# Opportunity for Developing an e-SAF Value Chain in NSW

NSW GOVERNMENT

Powerfuels including Hydrogen Network
DECARB HUB

UNSW SYDNEY

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This work was carried out by NSW PFHN with support from NSW OCSE.

CITATION
D. Gunawan, T. Gao, J. Christian, A. Samsudeen, R. Amal, R. Daiyan. (2025). Opportunity for Developing an e-SAF Value Chain in NSW.

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# About Powerfuels including Hydrogen Network, NSW Decarbonisation Innovation Hub

The NSW Decarbonisation Innovation Hub (Decarb Hub) supports a mature and collaborative decarbonisation innovation community in NSW through three innovation networks in the areas of power-to-x, electrical & energy systems, and land & primary industries.

The Powerfuels including Hydrogen Network (PFHN) is one of the innovation networks within the NSW Decarbonisation Innovation Hub. The Network supports the de-risking of powerfuels including hydrogen projects to address specific and systemic barriers through design, analysis, advanced research & engineering services. The Network aims to engage existing stakeholders locally, nationally & globally as the nexus for the acceleration of NSW's industrial translation of mature and emerging P2X technologies. The expertise in this Network will address challenges and promote innovative solutions across clean fuels and chemical value chains. One of the priority emerging pathways identified by the Network in consultation with government and industry partners is in synthetic Sustainable Aviation Fuels (e-SAF), to decarbonise the aviation sector. To explore the opportunities in e-SAF and specifically for the state, this report has been commissioned by the Network.

**Network Partners**

# About Office of NSW Chief Scientist & Engineer

The Office of NSW Chief Scientist & Engineer is the state's central agency for innovation with four functional areas:

- **Independent Advice** - delivering evidence-based scientific advice to government on a range of difficult challenges.
- **Industry Development** - bringing academia, government and industry together to drive the commercialisation of research excellence, with the aim of producing prosperous outcomes for the state. Advice is provided to government to assist in the development of new high-tech precincts - including the Western Sydney Aerotropolis and Tech Central - and in new industries, particularly advanced manufacturing.
- **Research Support** - manages the NSW Government's Research Attraction and Acceleration Program, which ensures that NSW attracts and retains researchers and research infrastructure.
- **Science Outreach and Education** - ensuring that both students and the general public are given the opportunity to engage with science and scientists.

# Executive Summary

The "Opportunity for Developing an e-SAF Value Chain in NSW" investigates the potential for developing a synthetic sustainable aviation fuel (e-SAF) industry in NSW, aligning with the state's decarbonisation goals and supporting the global aviation sector's shift towards low-emission fuels.

The aviation industry faces a significant challenge: the need to transition to a low-carbon future. SAF, a cleaner alternative to traditional jet fuel, can reduce aviation emissions significantly without requiring major changes to existing infrastructure. Currently SAF can be produced from sustainable feedstocks such as biomass. However, challenges regarding feedstock sourcing, their competing use and availability throughout the year presents limitations for bio-SAF production. Modelling prepared for the Air Transport Action Group's Waypoint 2050 report that bio-SAF feedstock can only supply 50% of the SAF required to meet the net-zero by 2050 target set by IATA[1].

e-SAF, that is generated by combining sustainable source of carbon dioxide ($CO_2$) with hydrogen generated from renewable electricity, is now widely accepted to be able to potentially fill in the gap and provide a complementary solution. A key differentiator of e-SAF compared to bio-SAF pathways is the potential scalability of the pathway given the abundant renewable energy and $CO_2$ source availability. However, owing to the lower technological maturity of this pathway, e-SAF costs are considerably higher than bio-SAF. This is however projected to decrease and reach parity in the next decade with technological advancements and scale-up.

This study explores the prospect for developing a e-SAF industry in NSW, outlining key comparative advantage of the state in e-SAF deployment, and carries out a high-level scoping study to investigate suitable e-SAF hubs and potential markets. Specifically, this study puts an emphasis on the design of a NSW conceptual hub for e-SAF production within the P2X Hub and Precinct Framework. Underpinning this analysis was feedback from stakeholders through a series of consultation events hosted by NSW PFHN and NSW OCSE on SAF, where the role of emerging e-SAF was prioritised. The NSW Government has committed to reducing emissions by 50% by 2030 and achieving net-zero emissions by 2050. As Australia's economic powerhouse, NSW has the potential to pioneer the e-SAF industry. NSW's Sydney Airport is the busiest airport in Oceania, serving as the primary hub for the country's airline, Qantas, and the main international gateway to Australia. Leveraging abundant renewable energy resources, NSW can foster a low-carbon aviation sector.

[1] *https://atag.org/resources/waypoint-2050-2nd-edition-september-2021*

# 1 Why e-SAF?

*This section outlines the importance of transitioning to sustainable aviation fuel (SAF) to meet net-zero targets by the aviation industry, a summary of global and Australian ambition in SAF, challenges with bio-SAF to meet complete SAF demand by 2050 in the context of NSW and concluding with global e-SAF state-of-play.*

## 1.1 Why Sustainable Aviation Fuel?

SAF is a term used to describe non-conventional aviation fuel produced from sustainable feedstocks as alternative to fossil-based jet fuel (International Air Transport Association, n.d.). The physical and chemical characteristics of SAF are almost identical to conventional aviation fuel produced from fossil feedstock. SAF presents such opportunity with economic and environmental benefits to solve the grand challenge faced by the global aviation industry.

With air traffic back to pre-pandemic level as of 2023, the challenge of net zero commitments remains. The industry desperately needs a low-cost decarbonisation pathway that can be rapidly deployed by 2030. Whilst electrification may facilitate decarbonisation of short-haul flights, decarbonisation of medium-to-long-haul flights, continues to be a key issue. Long lifespan of aircrafts and refuelling infrastructure, high-cost and low-maturity of electrification and renewable hydrogen applications, and limited technological improvement in fuel efficiency are some of the factors responsible for decarbonisation stagnation of the sector.

Aviation emissions have been increasing rapidly over the last two decades, reaching historical high at 1,027 million tonnes (Mt $CO_2$) in 2019 globally (International Energy Agency, 2022). Despite unprecedented collapse and emissions fall due to COVID-19, commuter and cargo flight volumes will return to pre-COVID level by 2025, and emissions will continue to rise. According to the projection by the International Energy Agency (IEA), aviation emissions is not on track towards net-zero in 2050. Aviation industry requires technically and commercially viable solutions to cut more than 500 Mt $CO_2$ by 2040 in line with IEA's Net Zero Emissions pathway (International Energy Agency, 2022) (Figure 1).

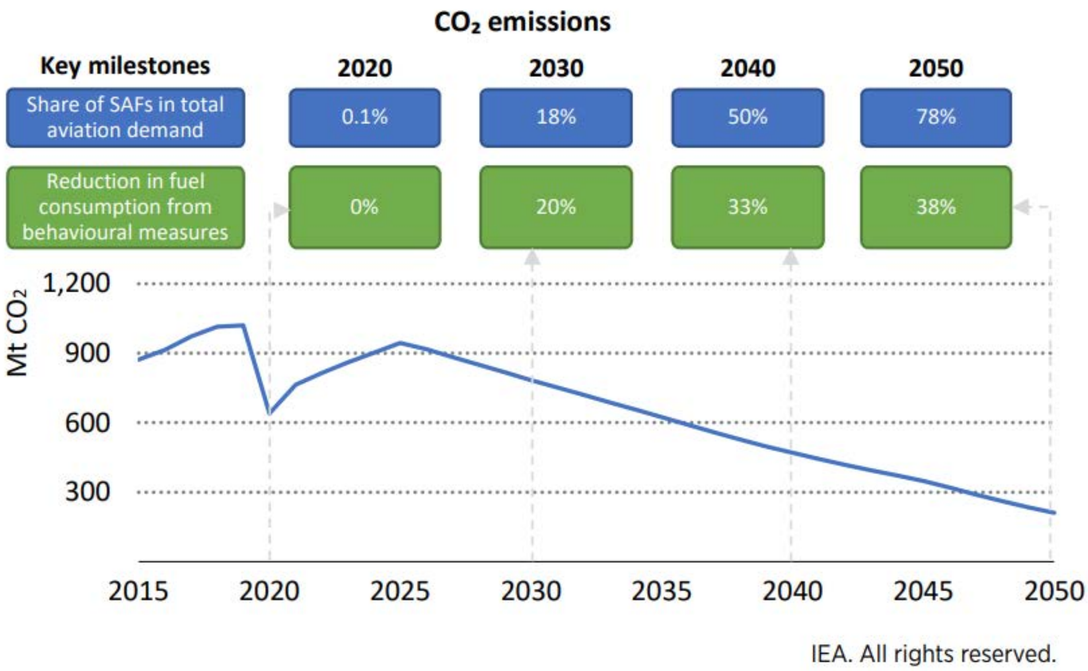



*Figure 1: CO2 emissions trajectory and key milestones for the aviation sector in the NZE, 2015-2050. Source: IEA (2021), Net Zero by 2050, IEA, Paris*

The challenge is significant for Australia given the importance of air transport to the country. In 2018, the aviation sector alone contributes approximately A$20 billion to the economy, accounting for around 1% of GDP (Australian National Audit Office, 2022). Air travel supports many industries and provides the key linkages for tourism, education, international trade and business. In Australia, domestic aviation alone is projected to emit 9 Mt $CO_2$ by 2025, in forecast modelling conducted by the Australian Government (Australian Government, 2021). Decarbonisation solutions are urgently needed for aviation industry ensuring Australia to meet the national 2030 target of reducing 43% emissions compared to 2005 levels.

