In 2020 the energy ministry introduced a B30 biodiesel program where all diesel sold in the country must contain 30% biofuel to cut costly fuel imports.[49] While plans intended to increase the blending mandate to 40% in a B40 policy, they have been pushed back to 2025 due to feedstock availability.[50] It is projected that biodiesel consumption in Indonesia will increase by 7% over the coming decade, accounting for two-thirds of additional consumption globally.[51]

Government SAF policy

Indonesia's Ministry of Energy and Mineral Resources (MEMR) attempted to implement a SAF blending mandate of 2% by 2016, which is set to increase to 5% by 2025. The Indonesian Aviation Biofuels and Renewable Energy Task Force (ABRETF) was established to oversee this mandate but the initial target was missed and compliance has not been enforced.[52]

Feedstock activity and plans

Indonesia is the world's largest producer and exporter of palm oil, positioning it to be a feedstock with significant potential for commercial SAF production. In recent years, at least 40 Mt of crude palm oil have been produced annually.[53] Continued support from the Indonesian Palm Oil Association and the government focus on biofuel production will likely see domestic demand rise. Additionally, corporations such as Unilever have invested in expanding Indonesia's palm oil refining capacity, alongside government biofuel subsidies to protect the domestic market and encourage production.[54] Government and capital interest in biofuels combined with Indonesia's palm oil refining capabilities suggest palm oil may be a promising feedstock for SAF production.

It is worth noting the sustainability of Indonesia's palm oil industry remains contentious due to outcomes such as environmental degradation and deforestation, land conflicts and human rights violations. Despite the adoption of Indonesian Sustainable Palm Oil and Roundtable on Sustainable Palm Oil certification schemes, there are few jurisdictions in which palm oil would be accepted as a feedstock.[55] This is evidenced by the EU ban on palm oil derived biofuel from 2018 under RED II.

49 Jakarta Globe (2019) Indonesia seeks to expand green fuel production to 100% by 2022. <https://jakartaglobe.id/business/indonesia-seeks-to-expand-green-fuel-production-to-100-by-2022> (accessed 19 May 2023).

50 Argus Media (2021) Indonesia to push back B40 rollout to 2025: MEMR. <https://www.argusmedia.com/en/news/2278871-indonesia-to-push-back-b40-rollout-to-2025-memr> (accessed 19 May 2023).

51 OECD/FAO (2022) OECD-FAO Agricultural Outlook 2022-2031, OECD Publishing, Paris.

52 Atmowidjojo A, Rianawati E, Chin BLF, Yusup S, Quitain AT, Assabumrungrat S, Yiin CL, Kiatkittipong W, Srifa A, Eiad-ua A (2021) Supporting clean energy in the ASEAN: policy opportunities from sustainable aviation fuels initiatives in Indonesia and Malaysia. IOP Conf. Series: Earth and Environmental Science 940.

53 Indonesia Investments (2017) Palm Oil. <https://www.indonesia-investments.com/business/commodities/palm-oil/item166> (accessed 19 May 2023).

54 Indonesia Investments (2017) Palm Oil. <https://www.indonesia-investments.com/business/commodities/palm-oil/item166> (accessed 19 May 2023).

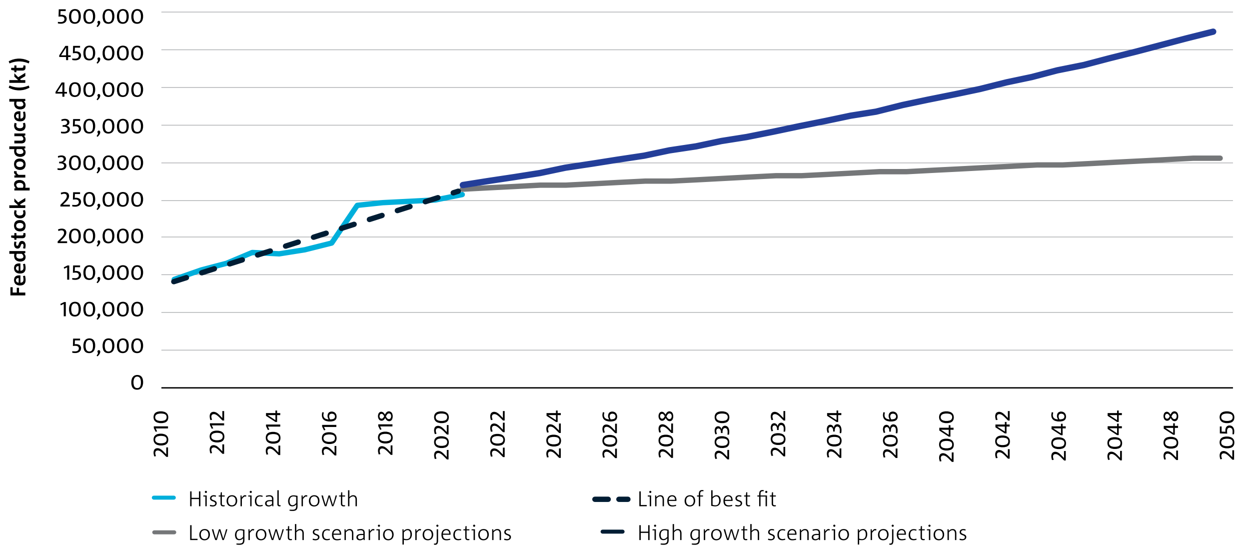
55 Barahamin A (2022) Indonesia, not the EU, needs to make its palm oil sustainable. China Dialogue. <https://chinadialogue.net/en/food/indonesia-not-the-eu-needs-to-make-its-palm-oil-sustainable/> (accessed 19 May 2023).

As per the approach of Australian feedstocks, palm fruit, sugarcane and bagasse were assessed to understand the potential for Indonesia. Firstly, historical data was used to calculate average growth since 2010. Using this trajectory, two growth scenarios (low and high) were applied to forecast production through 2050. It was assumed that palm fruit would be converted to SAF via HEFA, sugarcane via the ATJ pathway, and bagasse via gasification and FT. Secondly, to understand how feedstock allocation can impact fuel production, the proportion of annual feedstock production was varied (5% and 10% for palm fruit and sugarcane, 20% and 40% for bagasse), assuming high growth projections and high SAF yields.

Palm fruit

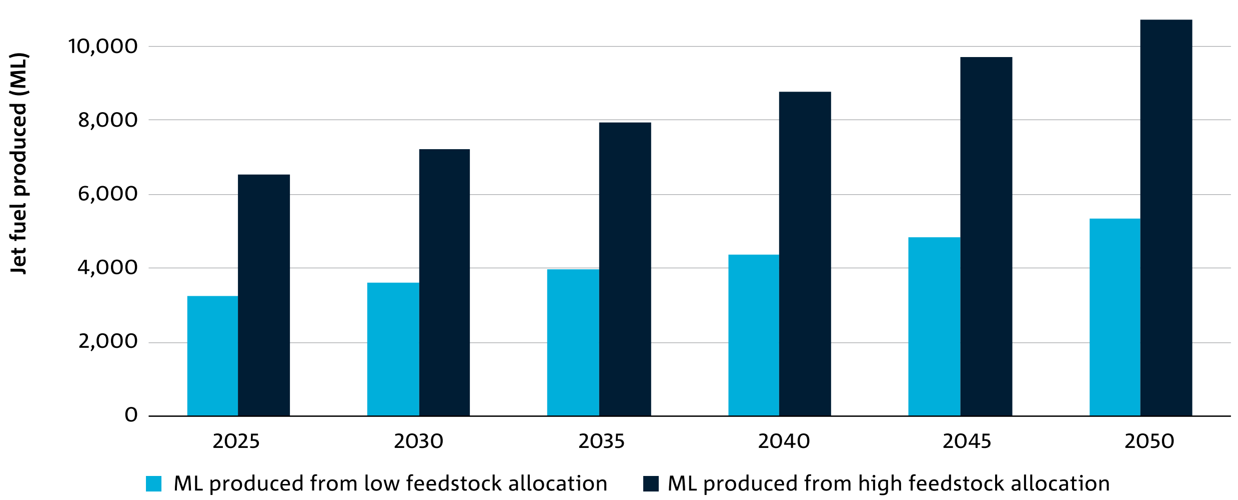
Assuming a high growth scenario, the palm fruit production level in Indonesia is projected to be 287,208 kt by 2025 and 471,195 kt by 2050.

Figure 5. Indonesia palm fruit growth projections



As per the figure below, utilising 5% of palm fruit through to 2050 could generate 5,356 ML of SAF, whereas utilising 10% of projected available palm fruit could produce 10,712 ML of SAF.

Figure 6. Potential SAF production from Indonesia palm fruit (high feedstock growth rate, high jet fuel yield scenario)



Sugarcane and bagasse

Assuming a high growth scenario, the annual amount of sugarcane produced in Indonesia is projected to be 33,004 kt by 2025 and 54,147 kt by 2050. The amount of bagasse produced is projected to be 9,901 kt by 2025 and 16,244 kt by 2050.

Figure 7. Indonesia sugarcane growth projections

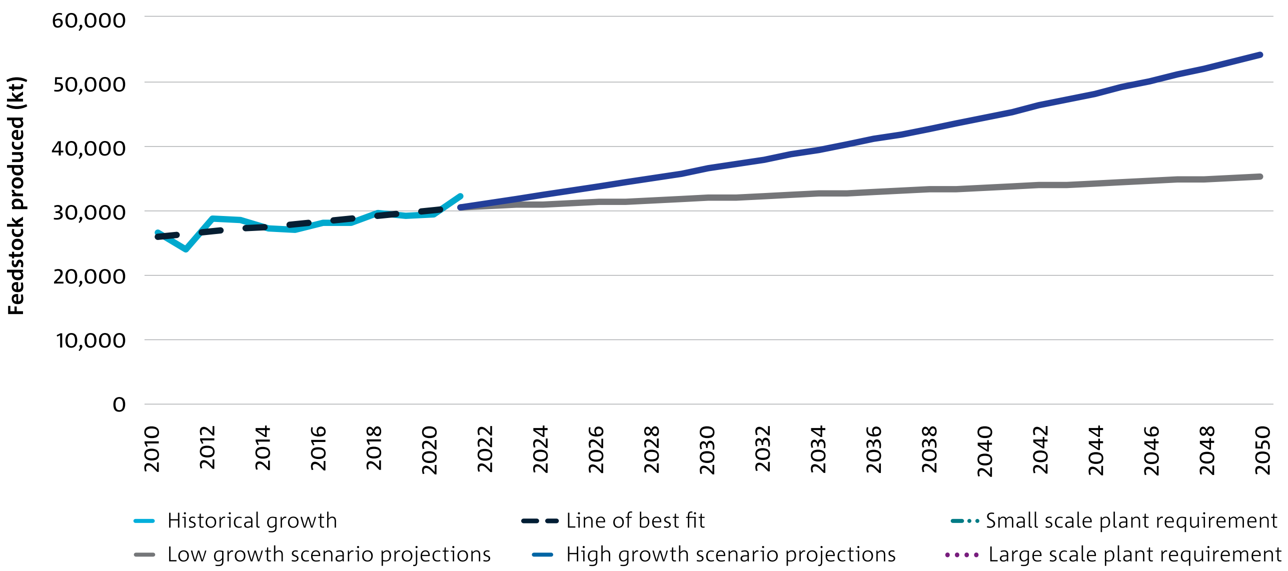
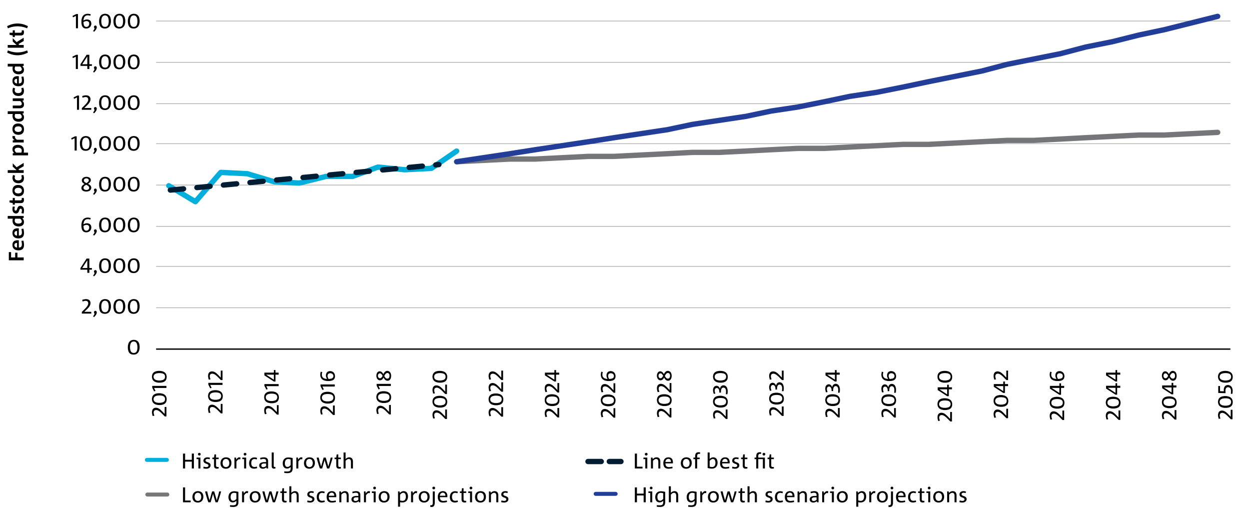
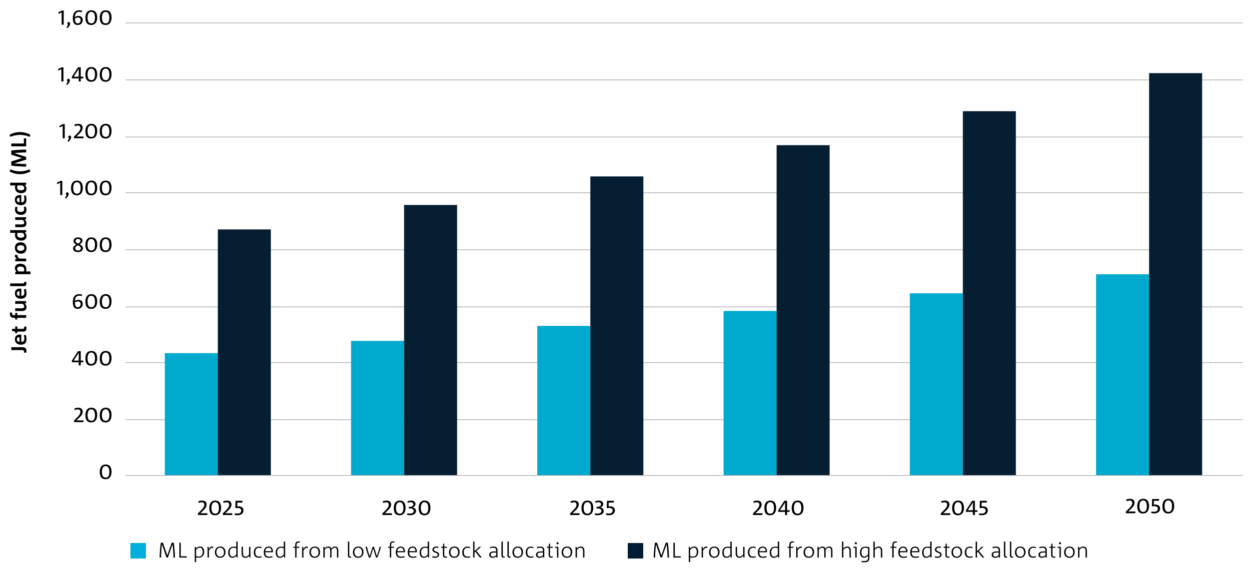


Figure 8. Indonesia sugarcane bagasse growth projections



As per the figure below, utilising 5% of sugarcane and 20% of bagasse through to 2050 could generate 713 ML of SAF, whereas utilising 10% of projected available sugarcane and 40% of bagasse could produce 1,427 ML of SAF.

Figure 9. Potential SAF production from Indonesia bagasse and sugarcane (high feedstock growth rate, high jet fuel yield scenario)



SAF activity and plans

Pertamina, the state-owned fuel company, has been producing a form of low carbon fuel via co-processing of biogenic feedstock with crude oil since 2021. Bio-Avtur J 2.4, derived from refined, bleached & deodorised palm kernel oil (RBDPKO) was successfully tested in an aircraft using a mix of Jet A1 and found to comply with ASTM 1655. Current refining capacity in Indonesia cannot compensate for the price difference between the Bio-Avtur and CJF (approximately 2.5-4%), signifying the need for coordinated government policy for commercial SAF production and refinement.[56] Plans for 2024 include increasing the capacity of the standalone biorefinery in Cilacap from 3,000 to 6,000 barrels per day, building an additional 20,000 barrel per day plant in Plaju and processing crude palm oil (CPO) instead of RBDPKO.[57]

56 The Star (2021) Palm oil-based jet fuel finally makes its debut in Indonesia. <https://www.thestar.com.my/aseanplus/aseanplus-news/2021/09/12/palm-oil-based-jet-fuel-finally-makes-its-debut-in-indonesia> (accessed 19 May 2023).

57 Aritenang W (2022) SAF Development Programme in Indonesia. ICAO. <https://www.icao.int/WACAF/Documents/Meetings/2022/SAF-CORSIA/5.%20Indonesia.%20SAF%20Development%20Programme.%20ICAO%20seminar%20on%20SAF%20and%20CORSIA%202022.pdf> (accessed 19 May 2023).

1.6 Japan

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	◑	• Long-term research & development programs into biomass utilisation for fuels and energy.
SAF policy	◑	• Announced a 10% SAF target for airlines by 2030, amounting to roughly 1.3 bL of SAF required. • No official commitments as yet.
Feedstock activity	◑	• Ethanol (from MSW and cellulosic material), algae, and UCO are being explored.
SAF activity	◑	• ATJ, HEFA, and FT are being explored.

Other biofuels experience

For the past two decades, Japan has promoted research and development efforts for biomass utilisation technologies centred on producing sustainable energy. The National Agriculture and Food Research Organisation's 2002 Biomass Nippon Strategy sought to investigate biomass that exhibited carbon-neutral characteristics. This was later revised by the Biomass Research & Development Centre in 2011 to include promoting activities such as biofuel for transportation and the production of sustainable energy from biofuel crops.[58] In 2016, this research was extended to a commercial level where the Ministry of Agriculture, Forestry and Fisheries introduced a Basic Plan for the Promotion of Biomass Utilisation outlining initiatives to develop the technology required for commercial biofuel production and refinement.[59] This aligns with Japan's broader carbon emissions target of net zero by 2050.

Government SAF policy

Recently, Japan has begun to shift biomass policy focus to the aviation sector, announcing a 10% SAF target for airlines by 2030, amounting to roughly 1.3 billion litres of SAF required.

Feedstock activity and plans

Various feedstocks have been used for the initial development of SAF in Japan, varying between projects. MSW in Japan is a potential feedstock, with approximately 60 Mt of combustible waste produced annually. Japanese manufacturing company Sekisui Chemical Co. announced the completion of a waste-to-ethanol plant in 2022 where MSW can be converted into ethanol using a gas fermentation process developed by LanzaTech. The aim is to achieve commercial production via 2025, producing 20 tonnes of ethanol per day, tackling MSW challenges in Japan. Sekisui Chemical Co. posited that ethanol produced could be utilised in SAF production through an ATJ process. Under a project partnership between biofuel organisation Byogy and Japan, commercial SAF production from cellulosic bioethanol using ATJ technology is expected to commence in 2025.[60,61]

Furthermore, Euglena algae were used as a feedstock for the first domestic biofuel at Narita airport, successfully tested at a 10% blend. Full-scale operation is expected to begin in 2026 with plans to supply roughly 250 ML of biofuels annually.[62] All Nippon Airways and Japan Airlines have both utilised SAF derived from feedstocks, including microalgae and wood chips, using a Velocys FT reactor for the latter.[63]

58 Ministry of Agriculture, Forestry & Fisheries Japan (2002) Biomass Nippon Strategy. MAFF.

59 Ministry of Agriculture, Forestry & Fisheries Japan (2016) Basic Plan for the Promotion of Biomass Utilization. MAFF.

60 LanzaTech (2022) New Waste-to-Ethanol Facility in Japan Turns Municipal Solid Waste into Products. <https://lanzatech.com/new-waste-to-ethanol-facility-in-japan-turns-municipal-solid-waste-into-products/> (accessed 19 May 2023).

61 The Taiwan Times (2021) Japan Leading The Way In Sustainable Aviation Fuel Development. <https://thetaiwantimes.com/japan-leading-the-way-in-sustainable-aviation-fuel-development/> (accessed 19 May 2023).

62 24 News Breaker (2022) First "domestic SAF' introduced at Narita Airport. Reason for attention: Euglena "We want to supply more and more". <https://24newsbreaker.com/market/278852.html> (accessed 19 May 2023).

63 Green Air (2021) Japan Airlines and ANA operate SAF flights with fuels made from wood chips and microalgae. <https://www.greenairnews.com/?p=1239> (accessed 19 May 2023).

While many feedstocks are attractive for SAF production in Japan, the Japan Transport and Tourism Research Institute emphasises the importance of policy tools to maximise domestic SAF production capability for Japan to meet their 2030 sustainable aviation targets.[64]

SAF activity and plans

While there is currently no centralised system of SAF production, many private sector companies are conducting projects to manufacture SAF. Engineering company JCG Holdings and oil wholesaler Cosmo Oil plan to start Japan's first commercial SAF production facility in 2025, which is expected to make up to 30 ML of SAF annually from used cooking oil.[65] Additionally, Mitsubishi Corp. and Eneos Holdings announced in 2022 that they would establish a domestic supply chain for SAF production by 2027 that would cover the procurement of raw materials for manufacturing and distribution. This project was primarily driven by the aim to reduce dependence on imports through domestic mass production of SAF.[66]

SAF imports to date include collaboration between Neste and Itsochu to supply airline customers such as All Nippon Airways, Japan Airlines and Etihad, since 2020.[67] Recently, Fuji Oil Company has joined the partnership to support local blending of neat SAF and demonstrate airline uptake from a third airport in Japan.[68]

1.7 Malaysia

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	●	• Large biodiesel producer, with 1.7bL produced in 2019 from palm oil, supported by blending mandates.
SAF policy	◑	• MITI led SAF taskforce developing national strategy. • No SAF policy announced to date.
Feedstock activity	○	• Palm oil is a likely feedstock candidate, with 20 million tonnes produced in 2020.
SAF activity	◑	• MoU has been signed to examine producing SAF from palm oil using HEFA by 2025. • Kuala Lumpur airport is working with Neste to supply SAF.