SAF is currently garnering widespread attention and support from all key stakeholders in the aviation industry. Governments, airlines, industry peak bodies and fuel producers are increasingly recognising the critical role that SAF plays in transitioning aviation sector towards a low-emissions future. As a 'drop-in' fuel, SAF has technical and economic superiorities including:

- High technology readiness level at market adoption phase for technology industrial translation and a growing pipeline of commercial projects across value chains.
- Significant emissions reduction potentials with wide applications to both passenger and cargo flights, long haul and regional flights due to advantages in high power density.
- Low impacts to airport refuelling infrastructure, aircraft design and manufacturing, refuelling model and duration as well as training and upskilling requirements for existing workforce.
- Established global supply chains with the support of financial incentives mechanisms by major economies and airlines globally.

The significance of SAF cannot be overstated in the context of addressing the aviation industry's environmental and economic challenges. Generally, SAF can be produced through two primary pathways: bio-SAF and e-SAF. Bio-SAF is derived from sustainable biomass sources, while e-SAF is synthesised by reacting $CO_2$—captured from direct air capture (DAC) or industrial flue gas (IFG)—with renewable hydrogen. Currently, bio-SAF production is well established and dominates SAF development efforts. However, the scalability of bio-SAF faces a significant challenge regarding feedstock availability and competition. Therefore, it is essential to accelerate e-SAF development as a complementary solution, supporting the aviation sector's transition to net zero emissions.

## 1.2 Global SAF Developments

The global SAF development is a dynamic and rapidly evolving field, driven by a confluence of factors, including increasing regulatory pressure, growing demand for sustainable aviation, advancements in technology, and growing corporate commitments to decarbonisation. In 2024, SAF production volumes reached 1 million tonnes (1.3 billion litres), doubling from 0.5 million tonnes (600 million litres) in 2023 (IATA, 2024). Forecasted production capacity is expected to reach 17.3 million tonnes by 2030 and 250 million tonnes by 2050 (Figure 2).

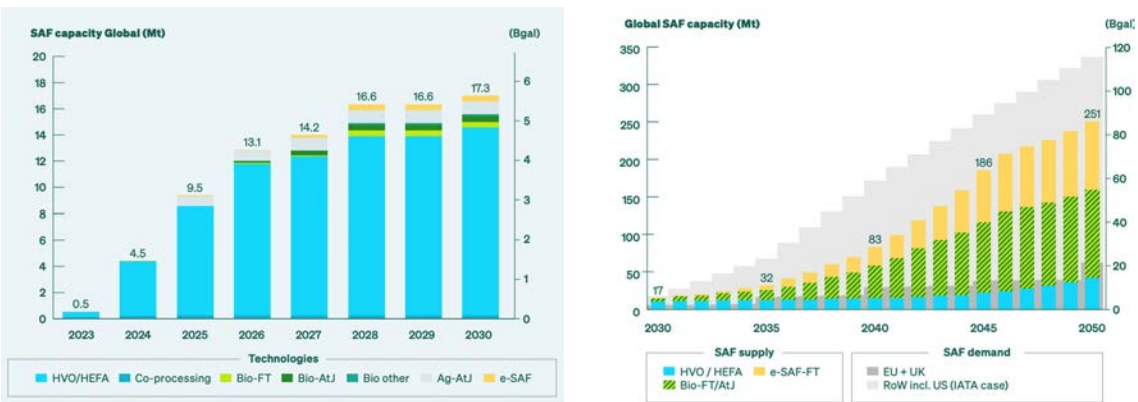



*Figure 2: Global SAF capacity announced projects including e-SAF (left) and global SAF capacity ramp up until 2050 based on rapid technology deployment and feedstock constraints (right).[2]*

[1] *SUSTAINABLE AVIATION FUEL MARKET OUTLOOK. June 2024.*

Current SAF global supply chain projects are mapped out based on the ICAO and IATA databases with the support of project scanning search on major economics (ICAO, 2025). The mapping identified that active industry players. The top three SAF manufactures are Gevo (8,200 million litres), Fulcrum (6,800 million litres) and Alder Fuels (5700 million litres) in terms of total offtake volume. Collectively, these three manufactures are making up 67.7% of global SAF production market securing long-term and high-volume offtake agreements with major airlines. The top three SAF purchasers are United Airlines (10,500 million litres), OneWorld Alliance (3,800 million litres) and American Airlines (2,400 million litres) in terms of total offtake volume. Collectively, these three airlines are purchasing 53.8% of global SAF stock.

## 1.3 Australian SAF Initiatives

As the world accelerates its transition towards a decarbonised aviation sector through the adoption of SAF, Australia is actively developing policies to promote the production and use of SAF as part of its commitment to achieving net zero aviation emissions.

In 2022, the Australian Government held an Industry Roundtable at the Australian International Airshow discussing the design and goals of a Jet Zero-style Council (Australian Government, 2022). In June 2023, the Australian Government announced the establishment of Australian Jet Zero Council (Australian Government, 2022). The council adopted a similar model from the UK Jet Zero Council[3] that forms partnerships between industry and government to lead efforts to deliver net zero aviation in Australia. The council has a role in coordinating advice to government on net zero transition issues. One key objective of the council is supporting the establishment of a SAF industry, encompassing production, refining, transport, and logistics capabilities, along with other net zero capabilities that can generate employment opportunities in Australia (Australian Government, 2022).

The Australian Government then released an Aviation White Paper in 2024, outlining a strategy roadmap to achieve net zero aviation emissions by 2050 (Commonwealth of Australia, 2024). The comprehensive plan emphasises several key initiatives to support the development and adoption of SAF. The Aviation White paper includes the following key recommendations: (i) expanding SAF research and development efforts, (ii) implementing incentives for SAF production, (iii) establishing SAF blending mandates to stimulate market demand, (iv) developing environmental certification and regulatory frameworks to verify the sustainability credentials of SAF and other low-carbon liquid fuels, and (v) enhancing collaboration with industry stakeholders and the Jet Zero Council.

In July 2023, the Australian Renewable Energy Agency (ARENA) released a $30 million SAF funding initiative examining opportunities across the supply chain from renewable feedstock supply to final fuel production, identifying their requirements to enable and scale a domestic SAF industry (Australia Renewable Energy Agency, 2023). The funding seeks proposals for commercial or pre-commercial SAF production with funding provided to support engineering feasibility and project development activities or funding for pilot scale and pre-commercial demonstrations. Projects exploring innovation in feedstock supply such as aggregation or business models to enable domestic SAF production could be funded through the program. Importantly, the program excludes Power to Liquids (PtL) or e-SAF production pathways.

Through this SAF initiative, ARENA is providing $8 million to Ampol for its Brisbane Renewable Fuels Pre-FEED Study, which will explore the development of a renewable fuels facility at the company's Lytton refinery (ARENA, 2024). This facility could potentially produce over 450 million litres of SAF and renewable diesel annually, equivalent to nearly 5 per cent of Australia's pre-COVID jet fuel consumption. GrainCorp will receive $6.1 million for its SAF Oilseed Crushing Facility Pre-Deployment Study (ARENA, 2024). This project aims to investigate the establishment of an oilseed crushing facility, capable of producing at least 330,000 tonnes of canola oil per year as feedstock for SAF production. Additionally,

*[3] The UK Jet Zero Council forms a partnership between industry and government aiming to achieve 10% SAF by 2030 and zero emissions within a generation (UK Government, n.d.). The UK JZC is chaired by senior government executives in transport, net zero and business and has memberships for executive officer-level stakeholders. Focused delivery groups have been established for the UK JZC (UK Government, n.d.) including 1) Sustainable Aviation Fuels Delivery Group advises on SAF mandate, technology feedstock requirement and SAF commercialisation and 2) Zero Emission Flight Delivery Group advises on aircraft, infrastructure and regulation for net zero emissions flight.*

ARENA is providing $8 million in funding to Licella and $2.4 million to Viva Energy for separate studies to develop renewable fuel alternatives for Australia's aviation industry (ARENA, 2025).

The Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) has unveiled a Sustainable Aviation Fuel Roadmap, emphasising that Australia is well-positioned to cultivate and expand SAF feedstock resources, making a significant contribution to the development of the SAF industry within the Asia Pacific region (CSIRO, 2023). This roadmap extends upon earlier CSIRO initiatives, primarily concentrating on evaluating the availability and production potential of SAF feedstocks in the APAC region, with a particular emphasis on Australia and New Zealand (CSIRO, 2023). Current industry policies and programs across the value chains are summarised in Table 1 for Australia. Australia has a few e-SAF proposals, but there are no commercial projects that have reached Final Investment Decision (FID). Australia's bio-SAF uptake has experienced challenges in the past, with major initiatives, such as Queensland Sustainable Fuel Initiative, shutting down in 2010. ARENA released Australia's Bioenergy Roadmap in 2021 which identified 2021-2024 opportunities for SAF to generate *"up to 1,908 ML per annum of SAF representing approximately 18 per cent of the aviation fuel market."*

*Table 1: Australia Industry Policies and Program Mapping*

| Company | Supply Chain | Initiatives |
|---|---|---|
| Sustainable Aviation Fuel Alliance of Australia and New Zealand (Working Group created by Bioenergy Australia) | Industry peak body comprising members of Australian airports (Adelaide, Melbourne, Brisbane, Sydney, Sunshine Coast, Perth, and Western Sydney airports), State Government agencies, engineering companies, airlines, equipment providers | Advocacy role in accelerating the advancement of SAF production, policy, education and marketing in both Australia and New Zealand. The Alliance has commissioned major industry report for SAF in ANZ. |
| Qantas | Airline and Offtake<br>Existing SAF partners include Airbus, Queensland Government, Heathrow Airport, LanzaJet. | Qantas has set their target to reach 10% SAF of overall fuel mix by 2030 and reach net-zero by 2050 (Qantas, 2022). Qantas is the first Australian airline to have an ongoing purchase agreement on SAF (which is delivered at London Heathrow Airport) (Qantas, 2022).<br>In 2022, Qantas and Airbus announced a joint investment of $USD200 million to establish SAF industry in Australia (Qantas, 2022). This investment is on top of the pledged $A50 million by Qantas 2020-2030 to help develop a SAF industry in Australia (Aviation Australia, 2022).<br><br>In March 2023, Qantas, Airbus and Queensland Government announced investment into Jet Zero Australia's proposed Queensland biofuel production facility and to carry out a detailed feasibility study. The proposed facility will convert sugarcane to SAF using LanzaJet's AtJ technology and is planned to produce 100 million litres of SAF in a year from 2024 (Qantas, 2023).<br><br>In March 2022, the Qantas Group entered SAF purchase agreement for delivery in California from 2025 (Qantas, 2022). |
| Virgin Australia | Airline and Offtake.<br>Existing SAF partners include the Queensland Government, Brisbane Airport Corporation, | Virgin has committed to net-zero by 2050 and SAF is stated to be a key vector in attaining such target (Virgin Ausrtalia, 2021). |

| Company | Supply Chain | Initiatives |
|---|---|---|
| | Gevo Inc. (US producer), Caltex and DB Schenker. | Virgin Australia initiated the first SAF trial in Australia, which has successfully completed as part of Brisbane Airport's jet fuel supply infrastructure (Virgin Australia, n.d.). The SAF produced from the trial is planned to supply international flights departing Brisbane Airport over a two year period. Virgin Australia the project has reached key milestone of suppling flies for over one million kilometres (Virgin Australia , 2019). |
| Ampol | Producer and Supplier. Existing SAF partners include ENEOS Group, the Queensland Government. | Ampol's Lytton refinery in Brisbane will be repurposed for SAF and renewable diesel production. The refinery will be jointed developed by Ampol and ENEOS Group under a Memorandum of Understanding (MoU) with the Queensland Government. The facility will have a capacity of 500 million litres of SAF and renewable diesel annually, using locally-sourced feedstocks including agricultural waste and animal fats (Ampol , 2023). |
| Oceania Biofuels | Fuel Producer and Supplier. Existing SAF partners include Queensland Government. | Oceania Biofuels has announced the plan for a A$500 million greenfield SAF and renewable diesel facility in Yarwan Industrial Precinct in the Gladstone State Development Area, Queensland (Queensland Government, 2022). The project is supported by the Queensland Government. Production feedstocks include used cooking oil, tallow and canola. |
| Licella Holdings | Fuel Producer and Supplier. Existing SAF partners include Amcor ANZ, Advanced Recycling Victoria | Licella Holdings has signed a Memorandum of Understanding with Amcor ANZ towards investment of Licella's first Australian Plastics Pre-Storing Facility and Catalytic Hydrothermal Treatment Plant. The facility will be constructed by the Advanced Recycling Victoria (Licella, 2022). |
| Airbus | Aircraft Manufacturer. Existing SAF partners include Qantas. | In 2022, Qantas and Airbus announced a joint investment of $USD200 million to establish SAF industry in Australia (Qantas, 2022). |
| Boeing | Aircraft Manufacturer. Existing SAF partners include Qantas, Virgin Airlines, and CSIRO. | CSIRO and Boeing has a thriving 30-year relationship jointly invested over $120 million across a wide range of projects, including aircraft repainting methods, sustainable aviation fuels, aircraft assembly processes, fire retardants and aircraft maintenance management software. |
| Jet Zero Australia | Fuel Producer and Supplier. Existing SAF partners include Queensland State Government and Singaporean company Apeiron Bioenergy. | Jet Zero Australia was established in 2021 with plans progressing to develop Australia's first Alcohol to Jet Fuel (ATJ) facility, taking surplus ethanol production on the east coast of Australia and converting it to Sustainable Aviation Fuel (SAF) via a plant to be built in Queensland. |
| HIF Global | Fuel Producer and Supplier. Existing SAF partner with Tasmanian State Government. | HIF Tasmania eFuels Facility: The project proponent is developing a synthetic eFuels production facility to be located near the town of Burnie in Tasmania. |

| Company | Supply Chain | Initiatives |
|---|---|---|
| Renewable Bio | Fuel Producer and Supplier. | Renewable.bio is planning to build a new biofuels facility in Western Australia. The facility, which will utilise renewable residue feedstocks, will produce three types of sustainable fuels including ethanol, sustainable aviation fuel (SAF) and renewable diesel. The facility is expected to be up and running by 2026. |

## 1.4 NSW Bio-SAF Challenges

NSW Government through Invest Regional NSW commissioned a NSW SAF market sounding study which offers comprehensive assessment on challenges and opportunities focusing on bio-SAF (Sustainable Aviation Fuel Prospectus, NSW Govt 2024). Not to duplicate efforts, this study will focus on e-SAF challenges and opportunities for NSW and will not dive deep in bio-SAF. Brief discussion on feedstock challenge for bio-SAF is presented here but more detailed analysis on bio-SAF can be found in the NSW Government's Sustainable Aviation Fuel Prospectus that has been published in March 2024 (Sustainable Aviation Fuel Prospectus, NSW Govt 2024).

The competition for feedstocks, within NSW and Australia for other uses or international markets, will cause fluctuations for the supply and price of feedstocks for local bio-SAF producers. Almost all of feedstocks for bio-SAF production have existing users and markets, which are expecting to compete with bio-SAF producers for feedstocks supply (CSIRO, 2023). Those competing feedstocks buyers, including bioenergy/biofuel for other sustainable fuels, human and animal feed, recycled materials, have existing offtake agreement, established supply chains and well-developed business models for their industries. This imposes significant challenges for SAF industry to secure feedstocks without policy intervention. Feedstock export is another risk factor that might limit local SAF industry development. For example, Australia is exporting 80% of canola oil and 75% of tallow to overseas markets (Bioenergy Australia, 2020). The use of these feedstock for bio-SAF production will face competition with export markets.

CSIRO Sustainable Aviation Fuel Roadmap modelling suggests that bio-SAF feedstock availability will not be sufficient to supply SAF demand or meet the emissions reduction target in Australia. As a result, a significant increase in e-SAF production is anticipated to meet the projected jet fuel demand after 2030 (Figure 3).

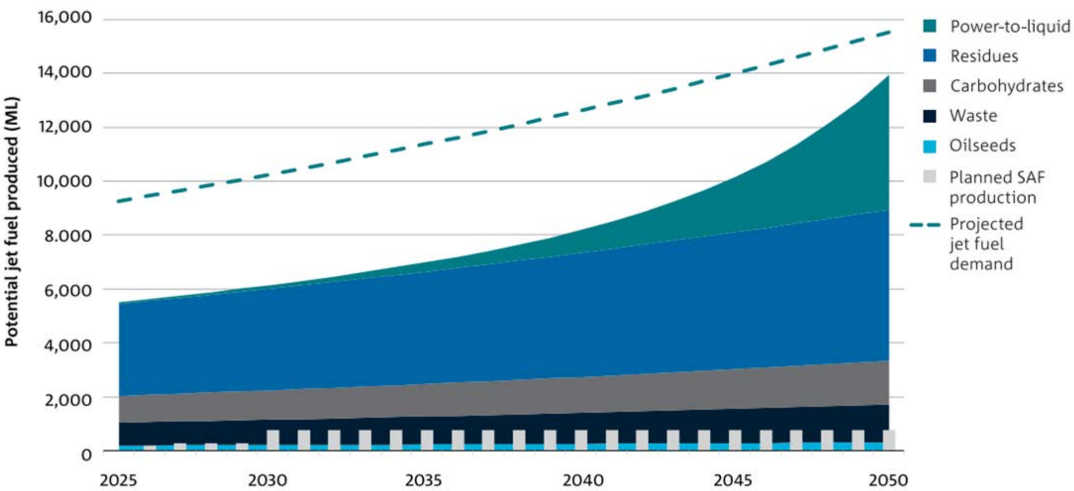



*Figure 3: Potential fuel production from projected feedstock production by CSIRO modelling (CSIRO, 2023)*

Modelling prepared for the Air Transport Action Group's Waypoint 2050 report bio-SAF feedstock can only supply 50% of the SAF required to meet the net-zero carbon by 2050 target set by IATA. Despite less mature technology and higher cost premium, e-SAF production pathways is expected to meet the other 50% of SAF demand. Fully commercialisation bio-SAF technology like HEFA SAF is limited by the availability of feedstock for a 10% contribution to SAF volumes by 2050 (ICF , 2011).

## 1.5 Global e-SAF Landscape

Whilst it is evident that at present, owing to cost and technological maturity, bio-SAF projects are leading the aviation sector decarbonisation initiative (Figure 2), e-SAF is expected to supply a significant proportion of SAF demand by 2050. The bio-SAF pathway faces its own challenges, particularly in regions with limited biomass resources, making e-SAF an increasingly attractive alternative. As global interest in e-SAF grows, projections suggest that by 2030, it could account for 2-5% of the SAF market, and by 2050, it may capture 40-60%, potentially becoming the dominant SAF pathway due to its higher emissions reduction potential and scalability (Figure 2).

### Airline Commitments to e-SAF

Airlines are playing a crucial role in driving demand for e-SAF by making commitments to its use:

**Direct e-SAF Purchase Agreements and Investments:** Some airlines, such as American Airlines, and IAG, are making direct e-SAF purchase agreements and investments in e-SAF production companies. For instance, IAG has partnered with Infinium, a US-based company, for supplying their UK operations starting in late 2026. This 10-year deal is designed to support all five of IAG's airlines: Aer Lingus, British Airways, Iberia, LEVEL, and Vueling. IAG has also partnered up with US company Twelve, under a 14 year contract, under which Twelve will supply IAG with 785,000 t of e-SAF to support its five European airlines (British Airways, Iberia, Aer Lingus, Vueling and LEVEL). American Airlines has also partnered with Infinium for e-SAF offtake from the company's Project Roadrunner facility in West Texas.