Other biofuels experience

In line with an emissions target of net zero by 2050, Malaysia has turned its attention to its biodiesel industry, aiming to minimise dependency on fossil fuels and fuel import costs. In 2019, biofuel production in Malaysia reached 1.69 BL, and exports accounted for 760 ML.[69] The country's National Biofuel Policy focuses on the commercialisation, usage, research, technology, and export of biodiesel, especially palm oil and its role in blended diesel.[70]

As one of the world's largest producers and exporters of palm oil, accounting for over 30% of global demand in 2020, Malaysia has targeted policy efforts to bolster its domestic market.[71] The B5 biodiesel blend program,

64 Nikkei Asia (2022) Japan targets 10% sustainable jet fuel for airlines by 2030. <https://asia.nikkei.com/Business/Transportation/Japan-targets-10-sustainable-jet-fuel-for-airlines-by-2030> (accessed 19 May 2023).

65 Nikkei Asia (2022) Japan targets 10% sustainable jet fuel for airlines by 2030. <https://asia.nikkei.com/Business/Transportation/Japan-targets-10-sustainable-jet-fuel-for-airlines-by-2030> (accessed 19 May 2023).

66 Nikkei Asia (2022) Japan's Mitsubishi and Eneos to mass-produce cleaner jet fuel. <https://asia.nikkei.com/Spotlight/Environment/Climate-Change/Japan-s-Mitsubishi-and-Eneos-to-mass-produce-cleaner-jet-fuel> (accessed 19 May 2023).

67 Neste (2022) Neste, ITOCHU and Fuji Oil supply sustainable aviation fuel to All Nippon Airways and Japan Airlines. <https://www.neste.com/releases-and-news/aviation/neste-and-itochu-expand-partnership-grow-availability-sustainable-aviation-fuel-japan> (accessed 19 May 2023).

68 Neste (2023) Neste, ITOCHU and Fuji Oil supply sustainable aviation fuel to All Nippon Airways and Japan Airlines. <https://www.neste.com/releases-and-news/renewable-solutions/neste-itochu-and-fuji-oil-supply-sustainable-aviation-fuel-all-nippon-airways-and-japan-airlines> (accessed 19 May 2023).

69 China Dialogue (2020) As palm oil for biofuel rises in Southeast Asia, tropical ecosystems shrink. <https://chinadialogue.net/en/energy/11957-as-palm-oil-for-biofuel-rises-in-southeast-asia-tropical-ecosystems-shrink/> (accessed 19 May 2023).

70 IEA (2015) National biofuel policy of Malaysia (2006). <https://www.iea.org/policies/5791-national-biofuel-policy-of-malaysia-nbp-2006> (accessed 19 May 2023).

71 Malaysian Palm Oil Industry (n.d.) About Palm Oil. <https://mpoc.org.my/malaysian-palm-oil-industry/> (accessed 19 May 2023).

initiated in 2011, mandates all biodiesel produced in the country to have a 5% blend of processed palm oil. This has recently been extended to a B20 target, expected to commence at the end of 2022, where biofuel must have a 20% palm oil component.[72]

Government SAF policy

The Ministry of International Trade and Industry (MITI) established a Sustainable Aviation Energy Task Force in 2022 and convened industry stakeholders, including fuel producers. A national development strategy is underway, which aims to recommend policy and coordinate the implementation of public-private partnership projects and initiatives for SAF production.[73]

No policy recommendations have been published yet.

Feedstock activity and plans

Despite the absence of a centralised SAF policy, the dominance of palm oil in Malaysia's agricultural industry positions it as a potential SAF feedstock. In 2020, total crude palm oil production was 19.14 million tons.[74]

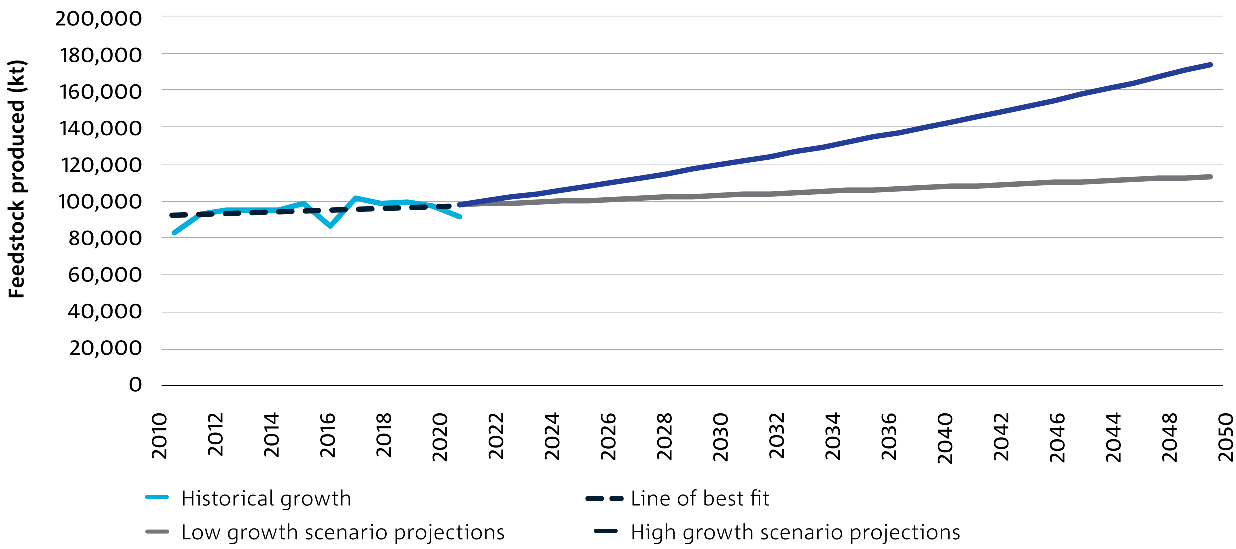
However, concerns exist surrounding an increased demand for palm oil, potentially increasing the rates of deforestation and loss of biodiversity in Malaysia.[75]

As per the approach of Australian feedstocks, agricultural residues[76] and palm fruit were assessed to understand the potential for Malaysia. Firstly, historical data was used to calculate average growth since 2010. Using this trajectory, two growth scenarios (low and high) were applied to forecast production through 2050. It was assumed that agricultural residues would be converted to SAF via gasification and FT, and palm fruit via HEFA. Secondly, to understand how feedstock allocation can impact fuel production, the proportion of annual feedstock production was varied (20% and 40% for agricultural residues, 5% and 10% for palm fruit), assuming high growth projections and high SAF yields.

Palm fruit

Assuming a high growth scenario, the palm fruit production level in Malaysia is projected to be 106,019 kt by 2025 and 173,936 kt by 2050.

Figure 10. Malaysia palm fruit growth projections



72 Enerdata Intelligence and Consulting (2022) Malaysia targets full implementation of B20 biodiesel mandate by end-2022. <https://www.enerdata.net/publications/daily-energy-news/malaysia-targets-full-implementation-b20-biodiesel-mandate-end-2022.html> (accessed 19 May 2023).

73 Malaysian Investment Development Authority (2022) MITI forms Sustainable Aviation Energy Task Force to reduce carbon footprint. <https://www.mida.gov.my/mida-news/miti-forms-sustainable-aviation-energy-task-force-to-reduce-carbon-footprint/> (accessed 19 May 2023).

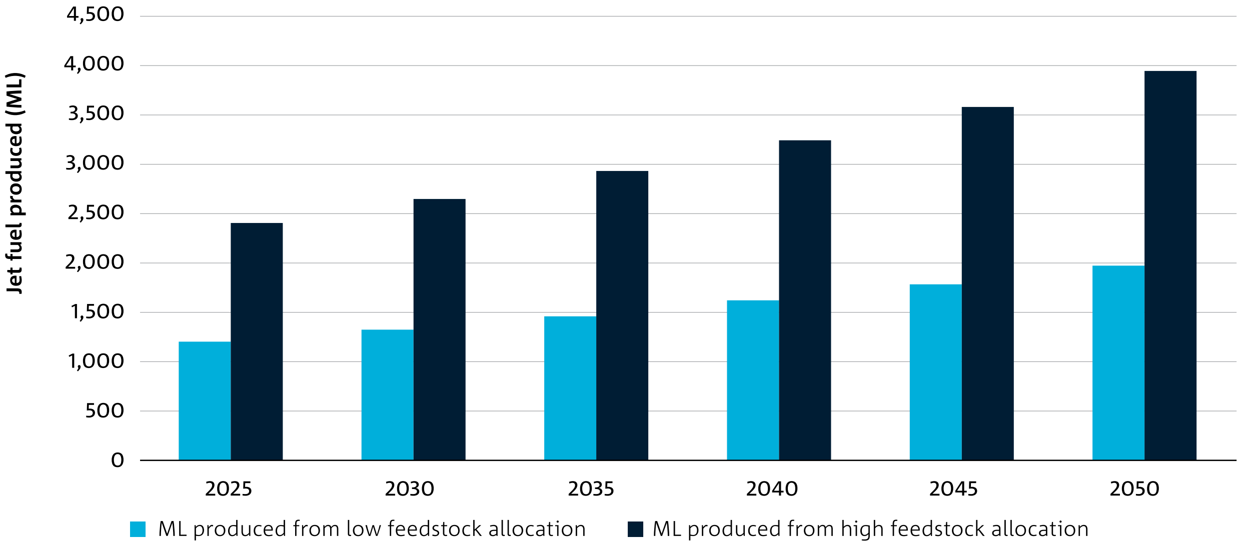
74 Parveez GKA, Tarmizi AHA, Sundram S, Loh SK, Ong-Abdullah M, Palam KDP, Salleh KM, Ishak SM, Idris Z (2021) Oil palm economic performance in Malaysia and R&D progress in 2020. Journal of Oil Palm Research 33(2), 181–214.

75 Malaysian Investment Development Authority (2021) Malaysia has started production of second-generation biodiesel, biojet fuel. <https://www.mida.gov.my/mida-news/malaysia-has-started-production-of-second-generation-biodiesel-biojet-fuel/> (accessed 19 May 2023).

76 From maize and rice crops.

As per the figure below, utilising 5% of palm fruit through to 2050 could generate 1,977 ML of SAF, whereas utilising 10% of projected available palm fruit could produce 3,954 ML of SAF.

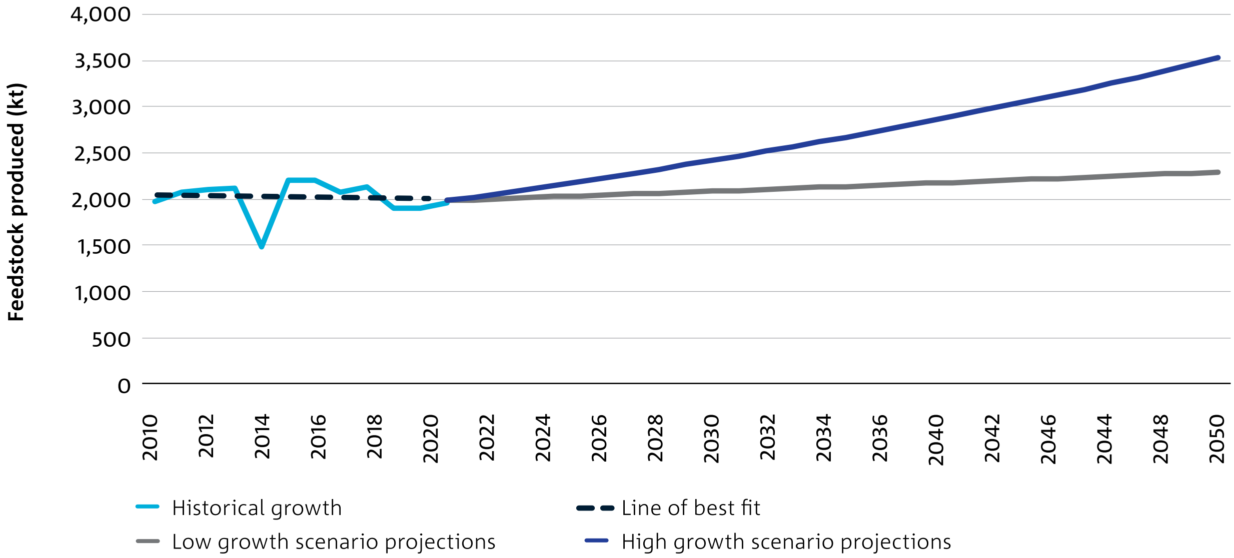
Figure 11. Potential SAF production from Malaysia palm fruit (high feedstock growth rate, high jet fuel yield scenario)



Agricultural residues

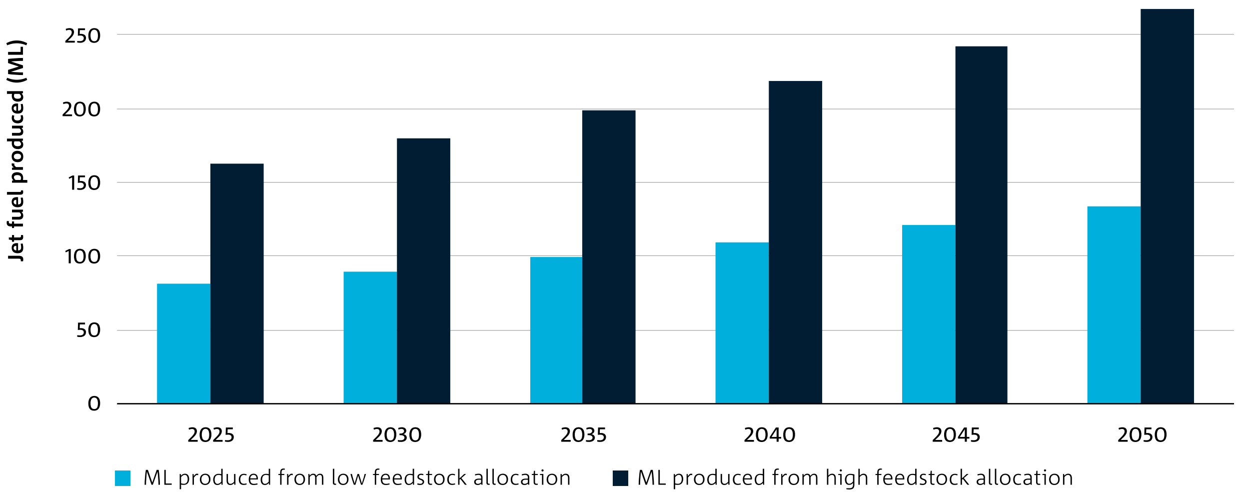
Assuming a high growth scenario, the annual amount of agricultural residues produced in Malaysia is projected to be 2,147 kt by 2025 and 3,522 kt by 2050.

Figure 12. Malaysia agricultural residues growth projections



As per the figure below, utilising 20% of agricultural residues through to 2050 could generate 133 ML of SAF, whereas utilising 40% of projected available residues could produce 267 ML of SAF.

Figure 13. Potential SAF production from Malaysia agricultural residues (high feedstock growth rate, high jet fuel yield scenario)



SAF activity and plans

While most palm oil is dedicated to the road transport sector, interest in its incorporation into SAF is growing. In 2021, Malaysia and Chinese-owned Shanxi Construction signed a MoU to collaborate on SAF production from palm oil, investing in a HEFA plant in Malaysia. The plant will synthesise fuel from the cracking and hydrogenation of palm oil and is expected to produce 625 ML of SAF annually upon commercialisation by 2025.[77]

Malaysian Airlines operated the country's first flight using SAF in 2021, blending approximately 38% SAF from used cooking oil. This occurred in partnership with Malaysian oil and gas company Petronas and renewable fuel producer Neste and aligns with Malaysian Airlines' 2025 commitment to make SAF the more viable energy option for regular flights.[78] Additionally, in 2022, the first SAF passenger flight in Malaysia occurred using waste and residue materials feedstocks.[79] Looking forward, Petronas has demonstrated the infrastructure capabilities at Kuala Lumpur International Airport and is ready to supply SAF. Any future SAF plans are likely to come out of the taskforce led by MITI.

77 Malaysian Investment Development Authority (2021) Malaysia has started production of second-generation biodiesel, biojet fuel. <https://www.mida.gov.my/mida-news/malaysia-has-started-production-of-second-generation-biodiesel-biojet-fuel/> (accessed 19 May 2023).

78 Neste (2021) Malaysia Airlines flies the first flight in Malaysia using Sustainable Aviation Fuel – PETRONAS and Neste collaborate with the airline to mark a major milestone in Malaysia's aviation history. <https://www.neste.com/releases-and-news/aviation/malaysia-airlines-flies-first-flight-malaysia-using-sustainable-aviation-fuel-petronas-and-neste> (accessed 19 May 2023).

79 Simple Flying (2022) Malaysia Airlines Operates First Passenger Flight Using Sustainable Aviation Fuel. <https://simpleflying.com/malaysia-airlines-first-flight-sustainable-aviation-fuel/> (accessed 19 May 2023).

1.8 Philippines

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	◑	• Mandates are set for biodiesel and ethanol, but limited feedstock and investment mean mandates are unachievable.
SAF policy	○	• No national policy related to SAF.
Feedstock activity	○	• No active planning for feedstocks to be utilised for SAF • Likely feedstocks include MSW, coconut oil and ethanol (from sugarcane).
SAF activity	◑	• International companies are looking to establish MSW to fuel plants. • Likely technologies given feedstocks are HEFA, ATJ and FT.

Other biofuels experience

Recent interest in biofuels has driven policy advancement in the Philippines with the 2007 national Biofuels Act mandating the blending of biofuels to reduce GHG emissions and costly fuel imports. The key biofuels utilised in the Philippines are biodiesel and bioethanol. Originally mandating biofuel blending of 20% bioethanol and 10% biodiesel by 2020, factors including limited investment and sustainable feedstock supply have meant only 10% bioethanol (E10) and 2% biodiesel (B2) blend were achieved. Looking forward, a Philippines Biofuels Roadmap for 2017-2040 outlines the short- and long-term goals to increase the blend component of biofuels and continue to develop different feedstock availabilities.[80]

Government SAF policy

No national policy standard or targets exist for SAF.

Feedstock activity and plans

The Philippines' efforts towards biodiesel can indicate potential feedstocks for SAF. Biodiesel is typically extracted from coconut oil, an integral crop in the Philippines' agricultural industry. They are one of the world's largest producers, with an annual production of over 14.7 million metric tons across the last decade. 15 dedicated refineries utilise this coconut oil to produce an aggregate of 585 ML of biodiesel annually. However, issues with the feedstock stability of coconut oil exist, with environmental factors and climatic instability leading to crop loss and fluctuating domestic coconut production. Hence, multiple feedstocks should be considered to maintain a consistent SAF supply.[81]

Bioethanol in the Philippines is mostly derived from sugar cane, with an annual crop production reaching 22.9 million metric tons in 2017, resulting in 282 million litres of bioethanol. However, more than this quantity of bioethanol is needed to meet the E10 biofuel mandate. This can be attributed to feedstock instability due to climatic events, labour shortages, lack of investment and inadequate land space for crop production. Due to increased demand in the transportation sector, bioethanol consumption is expected to reach 1,015 ML by 2030, highlighting the need for greater commercialisation or alternative feedstocks in this sector.[82]

Given the challenge of feedstock instability in the Philippines, alternative sources for commercial SAF production should be explored. MSW remains a prominent issue for cities in the Philippines, with 35,000 tonnes generated daily, most of which is openly burned and releases carbon dioxide and methane.[83]

SAF activity and plans

External companies such as California-based Wastefuel aim to develop five biorefineries in the Philippines by 2025 which would utilise the municipal solid waste to produce 160 ML of SAF annually.[84]

80 Acda MN (2022) Production, regulation, and standardization of biofuels: a Philippine perspective. Value-Chain of Biofuels.

81 Acda MN (2022) Production, regulation, and standardization of biofuels: a Philippine perspective. Value-Chain of Biofuels.

82 Acda MN (2022) Production, regulation, and standardization of biofuels: a Philippine perspective. Value-Chain of Biofuels.

83 Eco-Business (2017) Ditch NIMBY to fix Philippines' municipal solid waste problem. <https://www.eco-business.com/opinion/ditch-nimby-to-fix-philippines-municipal-solid-waste-problem/> (accessed 19 May 2023).

84 Green Air (2021) US start-up WasteFuel plans to pump municipal waste-based SAF in the Philippines by 2025. <https://www.greenairnews.com/?p=1046> (accessed 19 May 2023).

This shows the enormous feedstock potential to create SAF from MSW; however, establishing a comprehensive collection system is required to facilitate this, of which policy and investment still need to be improved.

While SAF is not commercially utilised in the Philippines, pilot SAF flights have been conducted. In 2022, Cebu Pacific operated the first flight using a blend of SAF and CJF, in line with the airline's 2050 net zero carbon emissions goal. This airline also aims to utilise SAF in green routes by 2025 and use SAF for its entire network by 2030.[85]

1.9 Papua New Guinea

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	○	• Only small-scale demonstrations.
SAF policy	○	• No national policy standard or targets exist for SAF.
Feedstock activity	○	• Likely feedstocks include palm oil, forestry and agricultural residues and MSW
SAF activity	○	• Given feedstocks, HEFA and FT would make likely candidates.

Other biofuels experience

Feedstocks such as copra and coconut oil have been utilised in small-scale biofuel projects in PNG. The National Fisheries Authority conducted a project using raw coconut oil to power small diesel engines and found that locally processed and produced coconut oil can be marketed at less than the diesel pump price. This proves advantageous for remote communities such as those in PNG, where imported diesel is costly, making coconut biofuel economically competitive.[86]

Government SAF policy

No national policy standard or targets exist for SAF.

Feedstock activity and plans

While there have been limited biofuel initiatives in PNG, the potential exists within the rich biodiversity and bioenergy of the country. This includes forestry industry and agricultural residues, transportation fuel crops, municipal organic waste, grass and other wild plants, animal manure and human waste. More specifically, palm oil presents as a potential feedstock for biofuel production, with PNG being the 5th largest global exporter, amounting to US$434 million in 2020.[87] Additionally, alongside the United Nations Development Programme, in 2018, the government created the Papua New Guinea Palm Oil Platform to facilitate a dialogue for sustainable palm oil production and implement strategies into a National Action Plan.[88] Further development and growth of PNG's palm oil industry will provide more significant commercial biofuel production opportunities.

As per the approach of Australian feedstocks, palm fruit and coconut were assessed to understand the potential for PNG. Firstly, historical data was used to calculate average growth since 2010. Using this trajectory, two growth scenarios (low and high) were applied to forecast production through 2050. It was assumed that both feedstocks would be converted to SAF via HEFA. Secondly, to understand how feedstock allocation can impact fuel production, the proportion of annual feedstock production was varied (5% and 10% for both feedstock), assuming high growth projections and high SAF yields.