**Long-Term Strategic Focus on e-SAF:** Lufthansa Group has partnered with Synhelion, a Swiss company specializing in solar fuel production. Synhelion uses concentrated sunlight to convert $CO_2$ and water into synthetic fuels, including e-SAF. One of Lufthansa's subsidiary airlines, SWISS, has signed a long-term agreement with Synhelion, becoming the first airline to sign a solar-to-fuel offtake. KLM-Air France alliance is also exploring e-SAF, with the company making an investment in US DG Fuels Louisiana facility, which is based on biomass gasification for sourcing of $CO_2$. The alliance has also signed an offtake agreement with DG Fuels 600,000 tons of e-SAF, with deliveries starting in 2027 and continuing until 2036. United Airlines has invested in companies which is advancing e-SAF, such as Cemvita Factory and Dimensional Energy, which are focused on developing $CO_2$ capture technology through their venture capital arm, United Airlines Ventures, is focused on finding new technologies to decarbonise flying, indicating their openness to e-SAF in the future. Both Japan Airlines and American Airlines have also signed agreement with Twelve, to explore e-SAF into their fuel mix supplied by the company.

## 1.6 Australian e-SAF Landscape

Compared to the current global e-SAF development progress, the e-SAF landscape in Australia is still in its early stages of development. As of April 2025, the country does not have a mandated SAF target and therefore no specific e-SAF fuel mandate exists. However, owing to Australia's abundant renewable energy resources, existing energy infrastructure and its strategic geo-political positioning, Australia is placed to be a front-runner for e-SAF production in the future. As outlined in Figure 4, CSIRO, has predicted a large market share for e-SAF (referred also as Power-to-liquid), with >5,000 million litres to be supplied by this pathway by 2050.

e-SAF costs in Australia are projected to be high compared to bio-SAF (Figure 4), but this is expected to fall as the Australian hydrogen economy grows, driving significant reductions in hydrogen production costs. The cost and availability of $CO_2$ source is also a key driver of e-SAF cost as outlined above, and these costs are also expected to decline.

[4] *https://www.infiniumco.com/news/iag-announces-new-e-saf-deal-with-infinium*
[5] *https://www.iairgroup.com/media/vt2m0ejr/iag-reaches-one-third-of-2030-saf-target-with-major-e-saf-deal-with-twelve.pdf*
[6] *https://synhelion.com/news/swiss-will-be-the-world-s-first-airline-to-use-synhelion-s-solar-fuels*
[7] *https://dgfuels.com/technology/*
[8] *Aviation Whitepaper Towards 2050. Australian Government. 2024.*

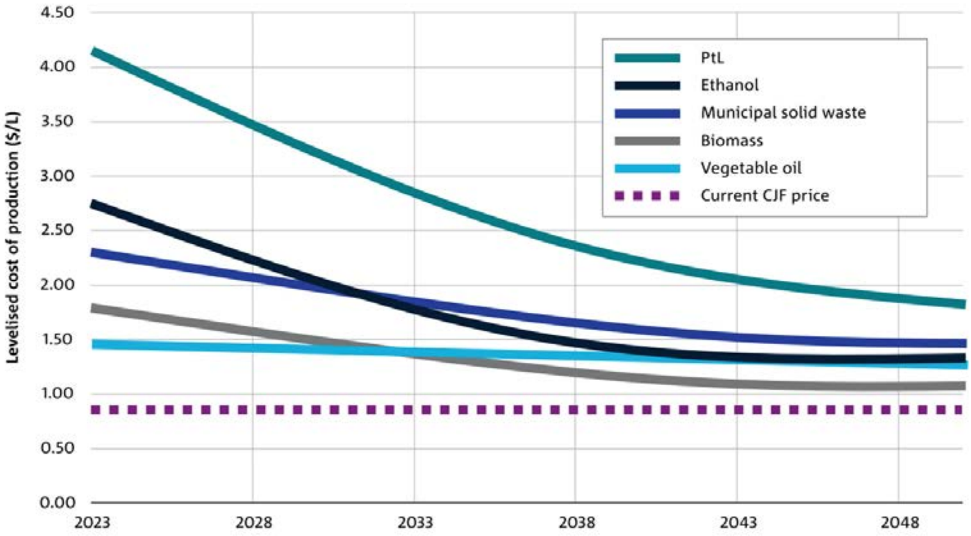



*Figure 4. Cost projections for E-SAF in Australia.*

There are a number of early-stage e-SAF projects in Australia including HIF Global's Tasmania facility, Zero Petroleum's Whyalla plant, amongst others.
HIF Global is developing a large-scale e-SAF facility near Burnie, Tasmania, representing a key e-SAF initiative in Australia. Utilising the Methanol to Jet fuel (MtJ) pathway, the facility will produce e-SAF from captured $CO_2$ and renewable hydrogen, leveraging Tasmania's abundant hydropower resources. HIF Global has partnered with Johnson Matthey and Honeywell UOP for preliminary engineering, drawing on experience from their US projects. With ambitious plans for the Asia-Pacific region, HIF Global aims to produce 36,000 barrels of e-fuel per day by 2030, a substantial portion of which will be e-SAF.

Zero Petroleum, a British synthetic fuel company, plans an e-SAF project in South Australia. Their "Plant Zero.SA" facility in Whyalla aims to produce 6-10 million litres of fuels annually, including gasoline, diesel, and importantly, e-SAF for sustainable aviation.

# 2 NSW's Competitive Advantage in e-SAF

*This section maps NSW's competitive advantage in e-SAF industry development, highlighting several potential locations for e-SAF production with proximity to demand, suitable CO2 source and renewable energy potential, and existing infrastructure.*

NSW is well-positioned to develop an e-SAF value chain given the fact that there is a significant demand for SAF, which may include e-SAF in the state. This is primarily due to NSW being home to Sydney Kingsford Smith airport, which is Australia's busiest airport, handling approximately 44 million passengers in 2018-2019. In addition, the state will host Western Sydney airport, which is expected to be operational by 2026. In addition to the Greater Sydney Metropolitan region, there are numerous regional airports across the state that can also be potential off-takers for e-SAF.

As e-SAF production relies on supplying hydrogen via renewable powered electrolysis and a sustainable $CO_2$ source, renewable electricity potential and sustainable $CO_2$ source availability are key deciding factors for the cost-competitiveness of e-SAF.

## 2.1 NSW's Renewable Energy Availability

NSW has extensive solar and wind energy resources and a significant pipeline of renewable projects. The state's renewable generation profile is relatively balanced with both solar and wind project as well as hydropower and battery energy storage. NSW has the strongest transmission and distribution network in the national energy market (NEM), with the fewest declared system strength shortages.

**Solar Capacity**

The state has high solar capacity factors between 22-26% throughout different zones. Currently, the state hosts an installed solar farm capacity of 2,123 MW (with 22 solar farms > 30 MW capacity) with a further 940 MW committed over the next few years and a further 62 MW capacity of PV farms currently in early stages of planning. The state is also home to one of Australia's largest solar plants, i.e., Darlington Point (324 MW), Limondale Solar Farm (306 MW) as well the under construction New England Solar Farm stage 1 (400 MW) (R. Daiyan R. A., 2023).

**Wind Capacity**

The state also exhibits high wind capacity factors between 32-55% throughout different zones. The state hosts 2,225 MW of current installed wind farm capacity (19 wind farms with greater than 100 MW capacity each and a further 3 under construction as of 2022) with additional 2,629 MW committed by 2030 and 7,610 MW of wind capacity proposed post 2030. Some notable large-scale plants include the Sapphire Wind Farm (270 MW), Silverton Wind Farm (200 MW) and the Bango Wind Farm (236 MW) and Collector Wind Farm (228 MW) both under construction (R. Daiyan R. A., 2023).

In addition, capacity expansion is expected in form of the development of Renewable Energy Zones (REZs) and this expansion is detailed in the main report. The Australian Energy Market Operator (AEMO) as part of its recent Integrated System Plan (ISP 2022) suggests potential development of REZs. Off these, the NSW government has already declared intentions to develop 5 REZs, the scope and status of which are provided in Table 2.

*Table 2: Status of REZ Development in NSW[9]*

| REZ Name | Status | Target Capacity | Current Progress |
|---|---|---|---|
| Central West & Orana | Development Phase | 3 GWs by mid 2020s | Initial expression of interest has attracted proposals of 27 GWs |
| New England | Early Planning | 8 GWs | Initial expression of interest has attracted proposals of 34 GWs |
| South West | Early Planning | 2.5 GWs | Initial expression of interest has attracted proposals of 34 GWs |
| Hunter – Central Coast | Early Planning | 1 GWs initial declaration | Initial expression of interest has attracted proposals of 40 GWs including offshore wind farms |
| Illawarra | Early Planning | 1 GWs initial declaration | Initial expression of interest has attracted proposals of 17 GWs including offshore wind farms |

**Battery and Pumped Hydro Storage:** In NSW, the government is investing heavily in both battery energy storage system (BESS) and pumped hydro energy storage (PHES) to ensure a reliable renewable energy supply, with example projects shown in Table 3.

*Table 3: Non-exhaustive list of battery and pumped hydro storage projects in NSW*

| Project Name | Technology | Capacity | Status |
|---|---|---|---|
| Liddell BESS | BESS | 500 MW / 1000 MWh | Operational |
| Waratah Super Battery | BESS | 850 MW / 1700 MWh | Operational |
| Orana BESS | BESS | 415 MW / 1660 MWh | Operational |
| Richmond Valley BESS | BESS | 275 MW / 2200 MWh | Operational |
| Stoney Creek BESS | BESS | 125 MW / 1,000 MWh | Planned |
| Griffith BESS | BESS | 100 MW / 800 MWh | Planned |
| Shoalhaven Scheme | PHES | 240 MW / 5760 MWh | Operational |
| Tumut 3 | PHES | 1800 MW / 60,000 MWh | Operational |
| Snowy 2.0 | PHES | 2200 MW / 350,000 MWh | Planned |
| ACEN Phoenix PHES | PHES | 800 MW / 11,990 MWh | Planned |
| Oven Mountain | PHES | 900 MW / 7200 MWh | Planned |

[9] *https://www.energyco.nsw.gov.au/renewable-energy-zones*

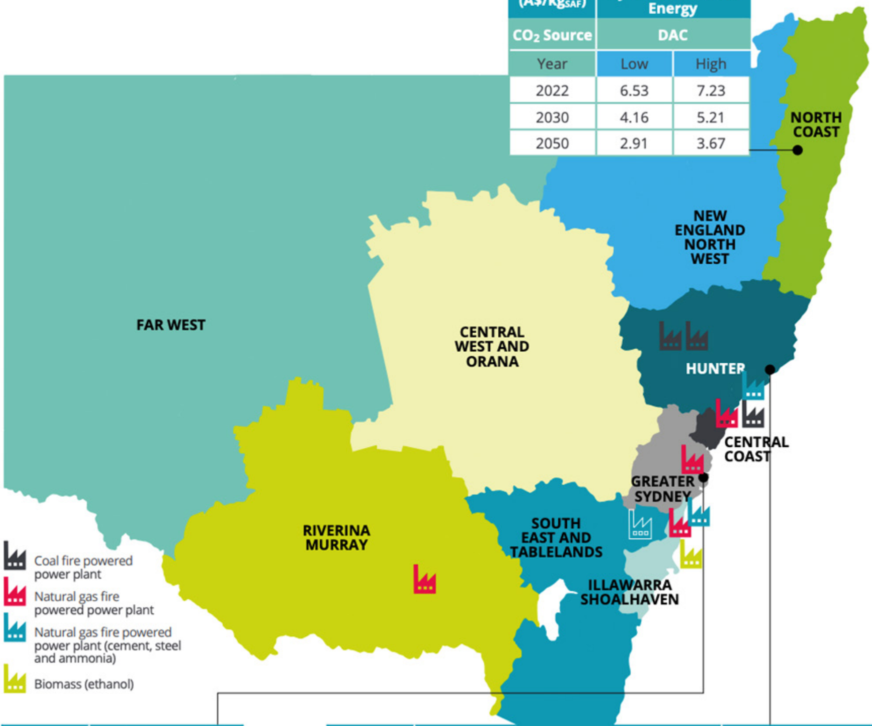
## 2.2 NSW's $CO_2$ Source Availability

In terms of $CO_2$ sources, NSW has several potential industrial flue gas (IFG) sources across the state (Table 4). While fossil-based $CO_2$ sources could be used in the medium term, they are not considered sustainable. Therefore, identifying alternative, sustainable $CO_2$ sources is crucial for the long-term viability of e-SAF production. One alternative is IFG $CO_2$ from biomass combustion or bioethanol plants; however, the current scale of these sources remains limited. Given this constraint, NSW could potentially rely on direct air capture (DAC), leveraging its abundant renewable electricity to provide a more sustainable and scalable $CO_2$ supply for e-SAF production.

*Table 4: List of potential CO2 emission sources suitable for carbon capture in NSW.*

| Project Name | Technology | Capacity | Status | Co2 Classification |
|---|---|---|---|---|
| Black coal fired power station | Bayswater | 12.8 | 10-12% | Non-renewable |
| | Liddell | 7.0 | 10-12% | Non-renewable |
| | Vales Point | 6.4 | 10-12% | Non-renewable |
| | Mount Piper | 7.1 | 10-12% | Non-renewable |
| | Eraring | 12.7 | 10-12% | Non-renewable |
| Cement Calcination | Berrima | 1.7 | 14 – 33% | Non-renewable |
| Steel Smelting | Port Kembla | 5.0 | 22% | Non-renewable |
| Ammonia Synthesis (SMR) | Kooragang Island | 0.54 | 19-19.5% | Non-renewable |
| Fuel Ethanol | Nowra | 0.225 | Near 100% | Renewable |
| Gas fired power station | Tallawarra | 0.259 | 3-8% | Non-renewable |
| | Uranquinty | 0.104 | 3-8% | Non-renewable |
| | Colongra | 0.042 | 3-8% | Non-renewable |
| | Smithfield | 0.019 | 3-8% | Non-renewable |
| Direct Air Capture | - | - | 399 ppm | Renewable |
| Woody biomass combustion | - | - | | Renewable |
| Biogas combustion | - | - | 3-8% | Renewable |

Across NSW, our previous NSW Power to X Industry Feasibility Study has identified three regions as potential development locations to produce e-SAF, including North Coast, Hunter, and Central Coast and Greater Sydney Metropolitan Area (Figure 5).




| ($A\$/kg_{SAF}$) | Hybrid Renewable Energy | |
|---|---|---|
| $CO_2$ Source | DAC | |
| Year | Low | High |
| 2022 | 6.53 | 7.23 |
| 2030 | 4.16 | 5.21 |
| 2050 | 2.91 | 3.67 |

| ($A\$/kg_{SAF}$) | Hybrid Renewable Energy | |
|---|---|---|
| $CO_2$ Source | DAC | |
| Year | Low | High |
| 2022 | 6.84 | 7.69 |
| 2030 | 4.48 | 5.67 |
| 2050 | 3.17 | 4.07 |

| ($A\$/kg_{SAF}$) | Hybrid Renewable Energy | | | | Offshore Wind | |
|---|---|---|---|---|---|---|
| $CO_2$ Source | DAC | | IFG | | DAC | |
| Year | Low | High | Low | High | Low | High |
| 2022 | 6.84 | 7.69 | 5.91 | 6.73 | 7.69 | 8.33 |
| 2030 | 4.48 | 5.67 | 4.20 | 5.18 | 5.29 | 6.54 |
| 2050 | 3.17 | 4.07 | 3.09 | 3.83 | 4.03 | 5.19 |

*Figure 5: Locations explored to produce Sustainable Aviation Fuel in NSW with indicative cost analysis.*[10]

## North Coast

In the North Coast, the production of e-SAF is expected to be based on DAC as the primary source of $CO_2$ since there were no suitable IFG sources identified in this region. Renewable power can be sourced from offshore wind and hybrid standalone power configurations. The North Coast region is home to Coffs Harbour airport, which was the 25$^{th}$ busiest airport in Australia between 2018 and 2019 (pre-COVID) and handled approximately 400,000 passengers. Assuming Coffs Harbour airport consumes 40 KTPA (50,000 $m^3$/yr) of aviation fuel at 50% blend, this would equate to 20 KTPA (25,000 $m^3$/yr) of SAF.

## Hunter

e-SAF production in Hunter can be based on a DAC and IFG $CO_2$ sources due to the availability of these two types of sources. Renewable power can be sourced from the hybrid renewable energy plant in Central West and Orana region. Offshore wind is another option for the Hunter as a power source. Newcastle airport, located near Williamtown in the Hunter region was Australia's 13$^{th}$ busiest airport in 2018-2019 and handled 1.26 million passengers. The airport is also home to RAAF Williamtown from which several types of military aircraft that could potentially use e-SAF in their fuel mix are based. Assuming Newcastle airport uses an annual aviation fuel consumption of 100 KTPA (125,000 $m^3$/yr), at 50% blend this would equate to 50 KTPA (62,500 $m^3$/yr) of SAF.

## Greater Sydney Metropolitan and Central Coast Region

The production of e-SAF in the Greater Sydney Metropolitan and Central Coast region is likely to be based on DAC as the $CO_2$ source due to the lack of IFG sources with a suitable scale. The renewable power supply can be sourced from hybrid renewable power generation plant from the Central West

[10]*NSW Power to X Industry Feasibility Study.*

and Orana region with a dedicated transmission network. The region is home to Sydney Kingsford Smith airport, which is Australia's busiest airport and handled approximately 44 million passengers in 2018-2019. In addition, the region hosts RAAF Richmond and is also going to be home to Western Sydney airport, which is expected to be operational by 2026. All the airports provide options for e-SAF demand. The existing Sydney airport has an average daily jet fuel demand of 10 million litres (equivalent to 2.92 MTPA). To meet 50% of this jet fuel demand would require an e-SAF production capacity of 1.46 MTPA.

# 3 Project Approach

The study adopts a combined quantitative and qualitative approach, incorporating capability mapping, economic modelling, and conceptual engineering design, supported by stakeholder consultations (Figure 6). These consultations were an integral part of the study, conducted through workshops hosted by OCSE and PFHN (see Appendix C), ensuring evidence-based recommendations for stakeholders.