85 JG Summit Holdings (2022) Cebu Pacific Launches Green Flight Powered by Sustainable Aviation Fuel. <https://www.jgsummit.com.ph/sustainability-highlights/cebu-pacific-launches-green-flight-powered-by-sustainable-aviation-fuel-20220530> (accessed 19 May 2023).

86 Nigo RY, Puy A (2013) Status and Prospects of Biofuels Development in Papua New Guinea. The Proceedings, The PNG University of Technology.

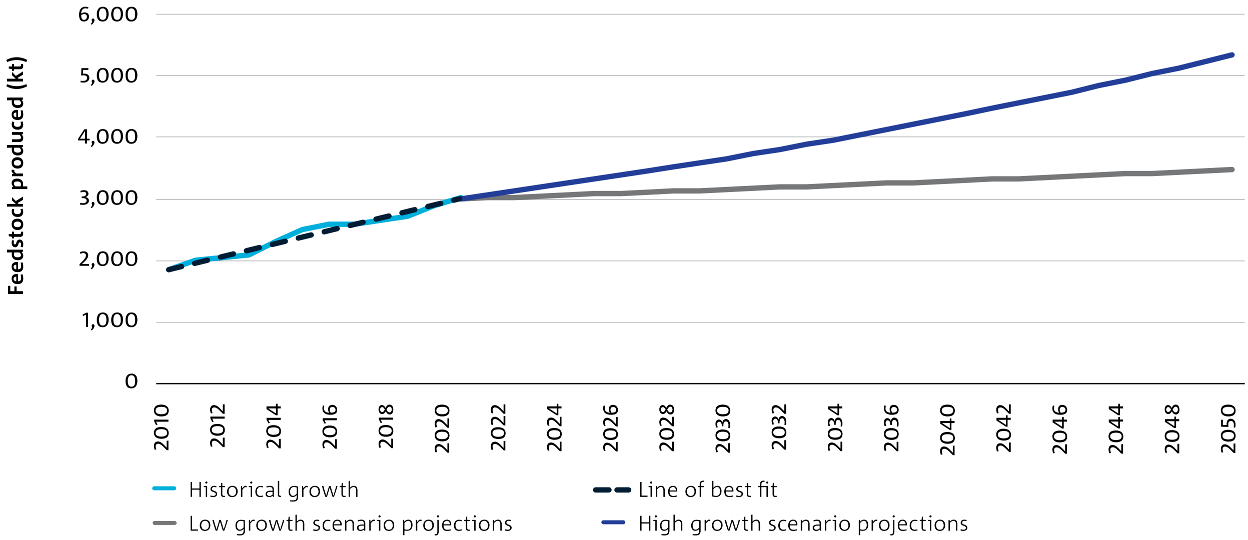
87 The Observatory of Economic Complexity (2020) Palm Oil in Papua New Guinea.

88 UNDP Food And Agricultural Commodity Systems (n.d.) Papua New Guinea: Sustainable Palm Oil. <https://www.undp.org/facs/papua-new-guinea-sustainable-palm-oil> (accessed 19 May 2023).

Palm fruit

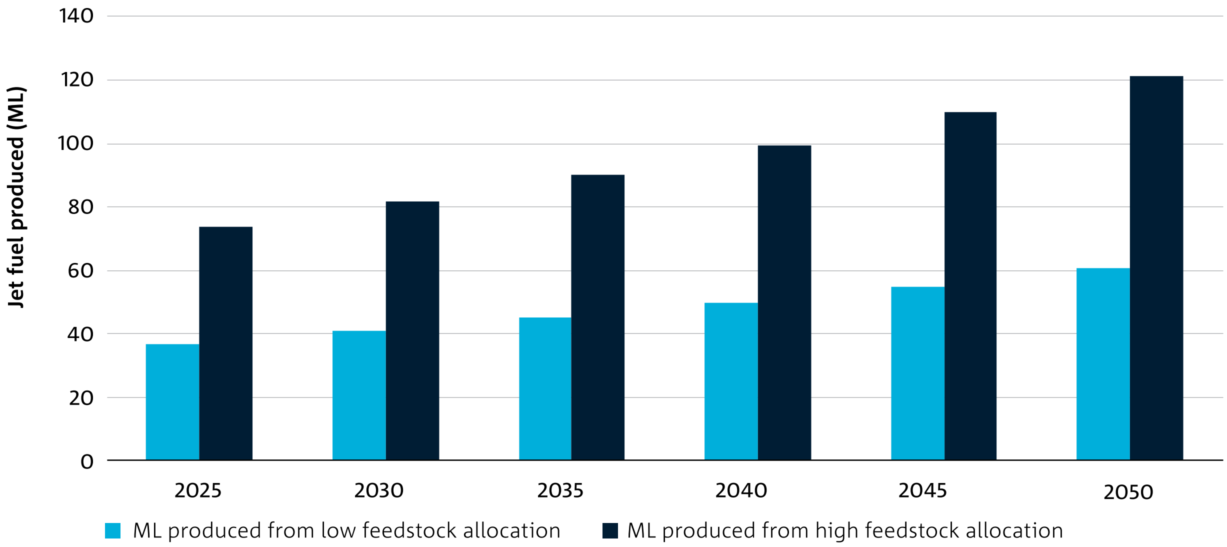
Assuming a high growth scenario, the annual amount of palm fruit produced in PNG is projected to be 3,252 kt by 2025 and 5,335 kt by 2050.

Figure 14. PNG palm fruit growth projections



As per the figure below, utilising 5% of palm oil through to 2050 could generate 61 ML of SAF, whereas utilising 10% of projected available palm oil could produce 121 ML of SAF.

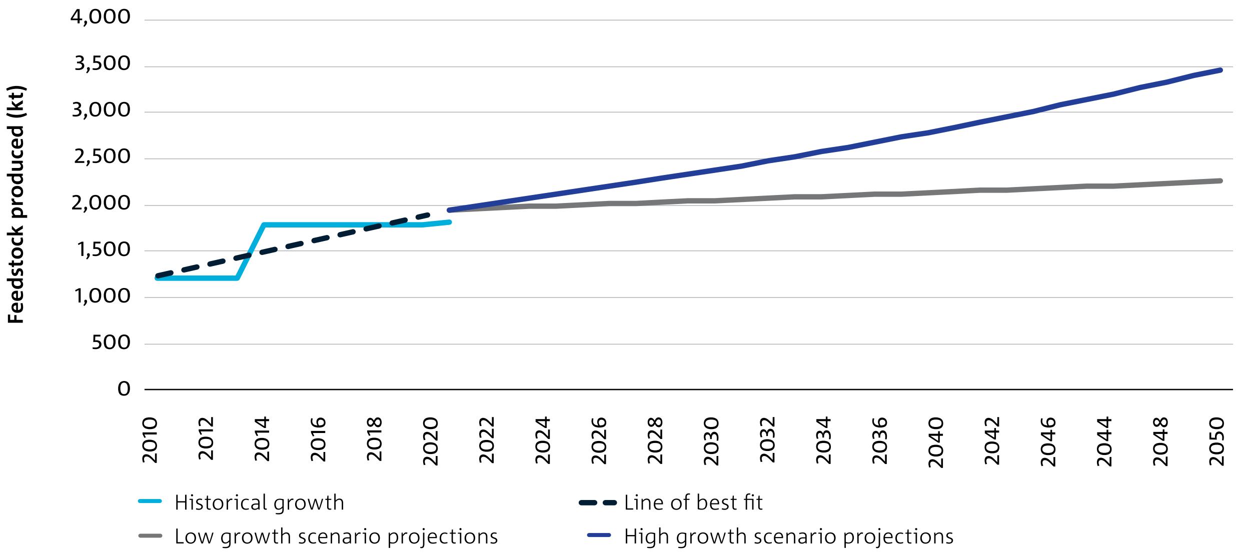
Figure 15. Potential SAF production from PNG palm fruit (high feedstock growth rate, high jet fuel yield scenario)



Coconut

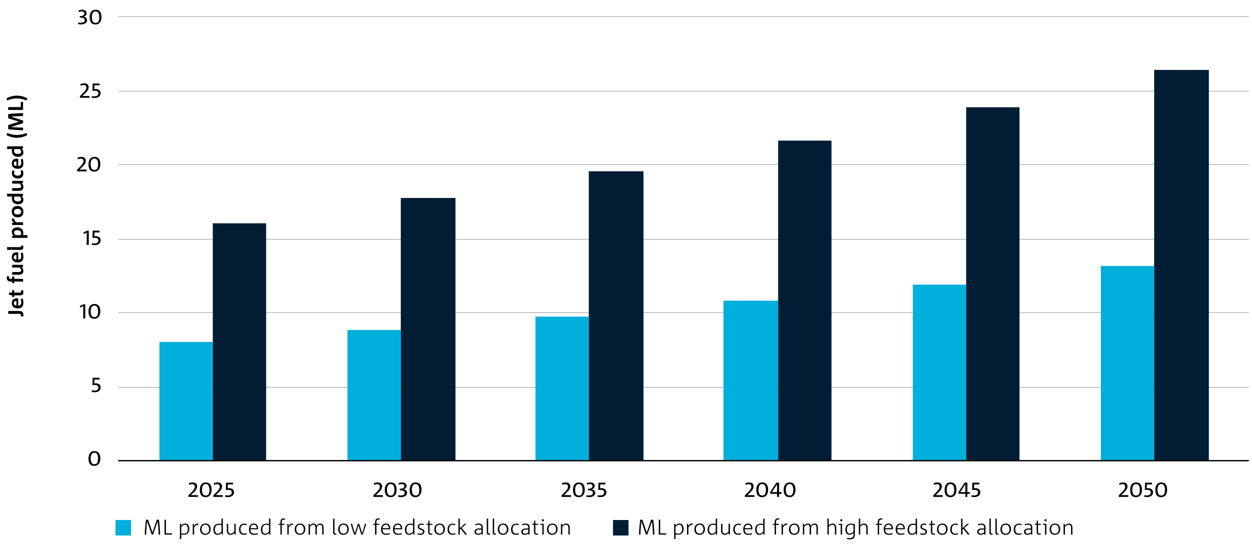
Assuming a high growth scenario, the coconut production level in PNG is projected to be 2,112 kt by 2025 and 3,465 kt by 2050.

Figure 16. PNG coconut growth projections



As per the figure below, utilising 5% of coconut through to 2050 could generate 13 ML of SAF, whereas utilising 10% of projected available coconut could produce 26 ML of SAF.

Figure 17. Potential SAF production from PNG coconut (high feedstock growth rate, high jet fuel yield scenario)



SAF activity and plans

Despite a lack of policy or initiatives regarding SAF, the Civil Aviation Department Investment Programme, funded by the Asian Development Bank, is an organisation focused on the redevelopment of PNG's aviation infrastructure and to create a sustainable civil aviation network that supports the current and future growth demands.[89]

1.10 Singapore

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	●	• Strong history of large-scale bio/renewable diesel produced from the imported feedstock.
SAF policy	◑	• No explicit targets from the government, but the government is keen to promote Singapore as a sustainable air hub.
Feedstock activity	●	• Due to land mass restraints, Singapore cannot produce its feedstocks. • Currently importing UCO and tallow for SAF production.
SAF activity	●	• Neste has a strong footprint in Singapore and is a major global SAF producer using UCO and animal fats via the HEFA pathway.

Other biofuels experience

Singapore's ambition to bolster itself as a 'hub city' has driven its efforts to become a major biofuel refiner and producer. Singapore is the world's largest bunkering port, one of the largest exporting refinery centres, South Asia's leading financial centre and a central airport hub. Its' unique geographical location and an existing biofuel refinery position it well for future trading of alternative fuels and energy, reducing its import dependencies.[90]

Singapore refines large amounts of biofuels, including 1.3 Mt per annum at the Neste refinery, with an upgrade expected to be completed in 2023, adding an extra 1.3 Mt per annum.[91] Refineries in Singapore currently use a range of imported feedstocks, including palm oil, soya oil, and small amounts of used cooking oil.[92]

Government SAF policy

Despite a lack of national SAF targets, government is pushing the promotion of a Singapore biofuels hub that utilises existing refining strengths and infrastructure.

The Civil Aviation Authority of Singapore (CAAS) is developing a structural offtake mechanism for SAF, based on recommendations submitted by the International Advisory Panel (IAP) on Sustainable Air Hub.[93] A study has been commissioned to assess various drivers, including whether participation in the offtake mechanism should be voluntary or mandatory, and determine funding sources. The outcome is anticipated in late 2023 and seeks to boost Singapore's competitiveness as a SAF hub.

89 The National (2022) Kavieng takes giant leap into the future. <https://www.thenational.com.pg/kavieng-takes-giant-leap-into-the-future/> (accessed 19 May 2023).

90 Schonsteiner K, Massier T, Hamacher T (2016) Sustainable transport by use of alternative marine and aviation fuels – A well-to-tank analysis to assess interactions with Singapore's energy system. Renewable and Sustainable Energy Reviews.

91 Neste (2023) Singapore. <https://www.neste.com/about-neste/who-we-are/production/singapore> (accessed 19 May 2023).

92 APEC (n.d.) Singapore Biofuels Activities. <https://egnret.ewg.apec.org/sites/default/files/geektic/web/me_singapore.html> (accessed 19 May 2023).

93 Tan J (2023) CAAS launches tender to study and develop offtake mechanism for sustainable aviation fuels. The Business Times. <https://www.businesstimes.com.sg/esg/caas-launches-tender-study-and-develop-offtake-mechanism-sustainable-aviation-fuels> (accessed 19 May 2023); Civil Aviation Authority of Singapore (n.d.) Annex A - Extract of Report of the International Advisory Panel on Sustainable Air Hub. <https://www.caas.gov.sg/docs/default-source/default-document-library/annex-a---extract-of-iap-report---saf-structural-offtake-mechanism.pdf> (accessed 19 May 2023).

Feedstock activity and plans

As a city-state, Singapore lacks land availability and large scale renewables to produce feedstocks. Although MSW may have the potential to play a small role in biofuels, Singapore will depend on imports for biofuel production. This is already the case with significant amounts of UCO and other fats and oils imported for biofuel production.

SAF activity and plans

Promoting the development and uptake of biofuels is integral for Singapore to meet their net zero carbon emissions by 2050 goal and to decarbonise hard-to-abate maritime and aviation industries. Singapore is leading initiatives to utilise SAF in its commercial aviation sector as a long-term measure to support the air transport industry's carbon-neutral growth goal beyond 2020. Singapore Airlines has been an active member of the Sustainable Aviation Fuel Users Group since 2011, which aims to accelerate the development and commercialisation of SAF. In 2017, the airline partnered with CAAS to operate 12 green package flights, utilising SAF derived from UCO.[94]

Furthermore, from the third quarter of 2022, Singapore Airlines has started a one-year pilot where all Singapore Airlines flights will utilise SAF, supplied at Changi Airport. Neste will supply 1.25 ML of SAF derived from UCO and waste animal fats, which will then be mixed with refined jet fuel by ExxonMobil.[95] This initiative coincides with the completion of Neste's refinery in Tuas, expected in 2023, making Singapore the country with the largest SAF refining capacity - approximately 1.25 billion litres of SAF annually.[96]

1.11 South Korea

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	◑	• Low biodiesel mandates were introduced in 2020.
SAF policy	○	• Aim for SAF to be introduced by 2026; detail is limited.
Feedstock activity	○	• Limited available and agricultural land allows for small amounts of agricultural and forestry residues. Import is likely.
SAF activity	◑	• Plans for two SAF plants to be commenced in 2024 and 2025 utilising UCO and palm oil.

Other biofuels experience

South Korea's Ministry of Trade, Industry and Energy, Ministry of Land, Infrastructure and Transport and Ministry of Oceans and Fisheries created a biofuel alliance in 2022 and signed a mutual growth MoU to undertake biofuel development measures. Biofuel is important to advance South Korea's energy security, as currently 98% of its fossil fuel consumption is covered by imports.

As of 2020, South Korea's biofuel mandate was a 2.5% blend for biodiesel. Despite a lack of advanced biofuel production facilities, on average, since 2007, biofuel production and usage of biofuels in South Korea have increased at an annual rate of 14% and 36%, respectively.[97]

94 Baxter G (2022) Assessing the carbon footprint and carbon mitigation measures of a major full-service network airline: a case study of Singapore Airlines. International Journal of Environment, Agriculture and Biotechnology.

95 Travel Radar (2022) Singapore Airlines To Use Sustainable Aviation Fuel as Part of New Pilot. <https://travelradar.aero/singapore-airlines-use-sustainable-aviation-fuel-part-new-pilot/> (accessed 19 May 2023).

96 EDB Singapore (2022) Singapore to have world's largest sustainable aviation fuel plant. <https://www.edb.gov.sg/en/business-insights/insights/singapore-to-have-world-s-largest-sustainable-aviation-fuel-plant.html> (accessed 19 May 2023).

97 Ebadian M, Dyk S, McMillan JD, Saddler J (2020) Biofuels policies that have encouraged their production and use: An international perspective. Energy Policy.

Government SAF policy

The Ministry's "Eco-Friendly Biofuel Development Measures" include initiatives to develop large-scale production technology and establish a stable supply chain for biofuels, ultimately aiming to introduce SAF into domestic aviation by 2026.[98]

Feedstock activity and plans

Potential feedstocks for biofuels in South Korea include rice straw, microalgae, and forestry residues such as *Miscanthus,* however, they only have limited availability.[99]

SAF activity and plans

In 2021, South Korean corporations Dansuk Industrial and LG Chem partnered to invest in the first HEFA plant, scheduled to commence in 2024. Dansuk further planned to develop a second SAF plant that is expected to become operational by 2025 and have a production capacity of 300 kt per annum.[100] Major refineries across the country also aimed to increase biofuel share to 7-10% of the overall aviation fuel output between 2022 and 2025.[101]

In 2017, Korean Air became the first South Korean airline to utilise SAF on an international flight. In 2022, it announced that it would utilise SAF on flights between Seoul and Paris.[102] Additionally, Korean Air authenticated a MoU with Hyundai Oilbank to establish the basis for biofuel use in aviation, specifically SAF refinement and production.[103]

1.12 Thailand

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels	●	• Significant production of ethanol from sugarcane and molasses and biodiesel from palm oil with plans to increase production. • Production is supported by blending mandates, tax incentives and R&D support.
SAF policy	○	• No national policy standard or targets exist for SAF.
Feedstock activity	○	• Likely candidates for SAF include palm oil, UCO and ethanol (from sugarcane/molasses)
SAF activity	◑	• Plans to build the first HEFA facility using UCO. • Research into fusel alcohol to get underway.

Other biofuels experience

Through Thailand's Alternative Energy Development Plan (2015-2036), significant progress has been made to promote bioethanol and biodiesel expansion in the country. This is to meet the national ambition to reduce 20-25% of GHG emissions by 2030. Under the plan, biodiesel production from palm oil is set to increase from 2 to 5.11 billion litres per year, and bioethanol production from sugarcane and molasses from 1.27 to 2.7 billion litres per year by 2036. The plan also includes a B20 target of 20% biodiesel blend in vehicles, an E20 and eventual E85 target of 20% and 85% blend of bioethanol in gasoline, respectively.[104]

98 Republic of Korea Ministry of Trade, Industry and Energy (2022) MOTIE announces Eco-Friendly Biofuel Development Measures. <http://english.motie.go.kr/en/pc/pressreleases/bbs/bbsView.do?bbs_cd_n=2&bbs_seq_n=1095> (accessed 19 May 2023).

99 Hochman G, Tabakis C (2020) Biofuels and Their Potential in South Korea. Sustainability.

100 Chem Analyst News (2021) South Korea to have its First Hydro-Treated Vegetable Oil and Sustainable Aviation Fuel Plant. <https://www.chemanalyst.com/NewsAndDeals/NewsDetails/south-korea-to-have-its-first-hydro-treated-vegetable-oil-and-sustainable-aviation-fuel-plant-7713> (accessed 19 May 2023).

101 S&P Global Commodity Insights (2022) South Korea's SK Innovation lays foundation to boost green aviation fuel production. <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/041422-south-koreas-sk-innovation-lays-foundation-to-boost-green-aviation-fuel-production> (accessed 19 May 2023).

102 The Global Economics (2022) Sustainable Aviation Fuel to Power Korean Air; emission reduction close to 80%. <https://www.theglobaleconomics.com/2022/03/10/sustainable-aviation-fuel/> (accessed 19 May 2023).

103 Biobased Diesel Daily (2022) Korean Air to use Shell's sustainable aviation fuel starting in 2026. <https://www.biobased-diesel.com/post/korean-air-to-use-shell-s-sustainable-aviation-fuel-starting-in-2026> (accessed 19 May 2023).

104 Thailand Ministry of Energy (2015) Alternative Energy Development Plan: AEDP2015. <https://www.eppo.go.th/images/POLICY/ENG/AEDP2015ENG.pdf> (accessed 19 May 2023).

The increase in biofuel production necessitates an increase in cultivation area for feedstock supply. This includes expanding the oil palm crop area from 0.72 to 1.63 million ha and the sugarcane crop area from 1.6 to 2.56 million ha. There are many concerns about the environmental impact of these land use changes, especially around freshwater depletion and increased water stress.[105]

To bolster biofuel demand and reduce dependence on petroleum imports, the Thai government introduces many incentives such as tax privileges for the Board of Investment, tax and retail price incentives, R&D support, and public awareness promotion. The government also subsidises prices and extends low-interest loans to palm oil farmers to encourage production.[106]

Government SAF policy

No national policy standard or targets exist for SAF.

Feedstock activity and plans

Potential feedstocks include palm fruit, sugarcane and ethanol. Feedstock activity is focused on road transport biofuels.

SAF activity and plans

In May 2022, energy conglomerate Bangchak Corporation began to develop Thailand's first SAF production facility, utilising UCO as feedstock. The facility is expected to commence by the fourth quarter of 2024 and have an annual capacity of 365 ML.[107]

In the same year, Bangchak, BBGI, the National Research Council of Thailand and the Rajamangala University of Technology Isan signed a MoU to expand the research into SAF production from fusel alcohol (alcohol with more than two carbons). Fusel alcohol is derived from ethanol production using sugarcane, cassava, and cellulosic sludge. As BBGI already produces commercial quantities of ethanol (219 ML per year), this agreement will increase the domestic application and export potential of SAF derived from fusel alcohol.[108]

105 Lecksiwilai N, Gheewala SH (2020) Life cycle assessment of biofuels in Thailand: Implications of environmental trade-offs for policy decisions. Sustainable Production and Consumption.