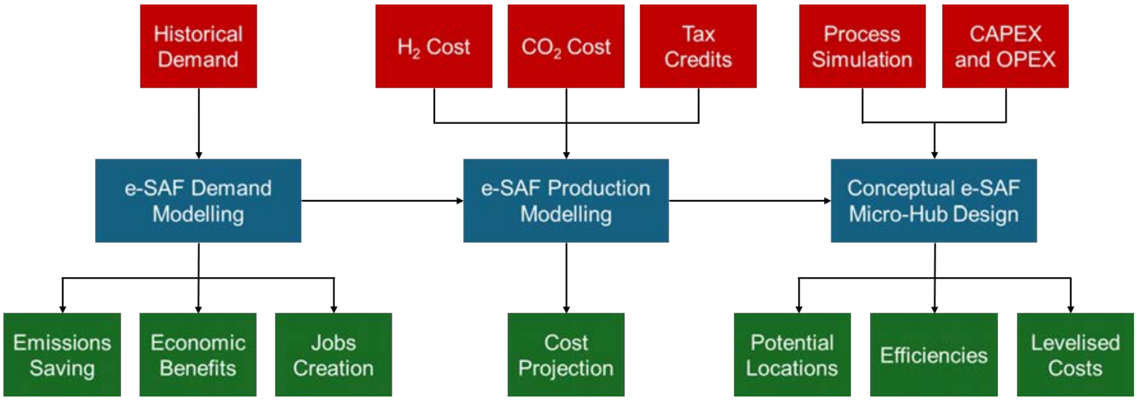



*Figure 6: Schematic diagram of project methodology*

First, the study establishes the context by analysing the demand for e-SAF in NSW under three different scenarios: business as usual, reduced fossil fuel usage, and net-zero emissions. Historical aviation fuel demand data was collected from publicly available sources, and future e-SAF demand was projected under these scenarios through 2050. This demand modelling was then used to estimate $CO_2$ emissions trajectories from the NSW aviation sector, providing insights into potential emissions reductions. In addition, the modelling assessed potential socioeconomic benefits, including the state's gross value added (GVA) and job creation.

Next, the study examines the high-level cost modelling of e-SAF production in NSW, focusing on a power-to-liquid configuration. This process involves supplying renewable hydrogen and sustainable $CO_2$ sources, which react to produce synthetic fuels via the reverse water gas shift (RWGS) followed by the Fischer-Tropsch (FT) process. A sensitivity analysis was conducted to assess the impact of captured $CO_2$ and hydrogen costs on e-SAF production expenses. Following this analysis, a cost-reduction trajectory for e-SAF production in NSW from 2023 to 2050 was developed, considering potential decreases in renewable power costs, water electrolysis, and $CO_2$ capture expenses. Additionally, the role of tax credits in narrowing the price gap was explored under different scenarios.

The study also investigates the potential for establishing e-SAF hubs in NSW. Suitable locations were identified, and a multi-criteria assessment framework was developed to assist stakeholders in evaluating the feasibility of e-SAF hub locations. Furthermore, a conceptual engineering design for an e-SAF micro-hub was carried out. A detailed process simulation was conducted, using $CO_2$ sourced from direct air capture (DAC) and renewable hydrogen produced from a standalone solar farm. The simulation provides insights into the efficiency of synthetic fuel production, forming the basis for estimating capital and operational expenditures and calculating the levelised cost of synthetic fuels.

Ultimately, the study identifies challenges in developing the e-SAF value chain in NSW and proposes potential solutions to accelerate its adoption for decarbonising the state's aviation sector.

# 4 NSW SAF Market Modelling

*This Chapter explores NSW e-SAF market demand and production conditions with state-level economic modelling with different scenarios and sensitivities.*

## 4.1 Demand Modelling

### 4.1.1 Demand Scenario Definition

In this study, we consider three scenarios in the NSW aviation sector, including (i) business as usual, (ii) reduced fossil, and (iii) net zero scenarios (Bergero, 2022). In the business as usual scenario, we assume that fossil jet fuel continues to be the main energy source for aviation, consistent with the NSW aviation fuel uses historical record obtained from the Australian Petroleum Statistics (DCCEEW, 2023). In the reduced fossil scenario, we follow IATA's net zero carbon emissions pathway introduced in the 77$^{th}$ Annual General Meeting. On the basis of IATA's proposition (IATA, 2021), by 2050, 65% of 2050 estimated emissions are mitigated with SAF, and new non-emitting propulsion technologies (electric and/or hydrogen planes) mitigates 13%, only allowing electric planes to deploy in short-haul flights, starting in 2025 with less than 1%, linearly increasing to 13% by 2050. The net zero scenario follows a more aggressive deployment of both SAF and new propulsion technologies by 2050, and we assume that the entirety of medium- and long-haul planes are powered with SAF and that for short-haul aviation, the split is 50-50 between SAF and new propulsion planes.

### 4.1.2 Demand Modelling Results

Current annual demand on aviation fuel in NSW is estimated based on annual aviation turbine fuel (avtur) sales historical data (2011-2022) obtained from the Australian Petroleum Statistics (DCCEEW, 2023). Prior to the COVID-19 pandemic, annual avtur demand was growing at an annual rate of approximately 1.9%. Travel advisories and border restrictions during the COVID-19 pandemic, however, led to a sharp decline in the air transport of passengers, driving the avtur demand down to about 1248.6 ML in 2021, nearly 65% below pre-pandemic level in 2019. As of late 2024, Australia's aviation sector appears to have recovered as passenger levels and capacity returned to pre-pandemic levels (ACCC, 2024). Based on the defined scenarios, we project the shares of fossil jet fuel, SAF, and non-emitting propulsion to supply aviation energy demand in NSW under different scenarios as illustrated in Figure 7. Under the reduced fossil usage scenario, SAF demand in NSW is expected to be 27.4 PJ (equivalent to ~800 ML) by 2035 and 121.1 PJ (equivalent to ~3500 ML) by 2050. Under the net zero scenario, SAF demand in NSW is anticipated to reach 68.5 PJ (equivalent to ~2000 ML) by 2030 and 145.6 PJ (equivalent to ~4200 ML) by 2050. The estimated SAF demand under the net zero scenario aligns with the recently published NSW Sustainable Aviation Fuel Prospectus, which predicts that NSW will require between 4000 and 4300 ML/year of SAF by 2050.

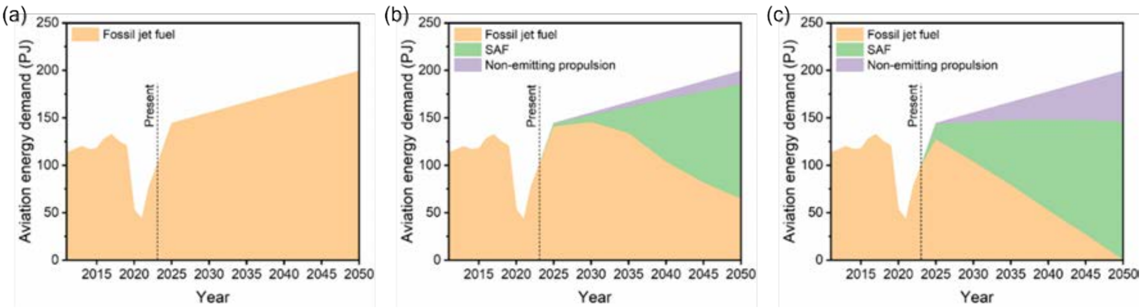



*Figure 7: Projected NSW's shares of fossil jet fuel, SAF, and non-emitting propulsion to supply aviation energy demand under different scenarios: (a) business as usual, (b) reduced fossil, and (c) net zero scenarios.*

To calculate current aviation $CO_2$ emissions and the trajectory to 2050, we estimate the carbon intensity of fossil jet fuel to be 73.5g$CO_2$ $MJ^{-1}$ (from tank to wake, excluding fuel production emissions) (Bergero, 2022). We neglect life-cycle well-to-tank emissions because such emissions can be assumed to represent a small fraction of the total and because these emissions are, in theory, much easier to avoid than the direct emissions from aviation. We assume that SAF is net zero carbon fuels and that the electricity to power short-haul planes comes from a renewable energy grid – and thus also has a net-zero carbon content – and that hydrogen is a product of renewables-driven electrolysis (Bergero, 2022). Figure 8 shows the projected NSW aviation CO2 emissions under different scenarios.

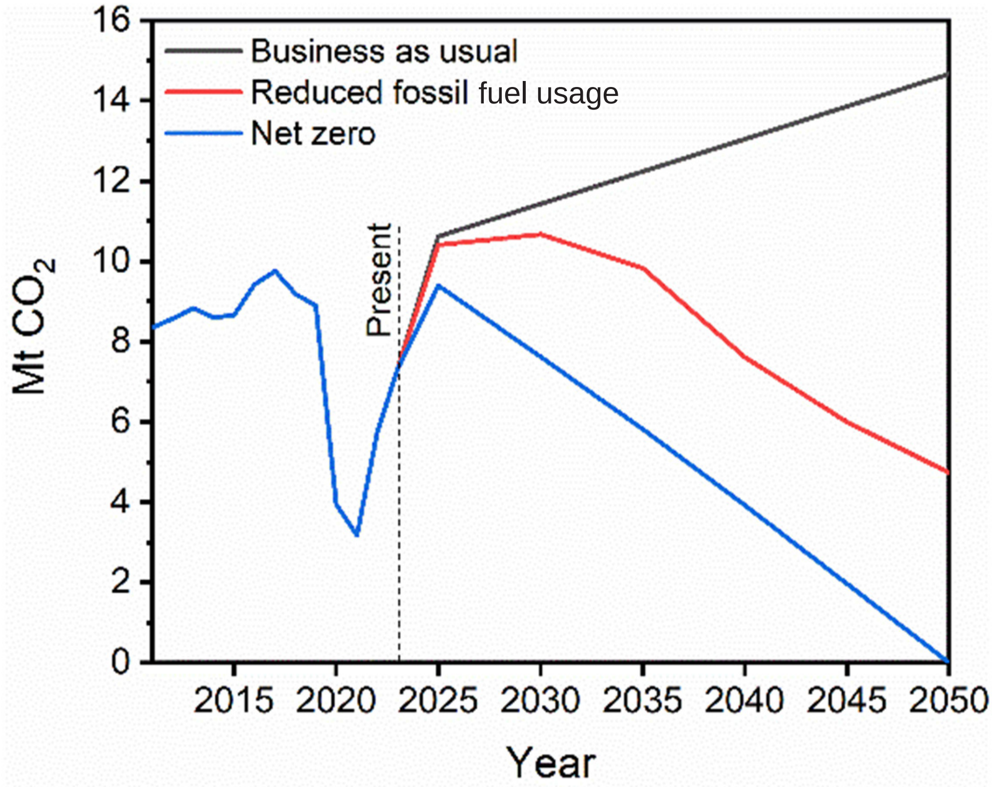



*Figure 8: Projected NSW's annual aviation CO2 emissions under different scenarios.*