106 Mukherjee I, Sovacool BK (2014) Palm oil-based biofuels and sustainability in southeast Asia: A review of Indonesia, Malaysia, and Thailand. Renewable and Sustainable Energy Reviews.

107 Bangkok Post (2022) Bangchak preps SAF production facility. <https://www.bangkokpost.com/business/2303358/bangchak-preps-saf-production-facility> (accessed 19 May 2023).

108 Bangchak (2022) Bangchak Group targets net zero piloting sustainable aviation fuel (SAF) production expanding on local research. <https://www.bangchak.co.th/en/newsroom/bangchak-news/832/bangchak-group-targets-net-zero-piloting-sustainable-aviation-fuel-saf-production-expanding-on-local-research> (accessed 19 May 2023).

1.13 Vietnam

Snapshot

CRITERIA	ASSESSMENT	DESCRIPTION
Other biofuels		• Government has a scheme to increase biofuel usage, mainly ethanol, aiming for 13% of road transport by 2030. • Supported by tax and retail incentives
SAF policy		• No national policy standard or targets exist for SAF.
Feedstock activity		• Ethanol (from sugarcane, molasses, cassava), rice residues, jatropha
SAF activity		• No current activity or plans. • Likely technologies would be ATJ and residues upgrading.

Other biofuels experience

In 2007, the Vietnam government implemented the "Scheme on Development of Biofuels up to 2015 with the Vision to 2025" to establish the national biofuel industry. The Scheme aims to produce 1.8 Mt of biofuels by 2025 with specific targets being 5% biofuels in total transport fuel demand by 2020 and 13% by 2030. The government also introduced tax and retail incentives and low-interest loans to attract foreign and private investments.

As of 2015, Vietnam had six biofuel plants, each producing 535 ML of ethanol annually.[109] However, most of Vietnam's ethanol is exported due to low domestic demand. Furthermore, a lack of a comprehensive biofuel policy, essential for development across the supply chain, has caused two ethanol plants to close as it was not economically competitive.[110]

Government SAF policy

No national policy standard or targets exist for SAF.

Feedstock activity and plans

Vietnam is rich in biomass resources, including sugarcane, molasses, maize, jatropha and agricultural residues. In 2019, Vietnam produced over 15 Mt of sugarcane and 10 Mt of cassava.[111,112] Combining this with the existing ethyl alcohol industry that utilises cane molasses and starches, sugarcane and cassava present as attractive feedstocks for biofuel and SAF production.

Vietnam has substantial cellulosic biomass potential, such as agricultural residues, of which 76 Mt are estimated to be produced annually from the rice industry.[113] Jatropha has been grown in Vietnam since 2006 and could be used as a feedstock for biodiesel production, however, concerns exist around its economic viability compared to CJF.[114]

As per the approach of Australian feedstocks, agricultural residues, sugarcane and bagasse were assessed to understand the potential for Vietnam. Firstly, historical data was used to calculate average growth since 2010. Using this trajectory, two growth scenarios (low and high) were applied to forecast production through 2050. It was assumed that agricultural residues and bagasse would be converted to SAF via gasification and FT, and sugarcane via the ATJ pathway. Secondly, to understand how feedstock allocation can impact fuel production, the proportion of annual feedstock production was varied (20% and 40% for agricultural residues and bagasse, 5% and 10% for sugarcane), assuming high growth projections and high SAF yields.

109 Biofuels International (2014) Vietnam set to increase biofuel use. <https://biofuels-news.com/news/vietnam-set-to-increase-biofuel-use/> (accessed 19 May 2023).

110 Chaiyapa W, Nguyen KN, Ahmed A, Vu QTH, Bueno M, Wang Z, Nguyen KT, Nguyen NT, Duong TT, Dinh UTT, Sjögren A, Le PTK, Nguyen TD, Nguyen HTA, Ikeda I, Esteban M (2021) Public perception of biofuel usage in Vietnam. Biofuels.

111 Selina Wamucii (n.d.) Vietnam Sugarcane Market Insights. <https://www.selinawamucii.com/insights/market/vietnam/sugarcane/> (accessed 19 May 2023).

112 Selina Wamucii (n.d.) Vietnam Cassava Market Insights. <https://www.selinawamucii.com/insights/market/vietnam/cassava/> (accessed 19 May 2023).

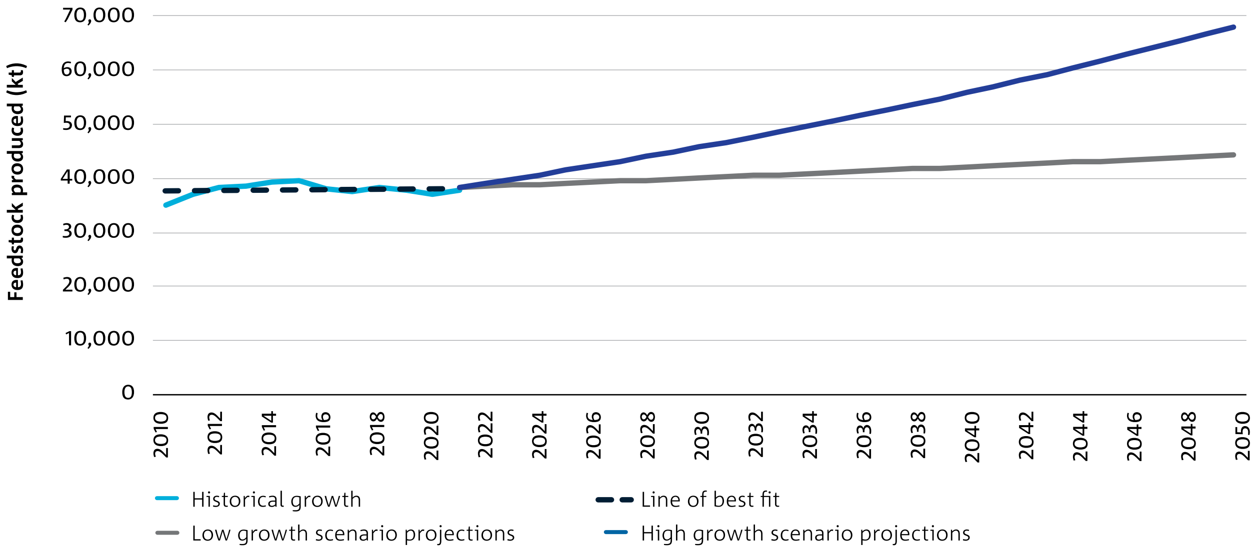
113 Nguyen MT, Nguyen TB, Dang KK, Luu T, Thach PH, Nguyen KLP, Nguyen HQ (2022) Current and Potential Uses of Agricultural By-Products and Waste in Main Food Sectors in Vietnam – A Circular Economy Perspective. Circular Economy and Waste Valorisation.

114 Trinh TA, Le TPL (2018) Biofuels Potential for Transportation Fuels in Vietnam: A Status Quo and SWOT Analysis. IOP Conference Series Earth and Environmental Science.

Agricultural residues

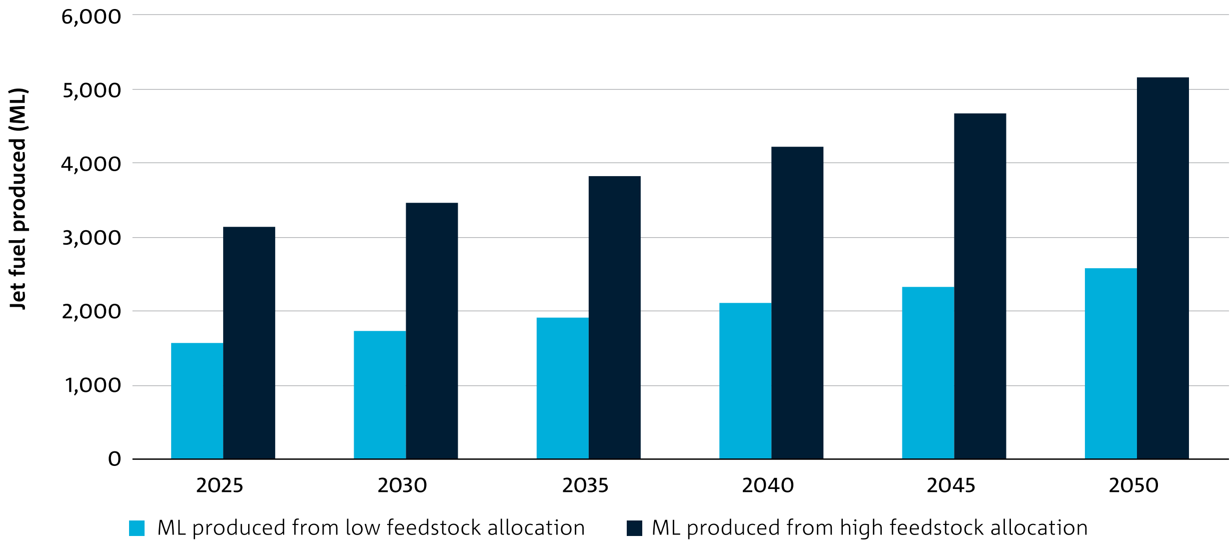
Assuming a high growth scenario, the annual amount of agricultural residues produced in Vietnam is projected to be 41,471 kt by 2025 and 68,037 kt by 2050.

Figure 18. Vietnam agricultural residues growth projections



As per the figure below, utilising 20% of agricultural residues through to 2050 could generate 2,578 ML of SAF, whereas utilising 40% of projected available residues could produce 5,156 ML of SAF.

Figure 19. Potential SAF production from Vietnam agricultural residues (high feedstock growth rate, high jet fuel yield scenario)



Sugarcane and bagasse

Assuming a high growth scenario, the annual amount of sugarcane produced in Vietnam is projected to be 14,971 kt by 2025 and 24,561 kt by 2050. The amount of bagasse produced is projected to be 4,491 kt by 2025 and 7,368 kt by 2050.

Figure 20. Vietnam sugarcane growth projections

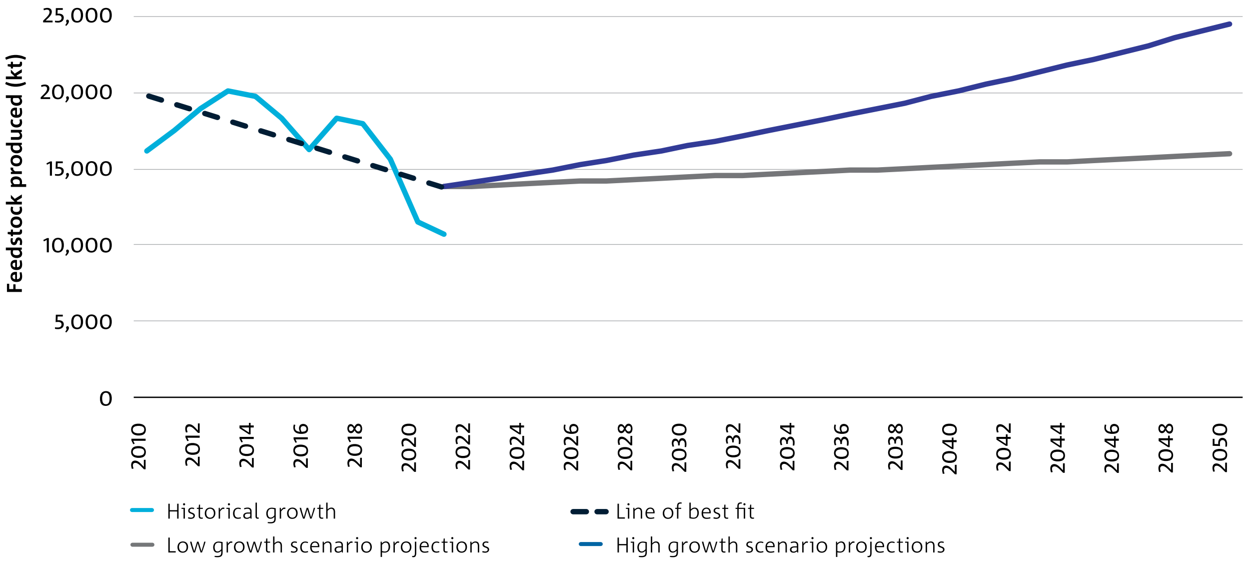
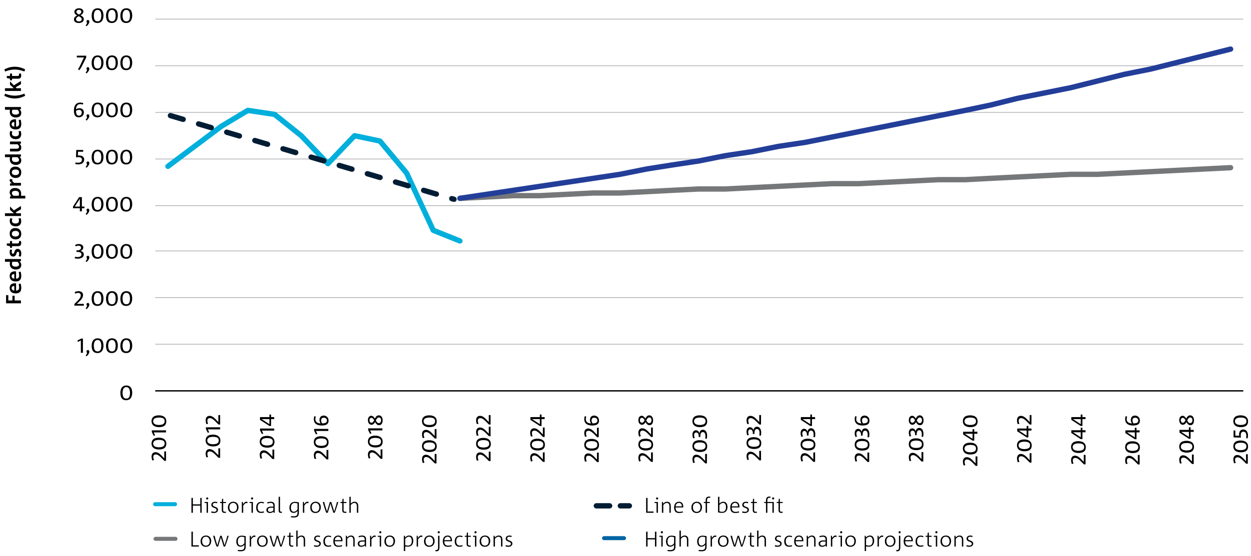
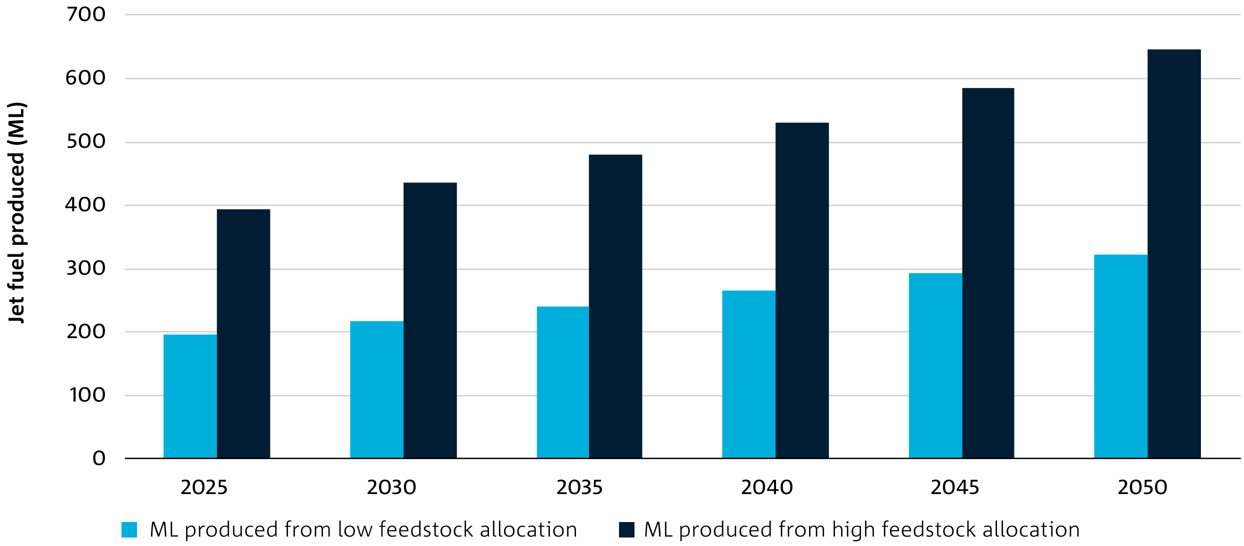


Figure 21. Vietnam sugarcane bagasse growth projections



As per the figure below, utilising 5% of sugarcane and 20% of bagasse through to 2050 could generate 324 ML of SAF, whereas utilising 10% of projected available sugarcane and 40% of bagasse could produce 647 ML of SAF.

Figure 22. Potential SAF production from Vietnam bagasse and sugarcane (high feedstock growth rate, high jet fuel yield scenario)



SAF activity and plans

No current activity or plans.

2 Appendices

2.1 Feedstock modelling for New Zealand

2.1.1 This analysis

Economic analysis of feedstock availability for SAF was undertaken by CSIRO Futures to assess the commercial opportunity for SAF in New Zealand by 2050. Sawmill residues and tallow were selected for analysis due to the commercial maturity of their production. Other woody biomass was excluded from this modelling exercise due to the contention over their use in biofuels as per chapter 3.3.
As such, this Appendix summarises the parameters, methodology and results of this modelling, developed in consultation and used to produce the estimates presented in this Roadmap.

2.1.2 Parameters

Jet fuel demand

- Projections of New Zealand's total jet fuel demand from 2025–2050 were obtained from its 2018 Biofuels Roadmap.
- These projections were used to calculate the percentage of fuel demand that SAF projections represented for context, allowing comparison across feedstocks and across time.

Table: Projected New Zealand jet fuel demand to 2050[115]

YEAR	PROJECTED JET FUEL DEMAND
2025	1,842 ML
2030	1,982 ML
2035	2,121 ML
2040	2,260 ML
2045	2,399 ML
2050	2,539 ML

Other parameters

- All other parameters are assumed to be the same as for Australia, as defined in Section 7.4.2.

115 Business NZ Energy Council 2018, BEC Energy Scenarios: BEC2050 (MARKEL), 2050 dataset, https://bec.org.nz/tools/scenarios/bec2050-energy-scenarios-markel/

Estimates for aviation TFC (PJ/y) for 2010, 2020, 2030, 2040, 2050 for the low use and high use scenario were used. The average estimates for the two scenarios were calculated and converted to ML/y using a ratio of 34.7 MJ/L of jet fuel. Jet fuel demand was estimated for 2025–2050 by applying a linear line of best fit with a least squares approach.

2.1.3 Sawmill residues

Calculations

(1) Potential domestic feedstock production by 2018 (t)	= A x 1,000 x B
Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x (1+C)^[32]
(2) Potential domestic SAF production (ML)	= [(1) x D x E]/1,000,000
(3) Potential SAF production as portion of projected fuel demand (%)	= [(2)/F] x 100

Assumptions

PARAMETERS			SAWMILL RESIDUES
A	Current estimate of domestic feedstock production based on historical trends (2018)[116]		4,342 kt
B	Feedstock portion allocated to jet fuel (%)	Low	20%
		High	40%
C	Forecast annual growth in feedstock production	Low	0.5%
		High	2%
D	G+FT jet fuel yield[117]	Low	5%
		High	15%
E	Jet fuel density[118]		1,263 L/t
F	Projected jet fuel demand		*See Table 3*
G	G+FT plant requirement	Small scale	264 kt
		Large scale	1,584 kt

116 New Zealand Ministry for Primary Industries 2019, Production of sawn timber, 1970 to most recent [XLSX, 21 KB]. https://www.mpi.govt.nz/forestry/forest-industry-and-workforce/forestry-wood-processing-data/wood-processing-data/

ABARES 2018, Future opportunities for using forest and sawmill residues in Australia, Australian Bureau of Agricultural and Resource Economics and Sciences. https://www.agriculture.gov.au/abares/research-topics/forests/forest-economics/forest-economic-research/forest-sawmill-residues-report

A reported ratio of 1m3 sawlogs = 0.5t sawmill residues was applied to sawn timber production data to estimate available sawmill residues. Calculation assumes sawlog = sawn timber + sawmill residues, and therefore 1m3 sawn timber = 1t sawmill residues.

A historical trend line was calculated from 2010–2018 feedstock production data reported, and then applied to obtain a 2018 current estimate to use for forecasts.

117 Low and high G+FT jet fuel yield figures were chosen based on what is feasible for Australia, obtained via literature review and industry stakeholder consultations.

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Bressanin JM et al. 2020, Techno-economic and environmental assessment of biomass gasification and Fischer-Tropsch synthesis integrated to sugarcane biorefineries, Energies, 13(17). https://www.mdpi.com/1996-1073/13/17/4576

118 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		SAWMILL RESIDUES
Potential domestic SAF production	2025	56.79 ML
	2050	64.33 ML
Potential SAF production as portion of projected fuel demand	2025	3.08%
	2050	2.53%

HIGH SCENARIO		SAWMILL RESIDUES
Potential domestic SAF production	2025	377.98 ML
	2050	620.12 ML
Potential SAF production as portion of projected fuel demand	2025	20.52%
	2050	24.43%

Figure 23. New Zealand sawmill residues growth projections and FT feedstock requirements based on plant size

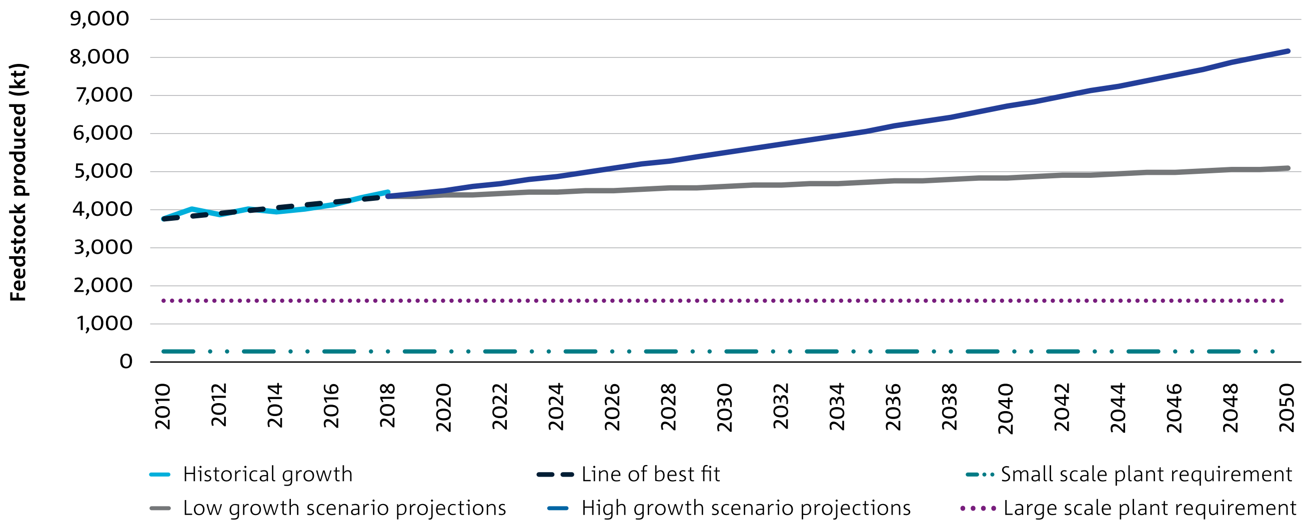
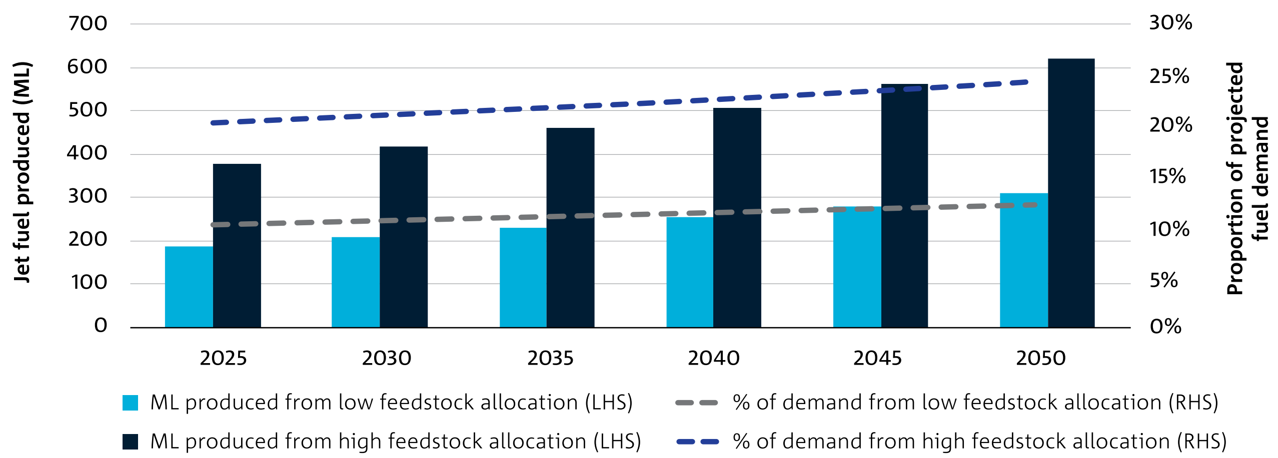


Figure 24. Potential SAF production from New Zealand sawmill residues and contribution toward domestic jet fuel demand (high feedstock growth rate, high jet fuel yield scenario)



2.1.4 Tallow

Calculations

(1) Potential domestic feedstock production by 2020 (t)	= A x 1,000 x B
Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x (1+C)^30
(2) Potential domestic SAF production (ML)	= [(1) x D x E]/1,000,000
(3) Potential SAF production as portion of projected fuel demand (%)	= [(2)/F] x 100

Assumptions

PARAMETERS			TALLOW
A	Current estimate of domestic feedstock production based on historical trends (2020)[119]		177 kt
B	Feedstock portion allocated to jet fuel (%)	Low	20%
		High	40%
C	Forecast annual growth in feedstock production	Low	0.5%
		High	2%
D	HEFA jet fuel yield[120]	Low	30%
		High	60%
E	Jet fuel density[121]		1,263L/t
F	Projected jet fuel demand		*See Table 3*
G	HEFA plant requirement	Small scale	66 kt
		Large scale	396 kt

119 Food and Agriculture Organization of the United Nations 2023, New Zealand tallow production quantity. https://www.fao.org/faostat/en/#data/QCL

A historical trend line was calculated from 2010–2020 feedstock production data reported, and then applied to obtain a 2020 current estimate to use for forecasts.

120 Low and high HEFA jet fuel yield figures were chosen based on what is feasible for Australia, obtained via literature review and industry stakeholder consultations.

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Han J, Elgowainy A, Cai H and Wang MQ 2013, Life-cycle analysis of bio-based aviation fuels, Bioresource Technology, 150, 447–456. https://www.sciencedirect.com/science/article/pii/S0960852413012297?via%3Dihub

Martinez-Hernandez E, Ramirez-Verduzco LF, Amezcua-Allieri MA and Aburto-J 2019, Process simulation and techno-economic analysis of bio-jet fuel and green diesel production – minimum selling prices, Chemical Engineering Research and Design, 146, 60–70. https://www.sciencedirect.com/science/article/pii/S0263876219301534?via%3Dihub

Pearlson M, Wollersheim C and Hileman J 2013, A techno-economic review of hydroprocessed renewable esters and fatty acids for jet fuel production, Biofuels, Bioproducts and Biorefining, 7(1), 89–96. https://onlinelibrary.wiley.com/doi/full/10.1002/bbb.1378

Tao L, Milbrandt A, Zhang Y and Wang WC 2017, Techno-economic and resource analysis of hydroprocessed renewable jet fuel, Biotechnology for Biofuels, 10(261). https://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/s13068-017-0945-3

121 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		TALLOW
Potential domestic SAF production	2025	13.72 ML
	2050	15.54 ML
Potential SAF production as portion of projected fuel demand	2025	0.74%
	2050	0.61%

HIGH SCENARIO		TALLOW
Potential domestic SAF production	2025	59.08 ML
	2050	96.92 ML
Potential SAF production as portion of projected fuel demand	2025	3.21%
	2050	3.82%

Figure 25. New Zealand tallow growth projections and HEFA feedstock requirements based on plant size

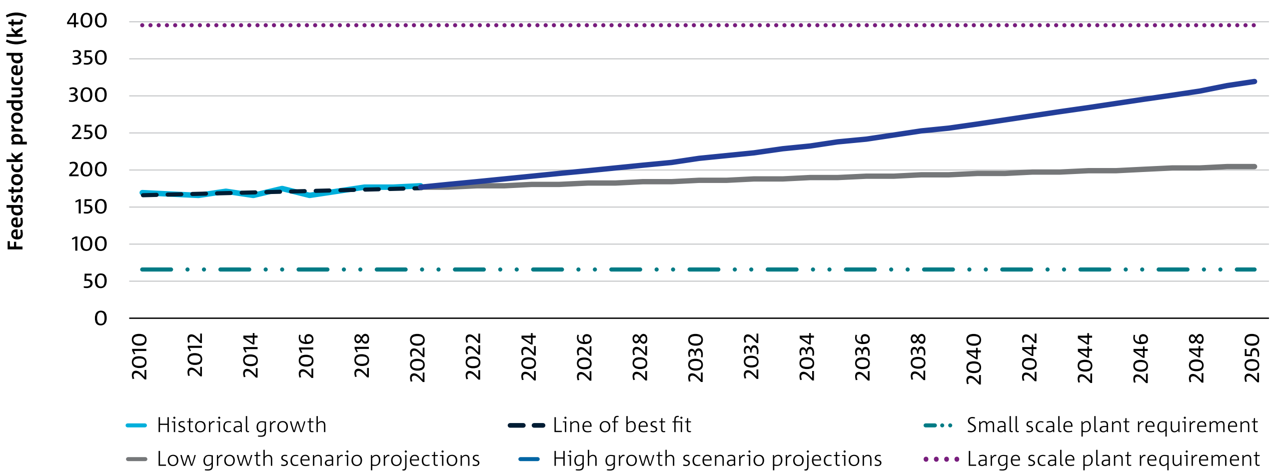
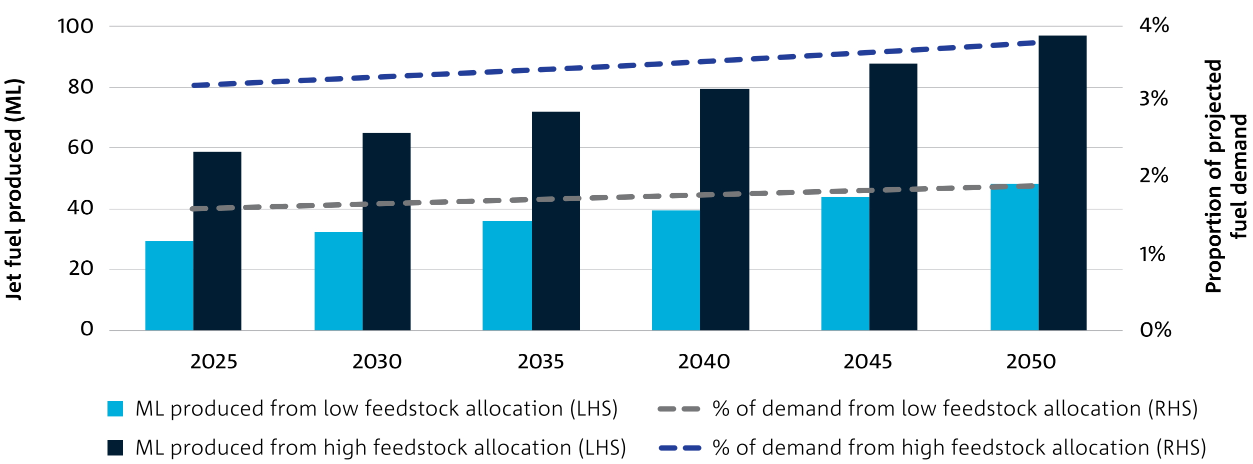


Figure 26. Potential SAF production from New Zealand tallow and contribution toward domestic jet fuel demand (high feedstock growth rate, high jet fuel yield scenario)



2.2 Feedstock modelling for Indonesia

2.2.1 This analysis

Economic analysis of feedstock availability for SAF was undertaken by CSIRO Futures to assess the commercial opportunity for SAF in Indonesia by 2050. Palm fruit was selected as the highest potential SAF feedstock in Indonesia given the fact that Indonesia is the world's largest producer and exporter of palm oil. Upon comparing the historical production data of major feedstock crops in Indonesia, sugarcane and bagasse produced consistently high volumes and were further selected for analysis. As such, this Appendix summarises the parameters, methodology and results of this modelling, developed in consultation and used to produce the estimates presented in this Roadmap.

2.2.2 Parameters

All parameters are assumed to be the same as for Australia, as defined in Section 7.4.2, with the application of Indonesian feedstock data to estimate potential SAF to 2050.

2.2.3 Palm fruit

Calculations

(1) Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x $(1+C)^{29}$
(2) Potential domestic oil production (t)	= (1) x D
(3) Potential domestic SAF production (ML)	= [(1) x E x F]/1,000,000

Assumptions

PARAMETERS			PALM FRUIT
A	Current estimate of domestic feedstock production based on historical trends (2021)[122]		265,336 kt
B	Feedstock portion allocated to jet fuel (%)	Low	5%
		High	10%
C	Forecast annual growth in feedstock production	Low	0.5%
		High	2%
D	Feedstock oil content[123]		30%
E	HEFA jet fuel yield[124]	Low	30%
		High	60%
F	Jet fuel density[125]		1,263 L/t

122 Food and Agriculture Organization of the United Nations 2023, Indonesia oil palm fruit production quantity. https://www.fao.org/faostat/en/#data/QCL

A historical trend line was calculated from 2010–2021 feedstock production data reported, and then applied to obtain a 2021 current estimate to use for forecasts.

123 Ruswanto A, Ramelan AH, Praseptiangga D, Partha IBB (2020) Palm oil yield potency on different level of ripening and storage time based on fruits percentage and fresh fruit bunches. IOP Conf. Series: Earth and Environmental Science 443.

Table 1 reports a range of palm fruit oil contents, and so 30% was selected as a middle-ground estimate.

124 Low and high HEFA jet fuel yield figures were chosen based on what is feasible, obtained via literature review.

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Han J, Elgowainy A, Cai H and Wang MQ 2013, Life-cycle analysis of bio-based aviation fuels, Bioresource Technology, 150, 447–456. https://www.sciencedirect.com/science/article/pii/S0960852413012297?via%3Dihub

Martinez-Hernandez E, Ramirez-Verduzco LF, Amezcua-Allieri MA and Aburto-J 2019, Process simulation and techno-economic analysis of bio-jet fuel and green diesel production – minimum selling prices, Chemical Engineering Research and Design, 146, 60–70. https://www.sciencedirect.com/science/article/pii/S0263876219301534?via%3Dihub

Pearlson M, Wollersheim C and Hileman J 2013, A techno-economic review of hydroprocessed renewable esters and fatty acids for jet fuel production, Biofuels, Bioproducts and Biorefining, 7(1), 89–96. https://onlinelibrary.wiley.com/doi/full/10.1002/bbb.1378

125 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		PALM FRUIT
Potential domestic SAF production	2025	1,538 ML
	2050	1,743 ML

HIGH SCENARIO		PALM FRUIT
Potential domestic SAF production	2025	6,529 ML
	2050	10,712 ML

Figure 27. Indonesia palm fruit growth projections

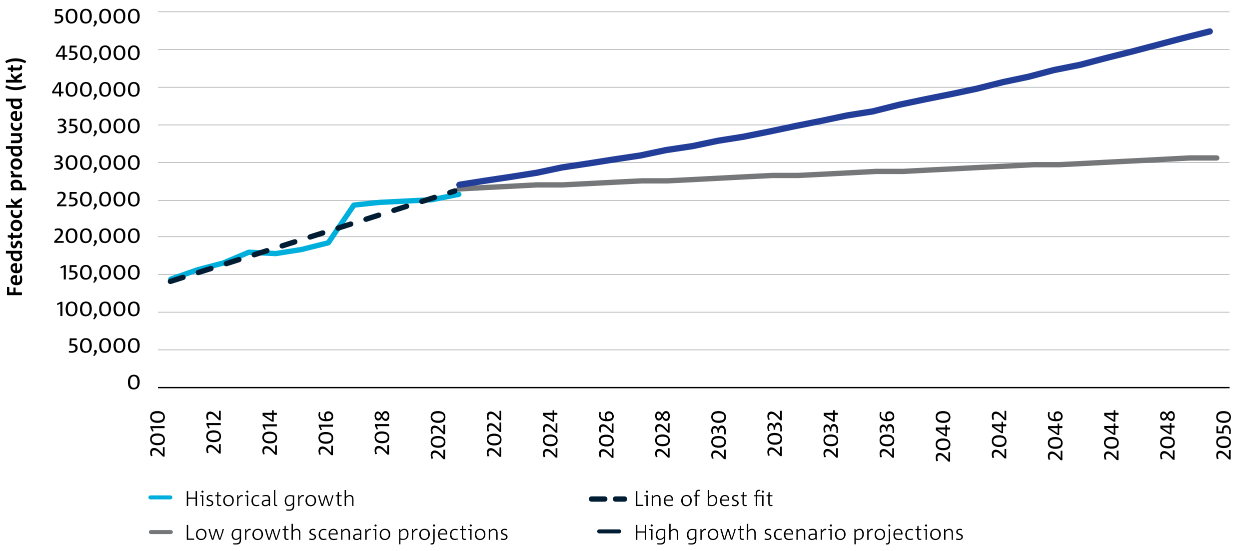
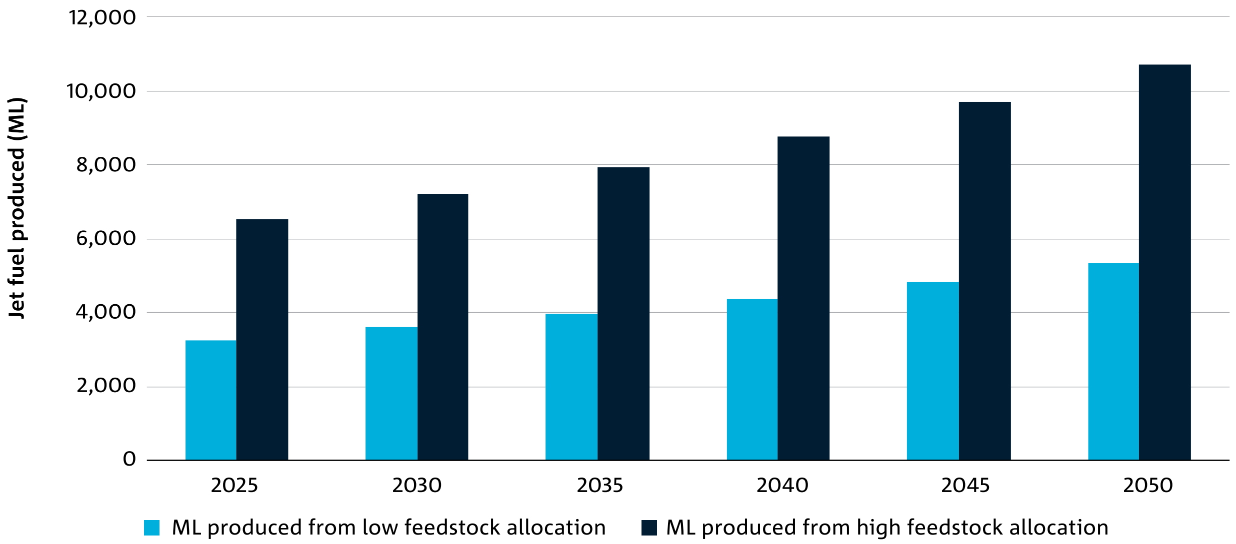


Figure 28. Potential SAF production from Indonesia palm fruit (high feedstock growth rate, high jet fuel yield scenario)



2.2.4 Sugarcane and bagasse

Calculations (sugarcane bagasse)

(1)	Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
	Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x $(1+C)^{29}$
(2)	Potential domestic SAF production (ML)	= [(1) x E x F]/1,000,000

Calculations (sugarcane)

(1)	Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
	Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x $(1+C)^{29}$
(2)	Potential domestic ethanol production (L)	= (1) x D
(3)	Potential domestic SAF production (ML)	= [(2) x E]/1,000,000

Assumptions

PARAMETERS			SUGARCANE BAGASSE	SUGARCANE
A	Current estimate of domestic feedstock production based on historical trends (2021)[126]		9,147 kt	30,491 kt
B	Feedstock portion allocated to jet fuel	Low	20%	5%
		High	40%	10%
C	Forecast annual growth in feedstock production	Low	0.5%	
		High	2%	
D	Ethanol yield from feedstock[127]			60 L/t
E	Jet fuel yield[128]	Low	5% (G+FT)	20% (ATJ)
		High	15% (G+FT)	60% (ATJ)
F	Jet fuel density[129]		1,263 L/t	

126 Food and Agriculture Organization of the United Nations 2023, Indonesia sugar cane production quantity. https://www.fao.org/faostat/en/#data/QCL

Queensland Government 2018, Queensland technical methods – cropping (sugarcane), Australian Biomass for Bioenergy Assessment.

A reported ratio of 1t sugarcane = 0.3t sugarcane bagasse was applied to sugarcane production data to estimate bagasse production.

A historical trend line was calculated from 2010–2021 feedstock production data reported, and then applied to obtain a 2021 current estimate to use for forecasts.