The increasing demand in e-SAF to support emissions reduction in aviation sector could benefit NSW's economy, see highlight in Table 5. NSW's e-SAF industry, specifically the green $H_2$ production stream that is considered as one of the most critical components requiring high investment, has the potential to generate A$4.7 billion in state gross value added (GVA) and to create 7,000-9,000 jobs per year by 2050 under a reduced fossil scenario. Following the net zero scenario, the NSW Government could potentially generate up to A$5.6 billion in state GVA and create 8,000-10,000 jobs per year by 2050. Further, the significant emissions reduction through the applications of e-SAF and non-emitting propulsion could benefit aviation stakeholders in NSW from participation in the Clean Energy Regulator Emissions Reduction Fund and receive Australian Carbon Credit Units (ACCUs) for every tonne of $CO_2$ avoided (A$17.12 per tonne $CO_2$) (CER, 2023). This would contribute A$170 million and A$250 million for reduced fossil and net zero scenarios, respectively.

*Table 5. Summary of SAF demand modelling encompassing the scenario description, emissions saving potential, economic benefits, and jobs creation opportunities.*

| Scenario | Scenario Description | Estimated Demand* | Emissions Saving | Economic Benefits | Jobs Creation |
|---|---|---|---|---|---|
| Business as usual | Scenario where fossil jet fuel continues to power 100% of planes to 2050. | 0 ML SAF | Baseline | Baseline | Baseline |
| Reduced fossil | Scenario that follows a pathway with 65% of medium- and long-haul aviation powered by SAF and 13% of short-haul planes powered by non-emitting propulsion systems by 2050. | ~800 ML SAF and ~3500 ML SAF by 2035 and 2050, respectively. | 20% and 68% $CO_2$ emissions reduction relative to business as usual scenario by 2035 and 2050, respectively. | A$4.7 billion in state GVA and A$170 million from $CO_2$ emissions saving by 2050. | 7,000-9,000 jobs per year by 2050. |
| Net zero | Scenario where SAF power 100% of medium- and long-haul aviation by 2050, and non-emitting propulsion systems power 50% of short-haul flights, with the remainder being powered by SAF. | ~2000 ML SAF and ~4200 ML SAF by 2035 and 2050, respectively. | 50% and 100% $CO_2$ emissions reduction relative to business as usual scenario by 2035 and 2050, respectively. | A$5.7 billion in state GVA and A$250 million from $CO_2$ emissions saving by 2050. | 8,000-10,000 jobs per year by 2050. |

## 4.2 Production Modelling

### 4.2.1 Levelised Cost of e-SAF

The major barrier to the penetration of e-SAF in NSW is cost, which highly depends on the cost of $H_2$ primarily reflects electrolyser and electricity costs and the cost of captured $CO_2$. Figure 9 illustrates the levelised cost of e-SAF as a function of $H_2$ cost and captured $CO_2$ cost. Assuming current costs of electrolysis $H_2$ production and $CO_2$ direct air capture are around A$7.43 per kg $H_2$ (Bruce, 2018) and A$0.5 per kg $CO_2$ (Srinivasan, 2021), respectively, e-SAF cost is about A$6.0 per kg, around 4 times higher than the global average cost of fossil jet fuel (A$1.5 per kg) (IATA, 2023). However, it is important to note that the actual costs of green $H_2$ and $CO_2$ direct air capture may be higher than the values used in this study, depending on renewable electricity prices and production scale.

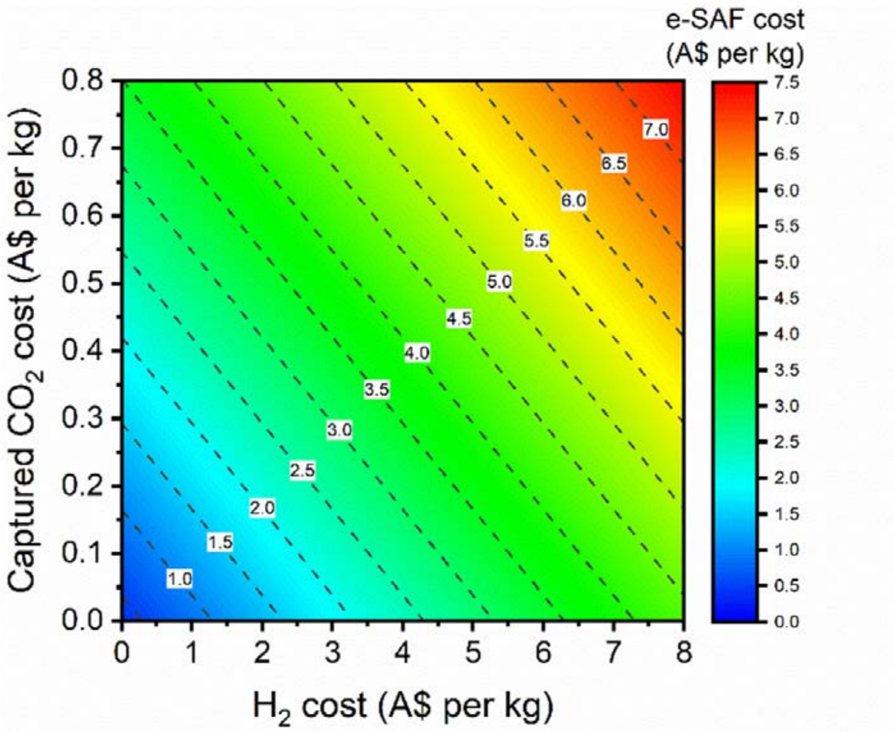



*Figure 9: Levelised cost of e-SAF as a function of $H_2$ cost and captured $CO_2$ cost.*

We perform a cost projection analysis to evaluate current and future feasibility of e-SAF by considering the reduction of major cost components, including $H_2$ production, $CO_2$ capture, and the reverse water gas shift followed by Fischer-Tropsch process (RWGS-FT). Figure 10 shows e-SAF cost breakdown and projection from 2023 to 2050. e-SAF production cost today is dominated by the $H_2$ production and $CO_2$ capture costs, accounting for 49% and 26%, respectively. The significant declines in $H_2$ production and $CO_2$ capture costs could bring the e-SAF production cost down from around A$6.0 per kg today to A$3.2 per kg by 2030 and A$1.4 per kg by 2050. This projection suggests that e-SAF could potentially reach cost parity with fossil jet fuel in 2050 through technology improvements, learning curve effects, and economies of scale.

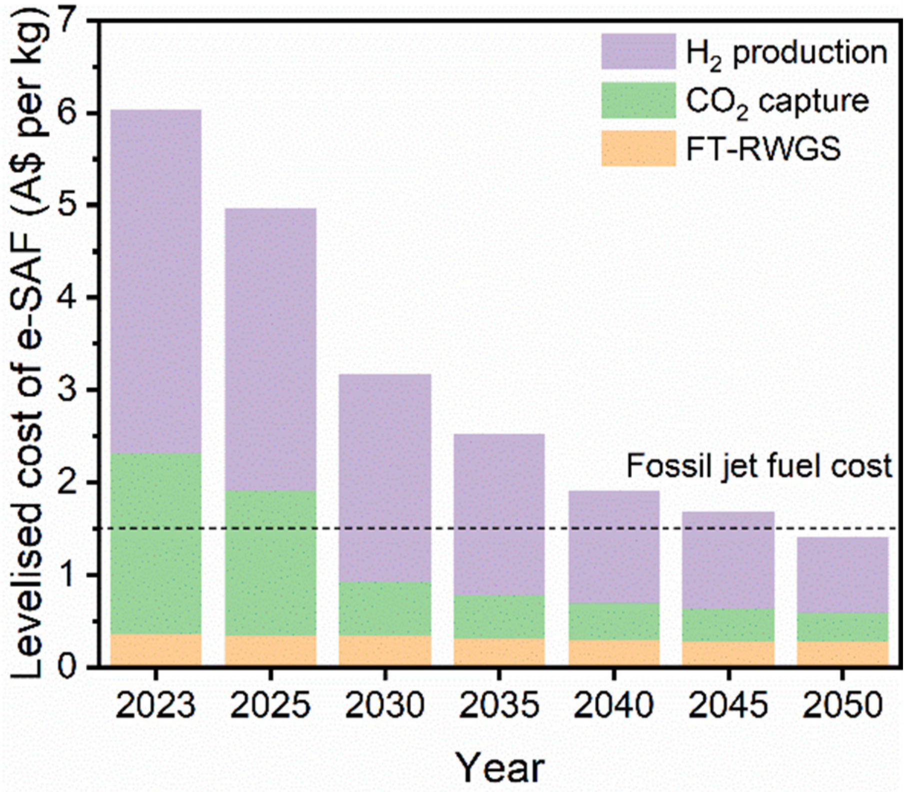



*Figure 10: Projected levelised cost of e-SAF from 2023 to 2050.*

To close the price gap at an accelerated rate, government interventions play a critical role. In this study, we model the effects of implementing various levels of tax credits for e-SAF projects (A$1, A$1.5, and A$2 per kg e-SAF) on potential cost reduction and time required for e-SAF to reach parity with fossil jet fuel (Figure 11). A$1 per kg tax credit can help e-SAF to be economically viable by 2040, while A$1.5 and A$2 per kg tax credits could bring forward the cost parity with fossil jet fuel to 2035 and 2030, respectively. The findings illustrate the critical importance of government incentives for e-SAF. Providing A$1 billion incentives (A$2 per kg tax credit) within 10-year timeframe, for instance, could support project development to produce approximately 500,000 tonnes of e-SAF, equivalent to 50,000 tonnes of e-SAF per year.