127 USDA 2006, The economic feasibility of ethanol production from sugar in the United States. https://www.fsa.usda.gov/Internet/FSA_File/ethanol_fromsugar_july06.pdf

Department of Agriculture and Food, Western Australia 2006, Ethanol production from grain. Department of Primary Industries and Regional Development, Western Australia, Perth. https://library.dpird.wa.gov.au/cgi/viewcontent.cgi?article=1031&context=pubns

128 Low and high jet fuel yield figures were chosen based on what is feasible, obtained via literature review.

ATJ:

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Geleynse S, Brandt K, Garcia-Perez M, Wolcott M, Zhang X 2018, The alcohol-to-jet conversion pathway for drop-in biofuels: techno-economic evaluation, Chemistry-Sustainability-Energy-Materials, 11(21), 3728–3741. https://chemistry-europe.onlinelibrary.wiley.com/doi/10.1002/cssc.201801690

G+FT:

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Bressanin JM et al. 2020, Techno-economic and environmental assessment of biomass gasification and Fischer-Tropsch synthesis integrated to sugarcane biorefineries, Energies, 13(17). https://www.mdpi.com/1996-1073/13/17/4576

129 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		SUGARCANE BAGASSE	SUGARCANE	TOTAL
Potential domestic SAF production	2025	118 ML	19 ML	137 ML
	2050	134 ML	21 ML	155 ML

HIGH SCENARIO		SUGARCANE BAGASSE	SUGARCANE	TOTAL
Potential domestic SAF production	2025	750 ML	119 ML	870 ML
	2050	1,231 ML	196 ML	1,427 ML

Figure 29. Indonesia sugarcane bagasse growth projections

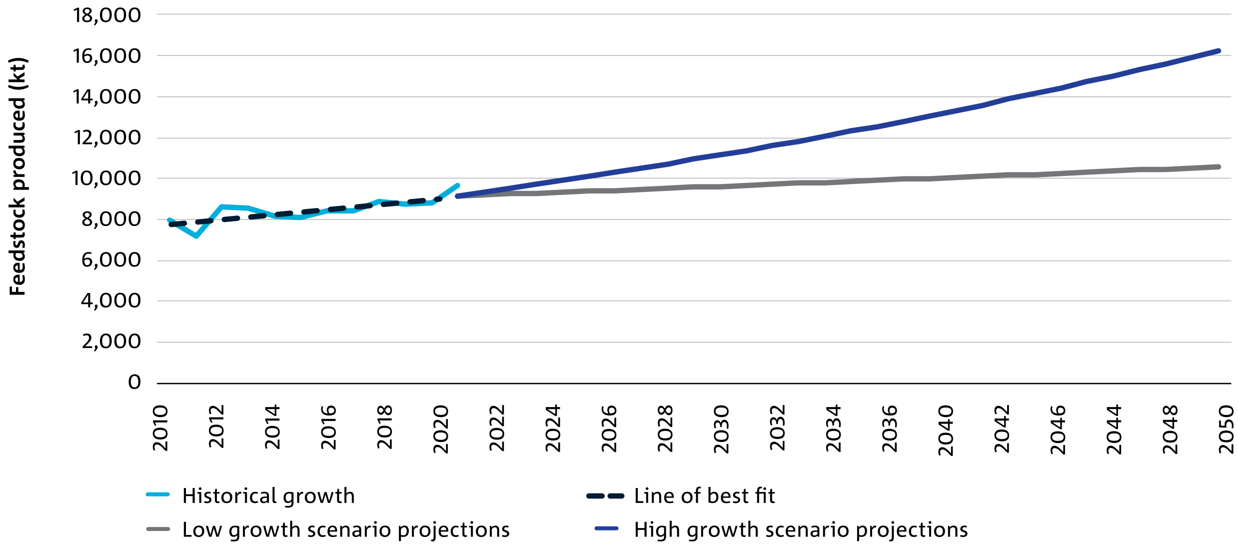


Figure 30. Potential SAF production from Indonesia sugarcane bagasse (high feedstock growth rate, high jet fuel yield scenario)

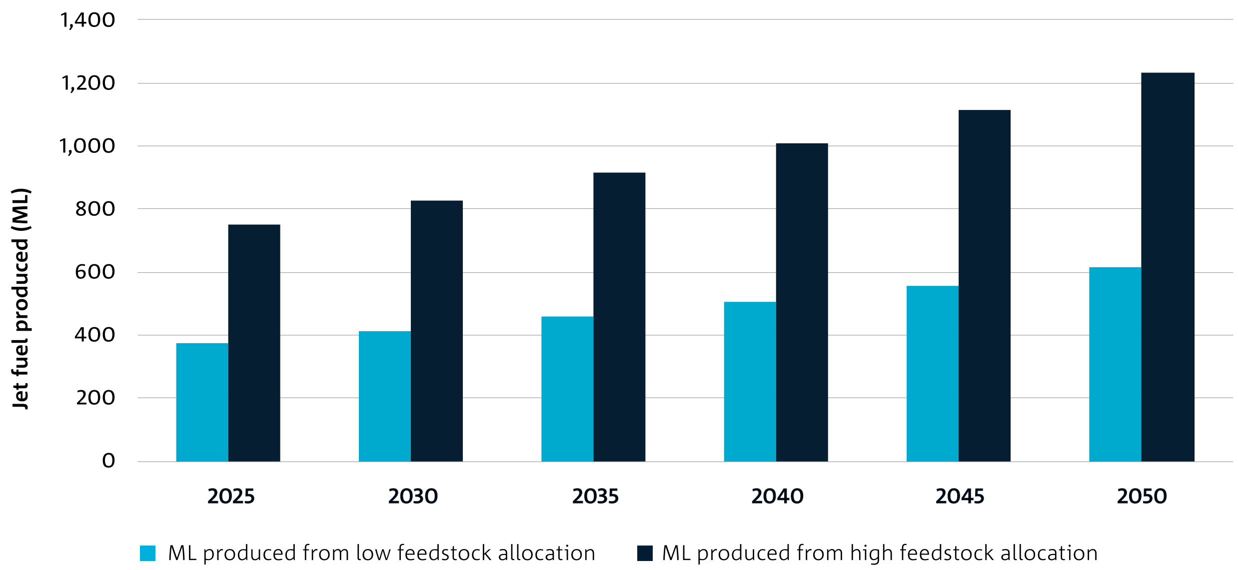


Figure 31. Indonesia sugarcane growth projections

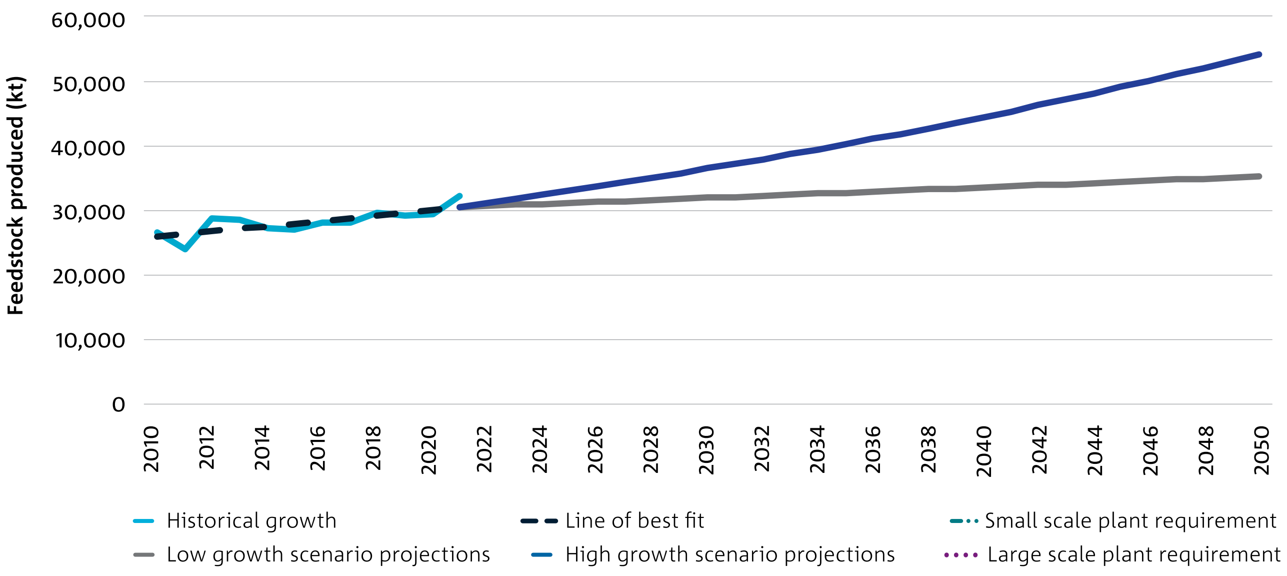


Figure 32. Potential SAF production from Indonesia sugarcane (high feedstock growth rate, high jet fuel yield scenario)

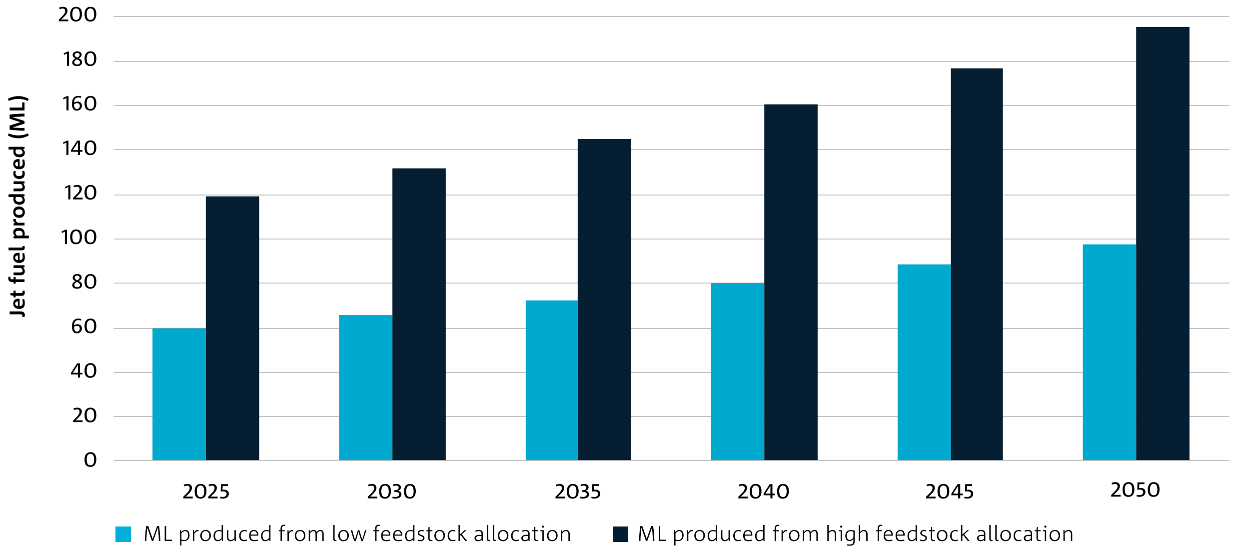
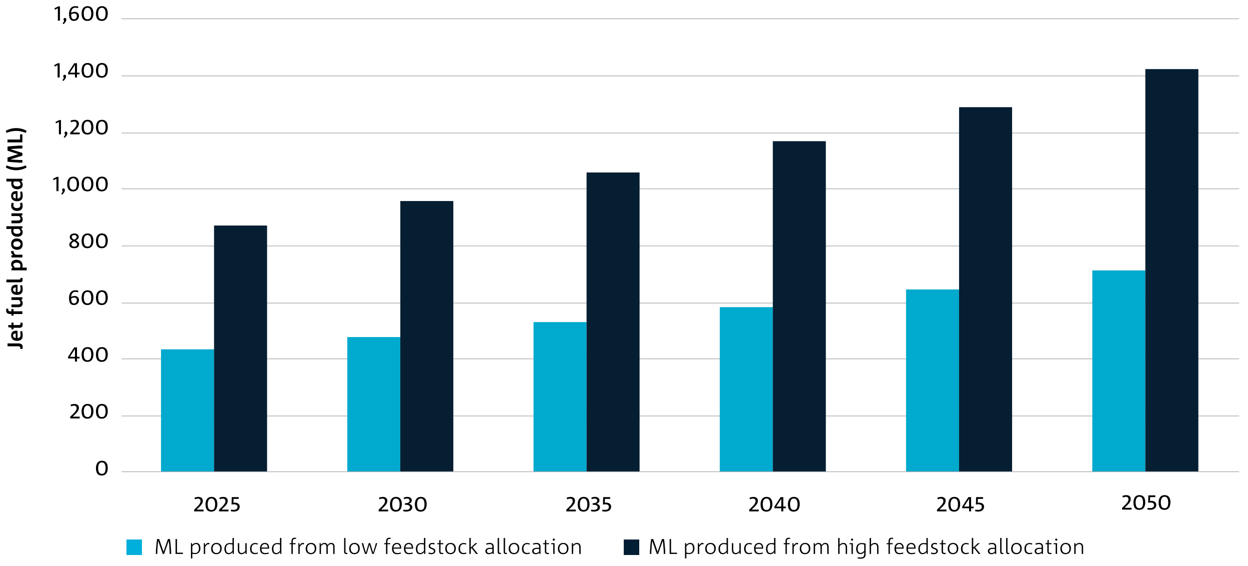


Figure 33. Potential SAF production from Indonesia bagasse and sugarcane (high feedstock growth rate, high jet fuel yield scenario)



2.3 Feedstock modelling for Malaysia

2.3.1 This analysis

Economic analysis of feedstock availability for SAF was undertaken by CSIRO Futures to assess the commercial opportunity for SAF in Malaysia by 2050. Palm oil production is a well-established industry in Malaysia, and as such palm fruit was selected as a potential feedstock for use in SAF production. As a primary agricultural producing country, Malaysia produces a substantial amount of agricultural residues that can be used for SAF production and was also selected for analysis. As such, this Appendix summarises the parameters, methodology and results of this modelling, developed in consultation and used to produce the estimates presented in this Roadmap.

2.3.2 Parameters

All parameters are assumed to be the same as for Australia, as defined in Section 7.4.2, with the application of Malaysian feedstock data to estimate potential SAF to 2050.

2.3.3 Palm fruit

Calculations

(1)	Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
	Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x $(1+C)^{29}$
(2)	Potential domestic oil production (t)	= (1) x D
(3)	Potential domestic SAF production (ML)	= [(1) x E x F]/1,000,000

Assumptions

PARAMETERS			PALM FRUIT
A	Current estimate of domestic feedstock production based on historical trends (2021)[130]		97,945 kt
B	Feedstock portion allocated to jet fuel (%)	Low	5%
		High	10%
C	Forecast annual growth in feedstock production	Low	0.5%
		High	2%
D	Feedstock oil content[131]		30%
E	HEFA jet fuel yield[132]	Low	30%
		High	60%
F	Jet fuel density[133]		1,263 L/t

130 Food and Agriculture Organization of the United Nations 2023, Malaysia oil palm fruit production quantity. https://www.fao.org/faostat/en/#data/QCL
A historical trend line was calculated from 2010–2021 feedstock production data reported, and then applied to obtain a 2021 current estimate to use for forecasts.

131 Ruswanto A, Ramelan AH, Praseptiangga D, Partha IBB (2020) Palm oil yield potency on different level of ripening and storage time based on fruits percentage and fresh fruit bunches. IOP Conf. Series: Earth and Environmental Science 443.
Table 1 reports a range of palm fruit oil contents, and so 30% was selected as a middle-ground estimate.

132 Low and high HEFA jet fuel yield figures were chosen based on what is feasible, obtained via literature review.
Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf
Han J, Elgowainy A, Cai H and Wang MQ 2013, Life-cycle analysis of bio-based aviation fuels, Bioresource Technology, 150, 447–456. https://www.sciencedirect.com/science/article/pii/S0960852413012297?via%3Dihub
Martinez-Hernandez E, Ramirez-Verduzco LF, Amezcua-Allieri MA and Aburto-J 2019, Process simulation and techno-economic analysis of bio-jet fuel and green diesel production – minimum selling prices, Chemical Engineering Research and Design, 146, 60–70. https://www.sciencedirect.com/science/article/pii/S0263876219301534?via%3Dihub
Pearlson M, Wollersheim C and Hileman J 2013, A techno-economic review of hydroprocessed renewable esters and fatty acids for jet fuel production, Biofuels, Bioproducts and Biorefining, 7(1), 89–96. https://onlinelibrary.wiley.com/doi/full/10.1002/bbb.1378

133 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		PALM FRUIT
Potential domestic SAF production	2025	568 ML
	2050	643 ML

HIGH SCENARIO		PALM FRUIT
Potential domestic SAF production	2025	2,410 ML
	2050	3,954 ML

Figure 34. Malaysia palm fruit growth projections

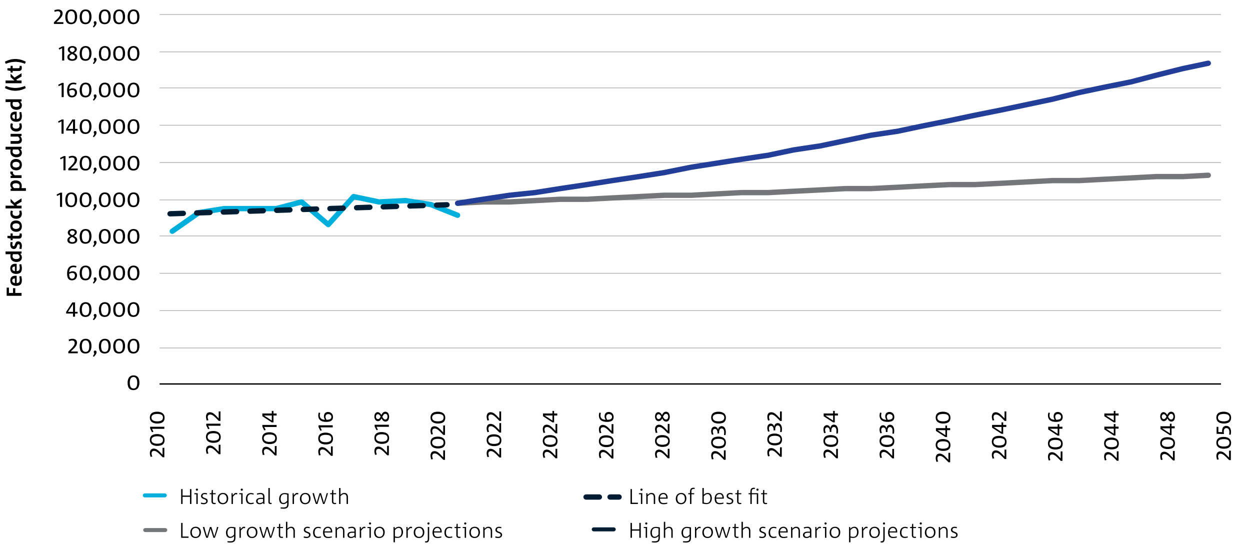
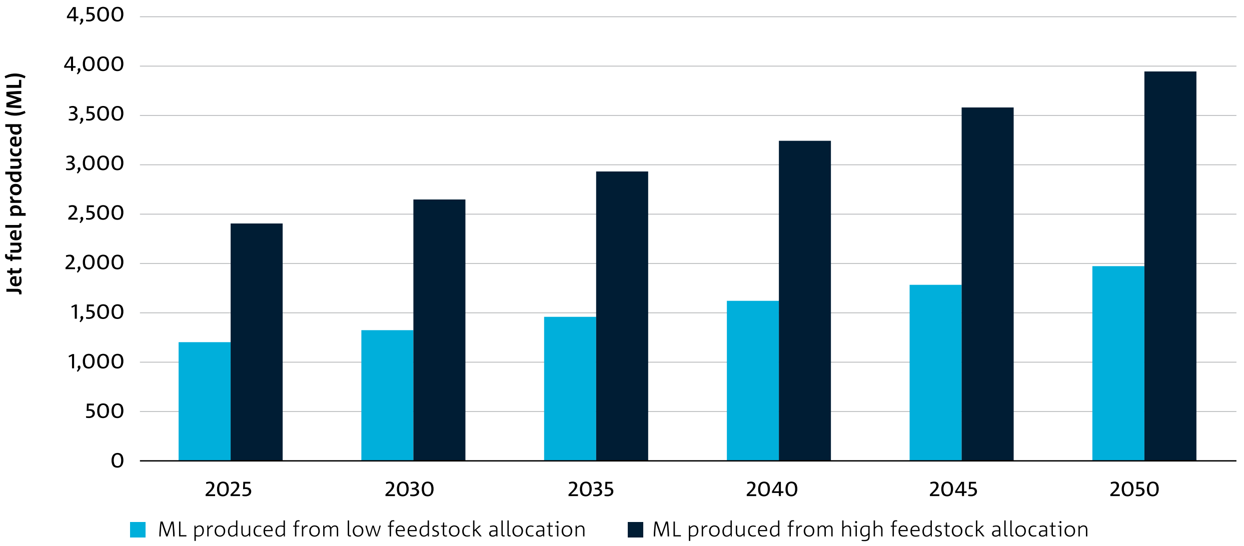


Figure 35. Potential SAF production from Malaysia palm fruit (high feedstock growth rate, high jet fuel yield scenario)



2.3.4 Agricultural residues

Calculations

(1)	Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
	Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x $(1+C)^{29}$
(2)	Potential domestic SAF production (ML)	= [(1) x D x E]/1,000,000

Assumptions

PARAMETERS			AGRICULTURAL RESIDUES
A	Current estimate of domestic feedstock production based on historical trends (2021)[134]		1,983 kt
B	Feedstock portion allocated to jet fuel (%)	Low	20%
		High	40%
C	Forecast annual growth in feedstock production	Low	0.5%
		High	2%
D	G+FT jet fuel yield[135]	Low	5%
		High	15%
E	Jet fuel density[136]		1,263 L/t

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		AGRICULTURAL RESIDUES
Potential domestic SAF production	2025	26 ML
	2050	29 ML

HIGH SCENARIO		AGRICULTURAL RESIDUES
Potential domestic SAF production	2025	163 ML
	2050	267 ML

134 Food and Agriculture Organization of the United Nations 2023, Malaysia primary crops production quantity and area harvested. https://www.fao.org/faostat/en/#data/QCL

Crops include maize and rice.

Herr A, O'Connell D, Dunlop, M, Unkovich M, Poulton P and Poole M 2012, Second harvest – is there sufficient stubble for biofuel production in Australia? GCB Bioenergy, 4, 654–660. https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1757-1707.2012.01165.x

A ratio of stubble potentially available for harvest with grain production (0.8) was calculated for Australian 1986–2005 data and applied to Malaysia agricultural production data for 2010–2021 to estimate available stubble.

A historical trend line was calculated from 2010–2021 feedstock production data reported, and then applied to obtain a 2021 current estimate to use for forecasts.

135 Low and high G+FT jet fuel yield figures were chosen based on what is feasible, obtained via literature review.

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Bressanin JM et al. 2020, Techno-economic and environmental assessment of biomass gasification and Fischer-Tropsch synthesis integrated to sugarcane biorefineries, Energies, 13(17). https://www.mdpi.com/1996-1073/13/17/4576

136 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Figure 36. Malaysia agricultural residues growth projections

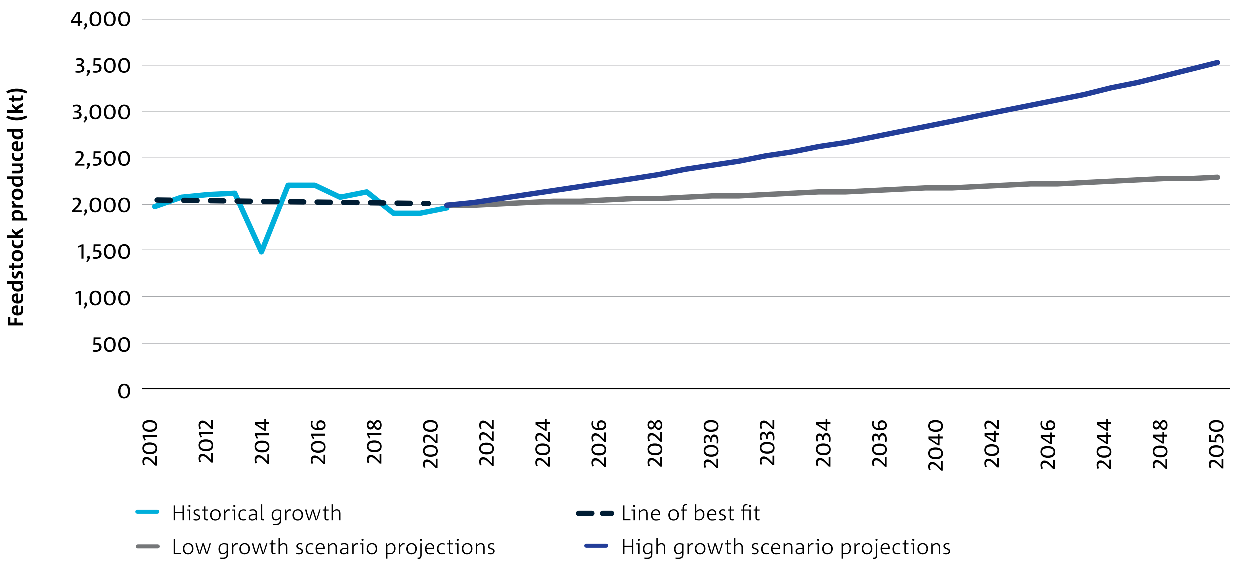
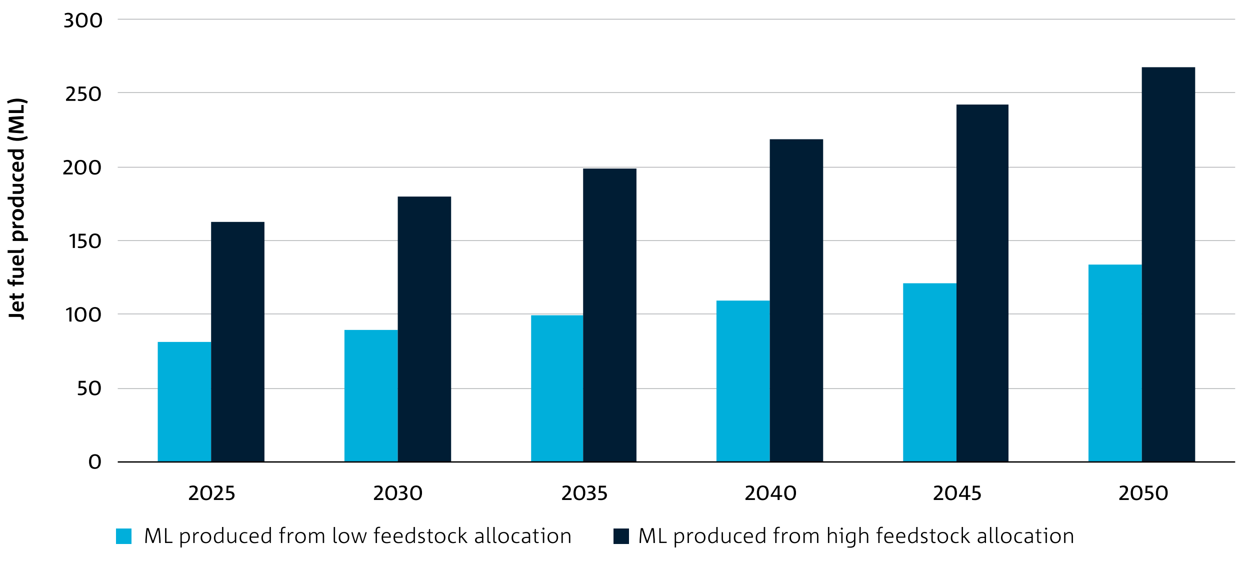


Figure 37. Potential SAF production from Malaysia agricultural residues (high feedstock growth rate, high jet fuel yield scenario)



2.4 Feedstock modelling for Papua New Guinea (PNG)

2.4.1 This analysis

Economic analysis of feedstock availability for SAF was undertaken by CSIRO Futures to assess the commercial opportunity for SAF in PNG by 2050. With many government and international initiatives and a National Action Plan for sustainable palm oil production as per chapter 6.9, palm fruit is positioned to be a potential feedstock for SAF production in PNG and was selected for analysis. Coconut was also included in this analysis due to its current application in small-scale biofuel projects as per chapter 6.9. As such, this Appendix summarises the parameters, methodology and results of this modelling, developed in consultation and used to produce the estimates presented in this Roadmap.

2.4.2 Parameters

All parameters are assumed to be the same as for Australia, as defined in Section 7.4.2, with the application of Papua New Guinean feedstock data to estimate potential SAF to 2050.

2.4.3 Palm fruit

Calculations

(1)	Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
	Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x $(1+C)^{29}$
(2)	Potential domestic oil production (t)	= (1) x D
(3)	Potential domestic SAF production (ML)	= [(1) x E x F]/1,000,000

Assumptions

PARAMETERS			PALM FRUIT
A	Current estimate of domestic feedstock production based on historical trends (2021)[137]		3,004 kt
B	Feedstock portion allocated to jet fuel (%)	Low	5%
		High	10%
C	Forecast annual growth in feedstock production	Low	0.5%
		High	2%
D	Feedstock oil content[138]		30%
E	HEFA jet fuel yield[139]	Low	30%
		High	60%
F	Jet fuel density[140]		1,263 L/t

137 Food and Agriculture Organization of the United Nations 2023, PNG oil palm fruit production quantity. https://www.fao.org/faostat/en/#data/QCL
A historical trend line was calculated from 2010–2021 feedstock production data reported, and then applied to obtain a 2021 current estimate to use for forecasts.

138 Ruswanto A, Ramelan AH, Praseptiangga D, Partha IBB (2020) Palm oil yield potency on different level of ripening and storage time based on fruits percentage and fresh fruit bunches. IOP Conf. Series: Earth and Environmental Science 443.
Table 1 reports a range of palm fruit oil contents, and so 30% was selected as a middle-ground estimate.

139 Low and high HEFA jet fuel yield figures were chosen based on what is feasible, obtained via literature review.
Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf
Han J, Elgowainy A, Cai H and Wang MQ 2013, Life-cycle analysis of bio-based aviation fuels, Bioresource Technology, 150, 447–456. https://www.sciencedirect.com/science/article/pii/S0960852413012297?via%3Dihub
Martinez-Hernandez E, Ramirez-Verduzco LF, Amezcua-Allieri MA and Aburto-J 2019, Process simulation and techno-economic analysis of bio-jet fuel and green diesel production – minimum selling prices, Chemical Engineering Research and Design, 146, 60–70. https://www.sciencedirect.com/science/article/pii/S0263876219301534?via%3Dihub
Pearlson M, Wollersheim C and Hileman J 2013, A techno-economic review of hydroprocessed renewable esters and fatty acids for jet fuel production, Biofuels, Bioproducts and Biorefining, 7(1), 89–96. https://onlinelibrary.wiley.com/doi/full/10.1002/bbb.1378

140 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		PALM FRUIT
Potential domestic SAF production	2025	17 ML
	2050	20 ML

HIGH SCENARIO		PALM FRUIT
Potential domestic SAF production	2025	74 ML
	2050	121 ML

Figure 38. PNG palm fruit growth projections

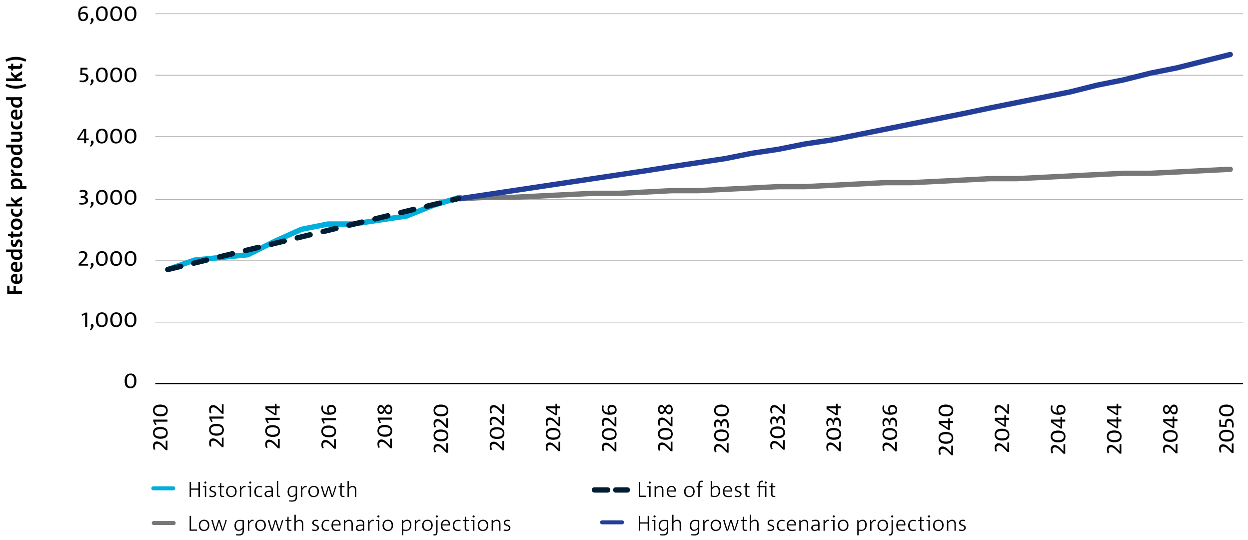
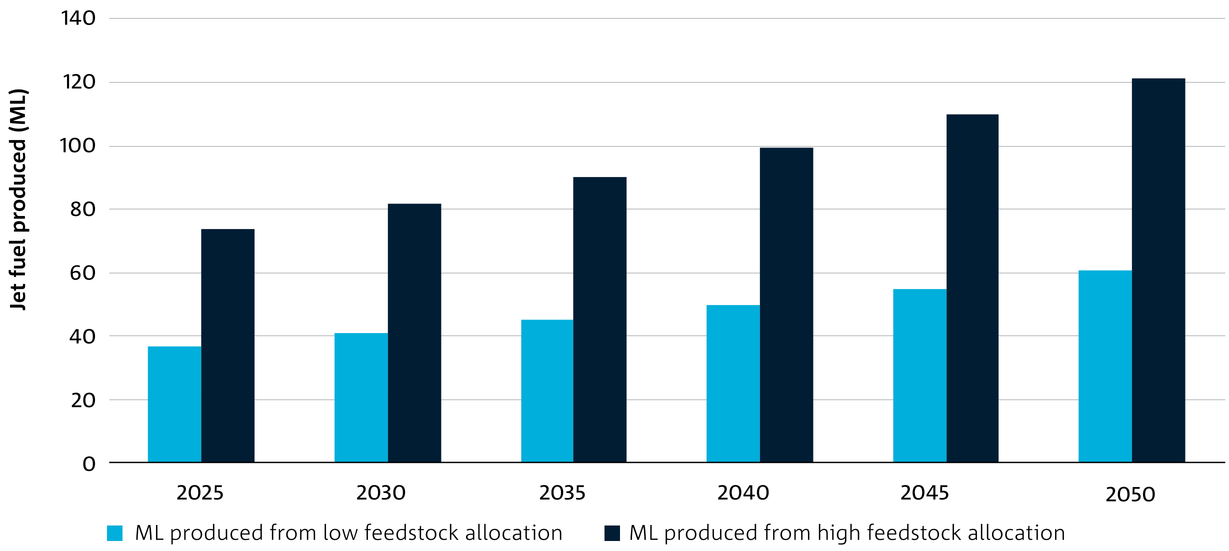


Figure 39. Potential SAF production from PNG palm fruit (high feedstock growth rate, high jet fuel yield scenario)



2.4.4 Coconut

Calculations

(1) Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x $(1+C)^{29}$
(2) Potential domestic oil production (t)	= (1) x D
(3) Potential domestic SAF production (ML)	= [(1) x E x F]/1,000,000

Assumptions

PARAMETERS			COCONUT
A	Current estimate of domestic feedstock production based on historical trends (2021)[141]		1,951 kt
B	Feedstock portion allocated to jet fuel (%)	Low	5%
		High	10%
C	Forecast annual growth in feedstock production	Low	0.5%
		High	2%
D	Feedstock oil content[142]		10%
E	HEFA jet fuel yield[143]	Low	30%
		High	60%
F	Jet fuel density[144]		1,263 L/t

141 Food and Agriculture Organization of the United Nations 2023, PNG coconut in shell production quantity. https://www.fao.org/faostat/en/#data/QCL
A historical trend line was calculated from 2010–2021 feedstock production data reported, and then applied to obtain a 2021 current estimate to use for forecasts.

142 Patil U, Benjakul S (2018) Coconut milk and coconut oil: their manufacture associated with protein functionality. Journal of Food Science 83(8).
10% feedstock oil content was estimated by multiplying coconut fruit with kernel meat and Table 1's reported oil composition.

143 Low and high HEFA jet fuel yield figures were chosen based on what is feasible, obtained via literature review.

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Han J, Elgowainy A, Cai H and Wang MQ 2013, Life-cycle analysis of bio-based aviation fuels, Bioresource Technology, 150, 447–456. https://www.sciencedirect.com/science/article/pii/S0960852413012297?via%3Dihub

Martinez-Hernandez E, Ramirez-Verduzco LF, Amezcua-Allieri MA and Aburto-J 2019, Process simulation and techno-economic analysis of bio-jet fuel and green diesel production – minimum selling prices, Chemical Engineering Research and Design, 146, 60–70. https://www.sciencedirect.com/science/article/pii/S0263876219301534?via%3Dihub

Pearlson M, Wollersheim C and Hileman J 2013, A techno-economic review of hydroprocessed renewable esters and fatty acids for jet fuel production, Biofuels, Bioproducts and Biorefining, 7(1), 89–96. https://onlinelibrary.wiley.com/doi/full/10.1002/bbb.1378

144 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		COCONUT
Potential domestic SAF production	2025	3.8 ML
	2050	4.3 ML

HIGH SCENARIO		COCONUT
Potential domestic SAF production	2025	16 ML
	2050	26 ML

Figure 40. PNG coconut growth projections

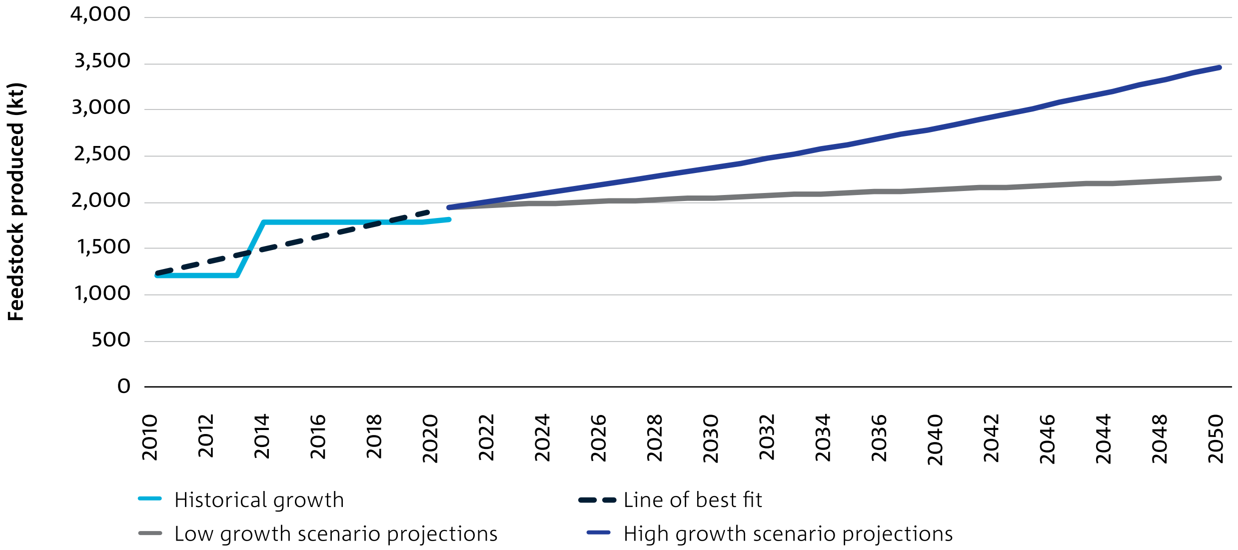
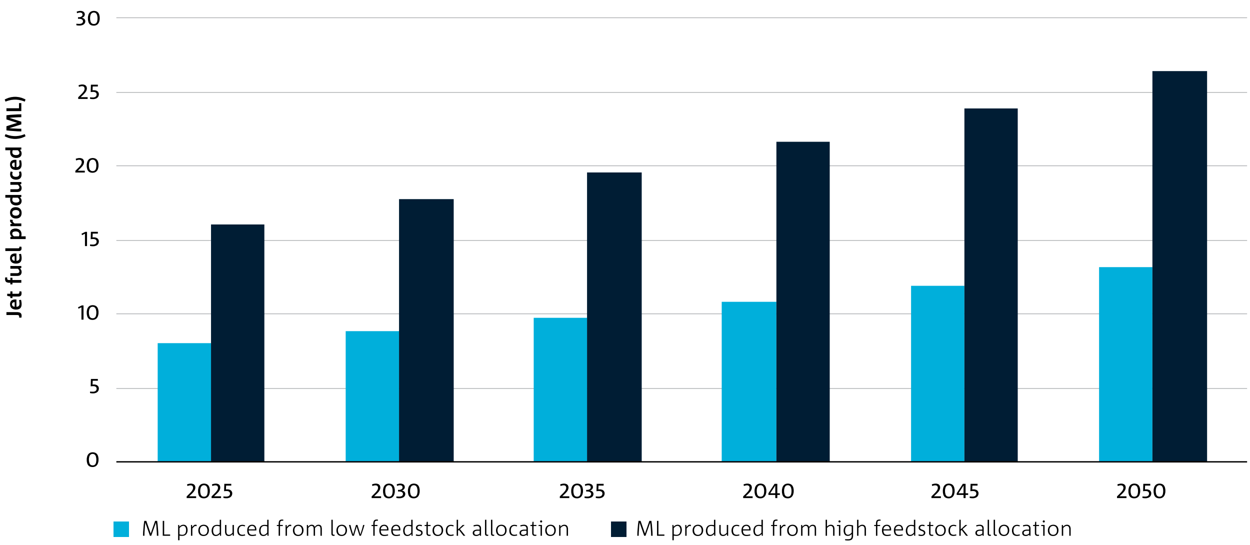


Figure 41. Potential SAF production from PNG coconut (high feedstock growth rate, high jet fuel yield scenario)



2.5 Feedstock modelling for Vietnam

2.5.1 This analysis

Economic analysis of feedstock availability for SAF was undertaken by CSIRO Futures to assess the commercial opportunity for SAF in Vietnam by 2050. As a primary agricultural producing country, Vietnam has substantial agricultural residues available that can be used for SAF production and was selected for analysis. Upon comparing the historical production data of major feedstock crops in Vietnam, sugarcane and bagasse produced consistently high volumes and were further investigated for SAF potential. As such, this Appendix summarises the parameters, methodology and results of this modelling, developed in consultation and used to produce the estimates presented in this Roadmap.

2.5.2 Parameters

All parameters are assumed to be the same as for Australia, as defined in Section 7.4.2, with the application of Vietnamese feedstock data to estimate potential SAF to 2050.

2.5.3 Agricultural residues

Calculations

(1)	Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
	Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x (1+C)[29]
(2)	Potential domestic SAF production (ML)	= [(1) x D x E]/1,000,000

Assumptions

PARAMETERS			AGRICULTURAL RESIDUES
A	Current estimate of domestic feedstock production based on historical trends (2021)[145]		38,313 kt
B	Feedstock portion allocated to jet fuel (%)	Low	20%
		High	40%
C	Forecast annual growth in feedstock production	Low	0.5%
		High	2%
D	G+FT jet fuel yield[146]	Low	5%
		High	15%
E	Jet fuel density[147]		1,263 L/t

145 Food and Agriculture Organization of the United Nations 2023, Viet Nam primary crops production quantity and area harvested. https://www.fao.org/faostat/en/#data/QCL

Crops include maize and rice.

Herr A, O'Connell D, Dunlop, M, Unkovich M, Poulton P and Poole M 2012, Second harvest – is there sufficient stubble for biofuel production in Australia? GCB Bioenergy, 4, 654–660. https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1757-1707.2012.01165.x

A ratio of stubble potentially available for harvest with grain production (0.8) was calculated for Australian 1986–2005 data and applied to Vietnam agricultural production data for 2010–2021 to estimate available stubble.

A historical trend line was calculated from 2010–2021 feedstock production data reported, and then applied to obtain a 2021 current estimate to use for forecasts.

146 Low and high G+FT jet fuel yield figures were chosen based on what is feasible, obtained via literature review.

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Bressanin JM et al. 2020, Techno-economic and environmental assessment of biomass gasification and Fischer-Tropsch synthesis integrated to sugarcane biorefineries, Energies, 13(17). https://www.mdpi.com/1996-1073/13/17/4576

147 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		AGRICULTURAL RESIDUES
Potential domestic SAF production	2025	494 ML
	2050	559 ML

LOW SCENARIO		AGRICULTURAL RESIDUES
Potential domestic SAF production	2025	3,143 ML
	2050	5,156 ML

Figure 42. Vietnam agricultural residues growth projections

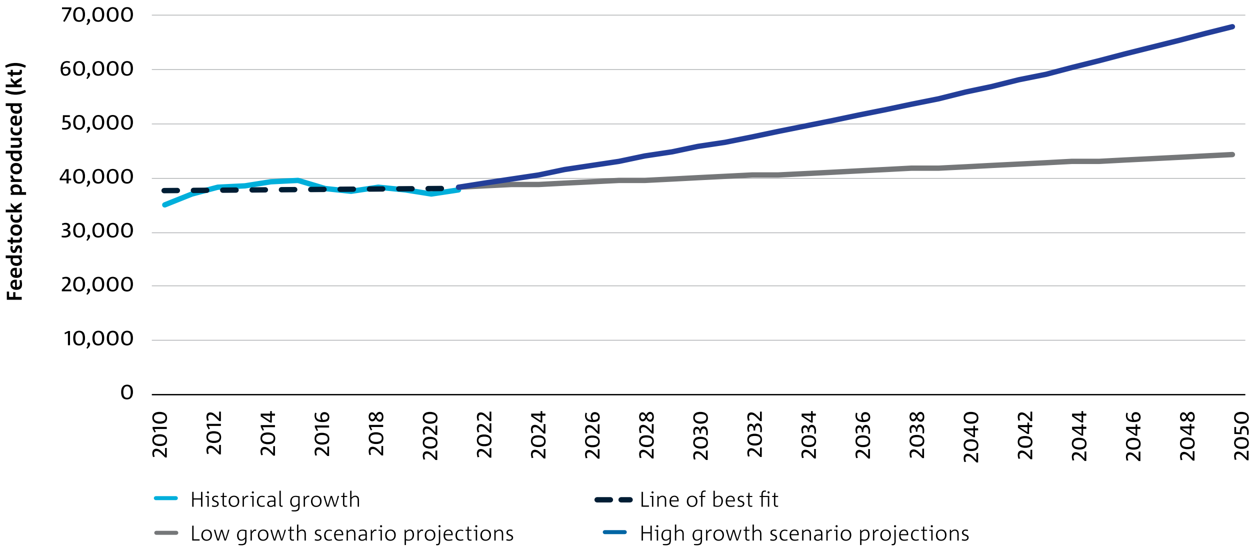
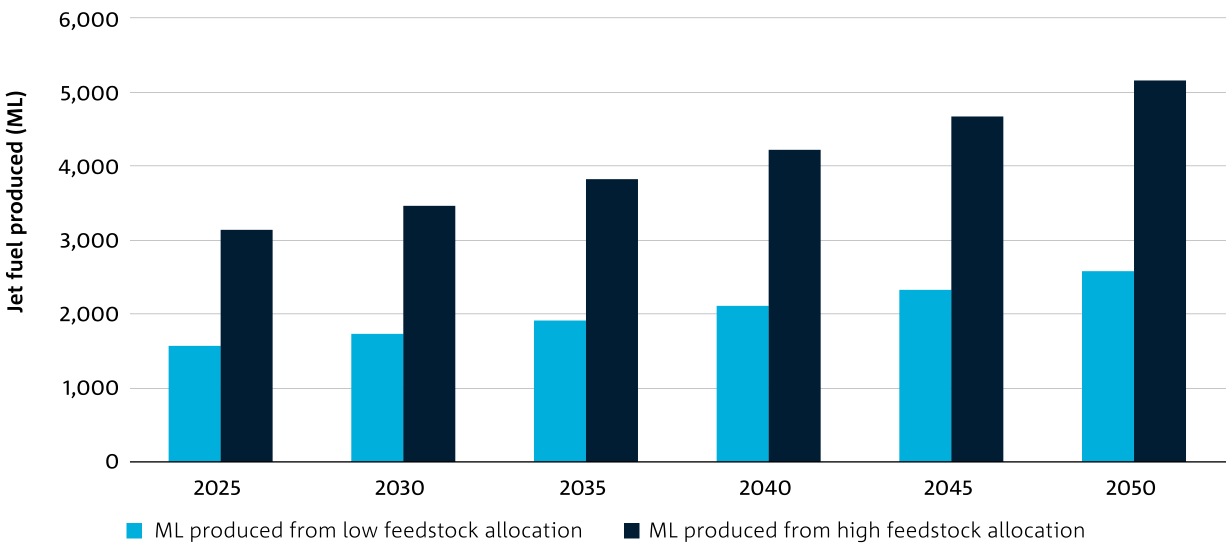


Figure 43. Potential SAF production from Vietnam agricultural residues (high feedstock growth rate, high jet fuel yield scenario)



2.5.4 Sugarcane and bagasse

Calculations (sugarcane bagasse)

(1) Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x (1+C)[29]
(2) Potential domestic SAF production (ML)	= [(1) x E x F]/1,000,000

Calculations (sugarcane)

(1) Potential domestic feedstock production by 2021 (t)	= A x 1,000 x B
Potential domestic feedstock production by 2050 (t)	= A x 1,000 x B x (1+C)[29]
(2) Potential domestic ethanol production (L)	= (1) x D
(3) Potential domestic SAF production (ML)	= [(2) x E]/1,000,000

Assumptions

PARAMETERS			SUGARCANE BAGASSE	SUGARCANE
A	Current estimate of domestic feedstock production based on historical trends (2021)[148]		4,149 kt	13,831 kt
B	Feedstock portion allocated to jet fuel	Low	20%	5%
		High	40%	10%
C	Forecast annual growth in feedstock production	Low	0.5%	
		High	2%	
D	Ethanol yield from feedstock[149]			60 L/t
E	Jet fuel yield[150]	Low	5% (G+FT)	20% (ATJ)
		High	15% (G+FT)	60% (ATJ)
F	Jet fuel density[151]		1,263 L/t	

148 Food and Agriculture Organization of the United Nations 2023, Viet Nam sugar cane production quantity. https://www.fao.org/faostat/en/#data/QCL

Queensland Government 2018, Queensland technical methods – cropping (sugarcane), Australian Biomass for Bioenergy Assessment.

A reported ratio of 1t sugarcane = 0.3t sugarcane bagasse was applied to sugarcane production data to estimate bagasse production.

A historical trend line was calculated from 2010–2021 feedstock production data reported, and then applied to obtain a 2021 current estimate to use for forecasts.

149 USDA 2006, The economic feasibility of ethanol production from sugar in the United States. https://www.fsa.usda.gov/Internet/FSA_File/ethanol_fromsugar_july06.pdf

Department of Agriculture and Food, Western Australia 2006, Ethanol production from grain. Department of Primary Industries and Regional Development, Western Australia, Perth. https://library.dpird.wa.gov.au/cgi/viewcontent.cgi?article=1031&context=pubns

150 Low and high jet fuel yield figures were chosen based on what is feasible, obtained via literature review.

ATJ:

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Geleynse S, Brandt K, Garcia-Perez M, Wolcott M, Zhang X 2018, The alcohol-to-jet conversion pathway for drop-in biofuels: techno-economic evaluation, Chemistry-Sustainability-Energy-Materials, 11(21), 3728–3741. https://chemistry-europe.onlinelibrary.wiley.com/doi/10.1002/cssc.201801690

G+FT:

Diederichs GW 2015, Techno-economic assessment of processes that produce jet fuel from plant-derived sources, university thesis. https://core.ac.uk/download/pdf/37440495.pdf

Bressanin JM et al. 2020, Techno-economic and environmental assessment of biomass gasification and Fischer-Tropsch synthesis integrated to sugarcane biorefineries, Energies, 13(17). https://www.mdpi.com/1996-1073/13/17/4576

151 Department of Climate Change, Energy, the Environment and Water 2023, Australian Petroleum Statistics – Data Extract December 2022 [XLSX]. https://www.energy.gov.au/publications/australian-petroleum-statistics-2022

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here. Discrepancies in summations are due to differences in rounding.

LOW SCENARIO		SUGARCANE BAGASSE	SUGARCANE	TOTAL
Potential domestic SAF production	2025	53 ML	8 ML	62 ML
	2050	61 ML	10 ML	70 ML

HIGH SCENARIO		SUGARCANE BAGASSE	SUGARCANE	TOTAL
Potential domestic SAF production	2025	340 ML	54 ML	394 ML
	2050	558 ML	89 ML	647 ML

Figure 44. Vietnam sugarcane bagasse growth projections

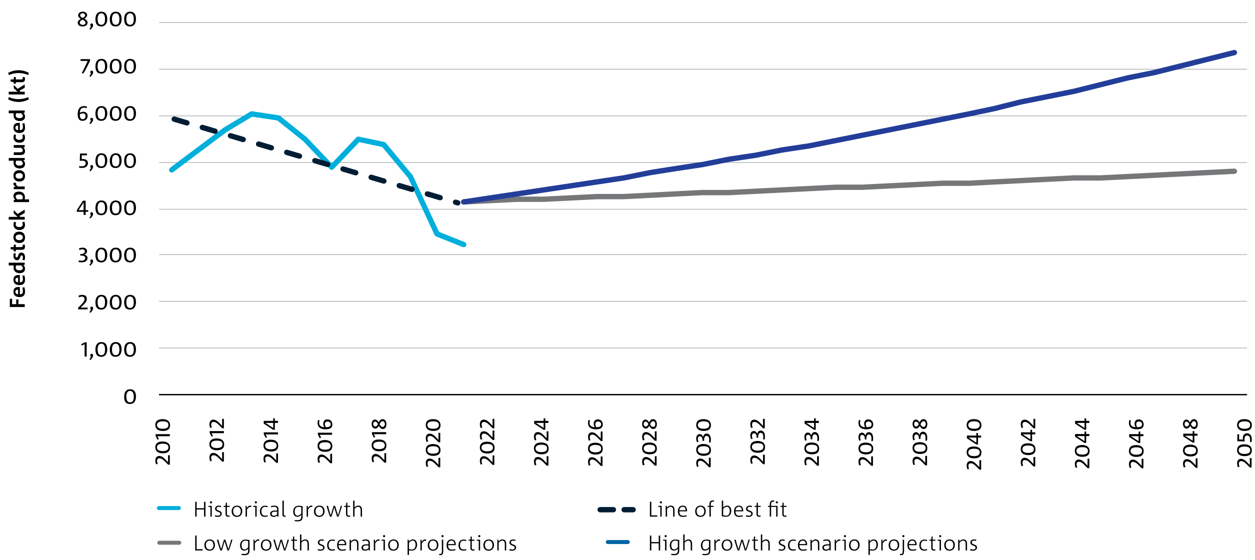


Figure 45. Potential SAF production from Vietnam sugarcane bagasse (high feedstock growth rate, high jet fuel yield scenario)

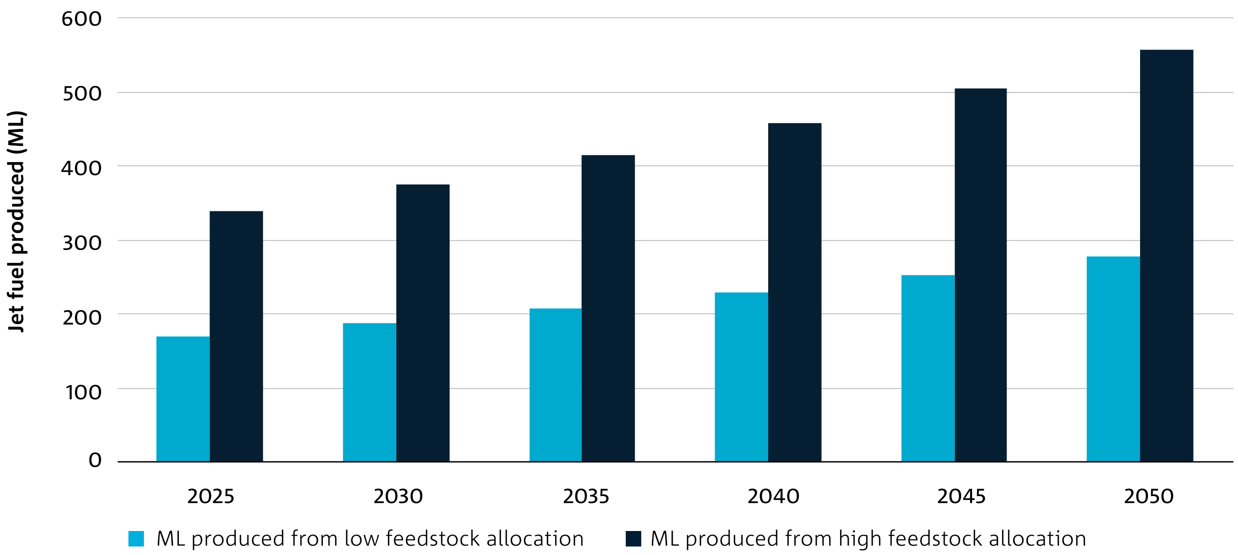


Figure 46. Vietnam sugarcane growth projections

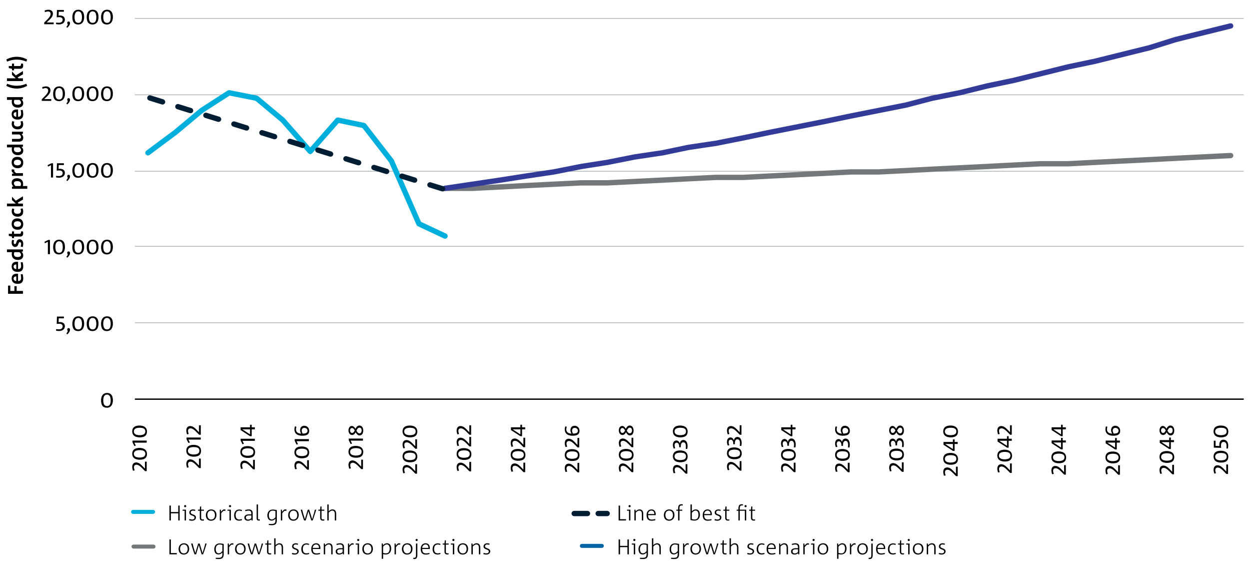


Figure 47. Potential SAF production from Vietnam sugarcane (high feedstock growth rate, high jet fuel yield scenario)

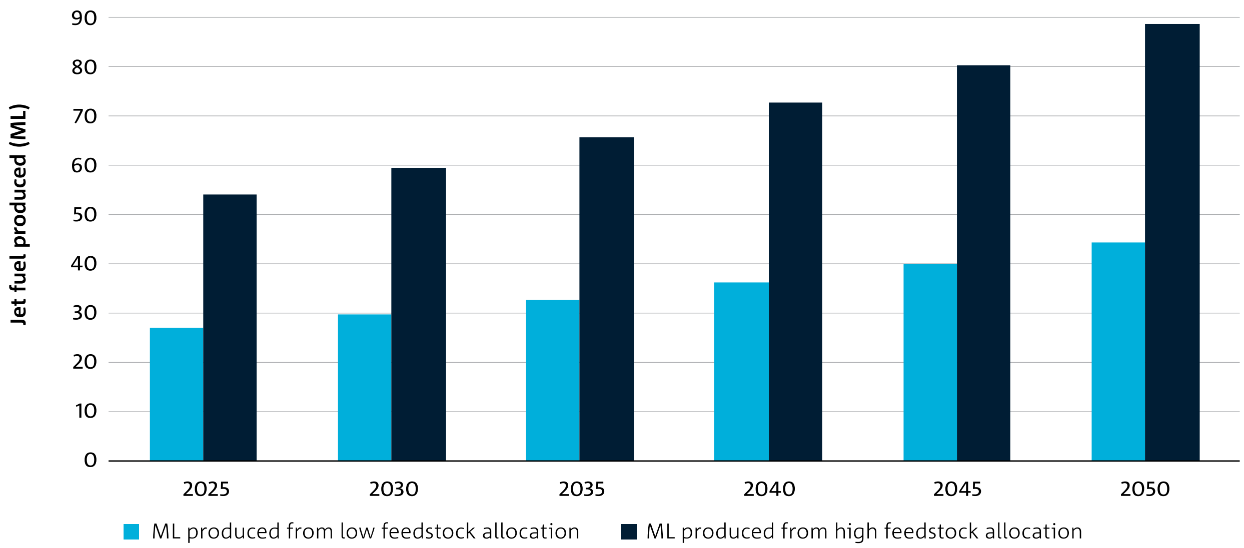
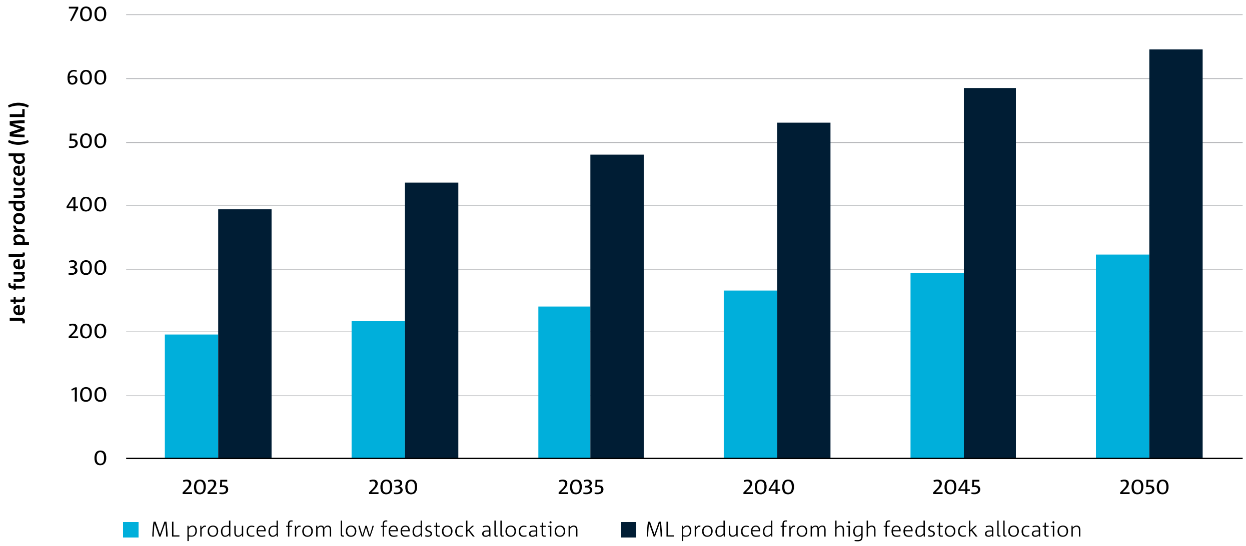


Figure 48. Potential SAF production from Vietnam bagasse and sugarcane (high feedstock growth rate, high jet fuel yield scenario)



2.6 Feedstock modelling country summary

2.6.1 Summary

Results

The lowest estimates (from our low feedstock portion allocated to jet fuel, low forecast annual growth rate, and low jet fuel yield scenario) and highest plausible estimates (from our high feedstock portion allocated to jet fuel, high forecast annual growth rate, and high jet fuel yield scenario) are summarised here for potential jet fuel produced (ML) from each country's top two highest potential feedstocks. Discrepancies in summations are due to differences in rounding.

The top two feedstocks for SAF production in Australia by 2025 are agricultural residues (from barley, corn (maize), grain sorghum, oats, rice, triticale, and wheat crops), and the combination of sugarcane and bagasse. By 2050, the two most potential feedstocks for SAF production come from the PtL process and agricultural residues. The two primary feedstocks available for SAF production in New Zealand up to 2050 are sawmill residues and tallow. For Indonesia, they are palm fruit and sugarcane and bagasse combined. The two most potential feedstocks for SAF production in Vietnam are agricultural residues and sugarcane and bagasse combined. For Malaysia, they are palm fruit and agricultural residues. For PNG, they are palm fruit and coconut.

LOW SCENARIO		AUSTRALIA	NEW ZEALAND	INDONESIA	VIETNAM	MALAYSIA	PNG
Potential domestic SAF production	2025	626 ML	71 ML	1,675 ML	556 ML	593 ML	21 ML
	2050	624 ML	80 ML	1,897 ML	629 ML	672 ML	24 ML

LOW SCENARIO		AUSTRALIA	NEW ZEALAND	INDONESIA	VIETNAM	MALAYSIA	PNG
Potential domestic SAF production	2025	3,871 ML	437 ML	7,399 ML	3,537 ML	2,573 ML	90 ML
	2050	9,794 ML	717 ML	12,139 ML	5,803 ML	4,221 ML	148 ML

Figure 49. Potential SAF production from each country's top two feedstocks (low scenario)

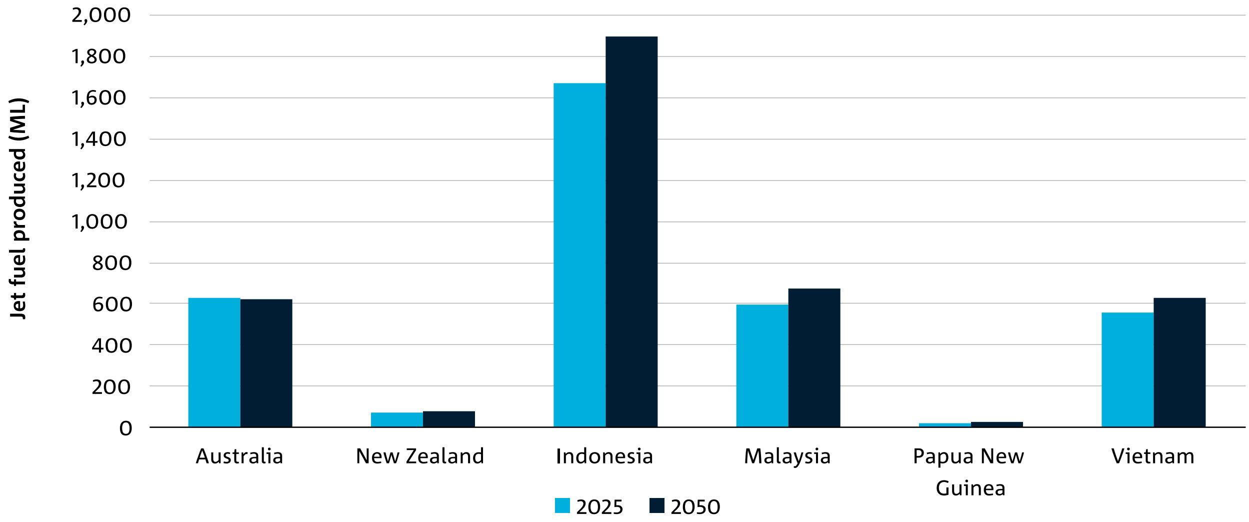
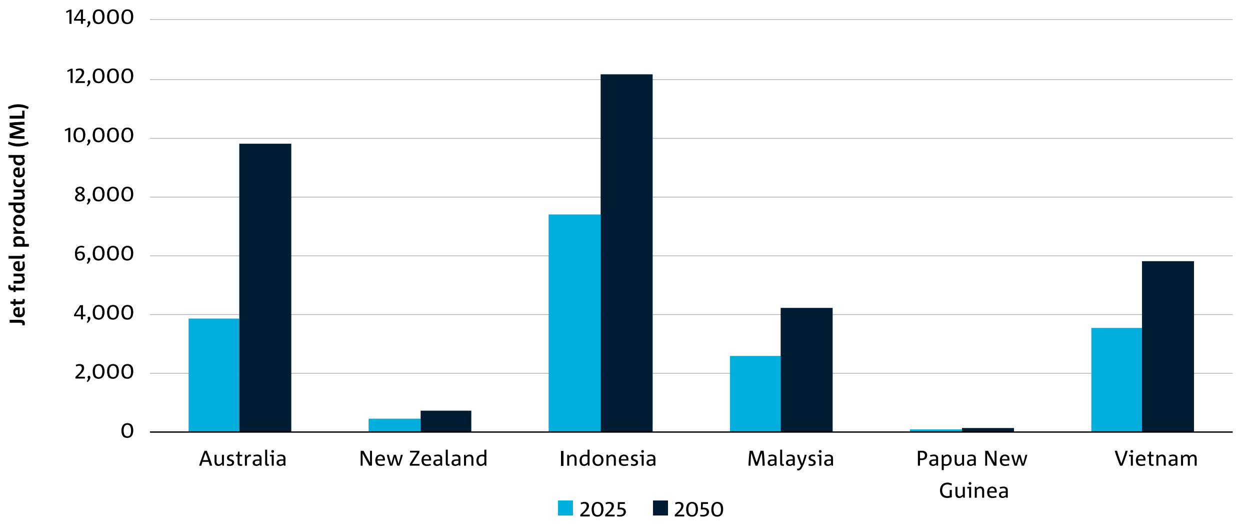


Figure 50. Potential SAF production from each country's top two feedstocks (high scenario)



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