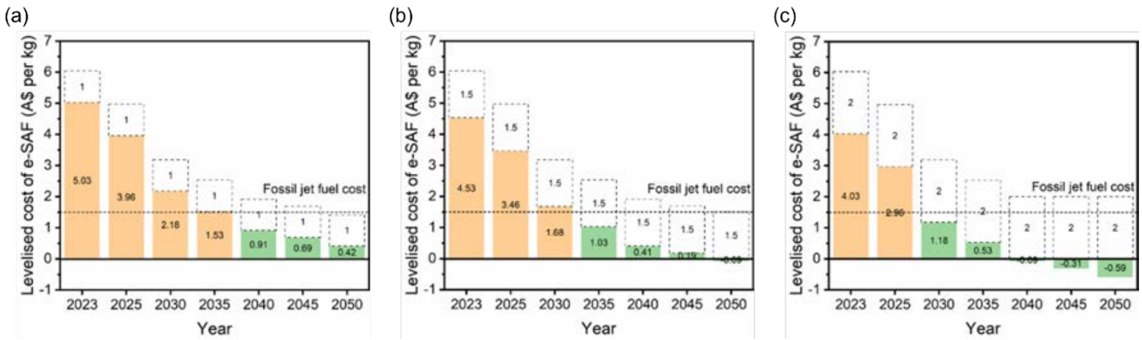



*Figure 11: Projected levelised cost of e-SAF from 2023-2050 under the implementation of various levels of tax credits: (a) A$1, (b) A$1.5, and (c) A$2 per kg e-SAF.*

# 5 NSW e-SAF Hub Pre-Feasibility

*Building on the e-SAF opportunity outlined in the previous sections, this section presents a location selection framework for decentralised e-SAF project and conceptual engineering design of e-SAF Hub with economic and risk assessment.*

## 5.1 NSW e-SAF Hub Concept and Locations

P2X hubs serve as pivotal clusters where diverse users of clean power fuels and chemicals, spanning across the industrial, transportation, and energy sectors, converge. The fundamental idea behind these hubs is to establish comprehensive, vertically integrated clusters that encompass production, transportation, and consumption, all aimed at satisfying aggregated demand and supply requirements. Through this concept, these hubs aim to nurture shared infrastructure and engage multi-sector consumers, thus enhancing cost-efficiency and operational effectiveness to catalyse the emergence of a nascent industry. A visualisation of P2X Hub centred eco-industrial precinct is shown in Figure 12. A pertinent example of this concept can be found in Australia, where hydrogen hubs are in their embryonic stages, representing a promising model for the development of P2X Hubs dedicated to large-scale hydrogen production for industrial utilisation and export purposes.

The focus of this project is to design a NSW conceptual Hub for e-SAF production within the P2X Hub and Precinct Framework. These hubs possess the potential to cultivate innovation and promote collaboration, facilitating ongoing cost reductions and process optimizations that bridge the price gap with fossil jet fuel. It's important to note that the specific characteristics of these hubs, including their size, funding models, and organisational structures, can vary significantly.

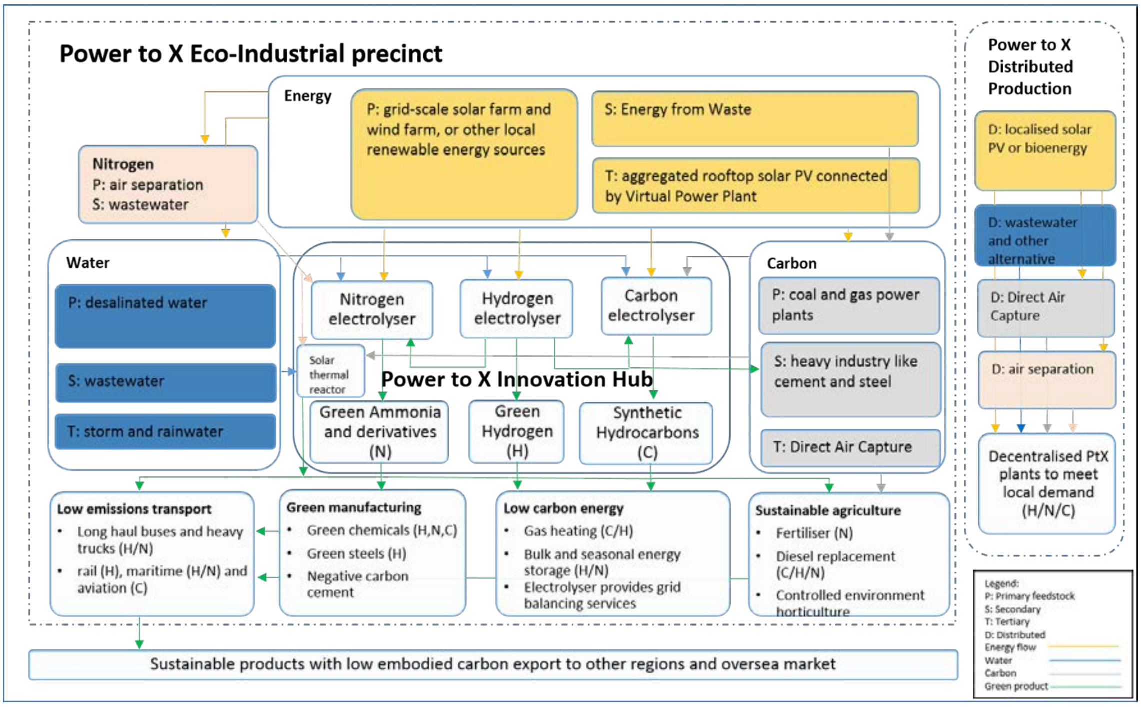



*Figure 12: P2X Hub and Precinct Opportunities Visualisation*

The project will need to determine airport groups for e-SAF feasibility assessment between international airports and domestic airports. The infrastructure, traffic management and financial capability are very distinct between the international and domestic airports. Those factors will determine the feasibility study methodology, and the project needs to narrow down to one group for feasibility studies.

International airports are actively exploring decarbonisation pathways to achieve low-emissions travel. These airports are well resources for their investigation on P2X decarbonisation pathways, some released feasibility studies and some have commercial pilot projects at deployment phase. For example, the Schiphol Airport in Amsterdam is developing a commercial plant e-SAF facility in partnership with Synkero for completion in 2027 (Schiphol Airport, 2021).

Sydney is the most important airway gate for Australia connecting more than 90 destinations around the world with two international airports:

- Sydney Kingsford Smith Airport (Sydney Airport) is one of the most important pieces of aviation infrastructure of the air network. Sydney Airport has an average daily jet fuel demand around 10 million litres refuelling 1,500 aircrafts (2019 data) (Sydney Airport, 2023). Sydney Airport's jet fuel facilities include five storage tanks that have a maximum capacity of 29 million litres of aviation fuel, 11 kilometres of pipeline that transporting the fuels from storage tanks to terminals and 11 hydrant pumps used to pressuring hydrant lines up to a capacity of 45,000 litres per minute (Sydney Airport, n.d.).
- Western Sydney International Airport (Western Sydney Airport) is underway and on track to begin operation in 2026. The Western Sydney Airport is expected to accommodate 10 million passengers every year and new hub for high-value agriculture products for exporting (Western Sydney Airport, n.d.). There is a substantial and growing jet fuel demand from the Western Sydney Airport, estimated at around 570 million litres per annum in 2031 and 2.82 billion litres per annum in 2051 (Deloitte, 2017).

Like other international airports, the two NSW international airports will be well resourced to conduct comprehensive feasibility studies on their e-SAF supply chain. The market sounding exercise conducted through OCSE SAF workshops expressed strong interest from stakeholders to investigate the feasibility of small-scale SAF projects for regional commercial airports and military airports in NSW. Preliminary market scanning suggests that very limited SAF activities from domestic airports and no released feasibility studies on e-SAF supply chains. There is a clear market gap of e-SAF techno-economic analysis for NSW domestic airports is the focus for this project.

NSW has four Royal Australian Air Force (RAAF) bases; RAAF Base Williamtown, Glenbrook, Richmond and Wagga, which could be another large potential consumer for SAF. As the defence sector actively decarbonises its operations, military aircraft fleets have the potential as being the early adopters for SAF given their relatively smaller size of fuel tanks and the 'return to base' model of operation (Australian Defence Force, 2024). RAAF bases have existing fuel transportation and supply infrastructure, and their regional locations have access to bioenergy feedstock or dedicated energy supply would lower production costs. However, the challenge for designing e-SAF Hub for RAAF bases exist in accessing to the data such as fuel consumption, tariff volume, pipeline and infrastructure. The complexity and uncertainty in approval process in accessing to those data misaligned with project timeline. High sensitivity of P2X for military use excluded such discussion from OCSE and PFHN workshops.

NSW has the most established air network in the southern hemisphere that covering major regional cities and town centres in the state (Figure 13). There are 60 reginal airports in service that have the capability to export high-value perishable communities such as beef, lamb, summer fruit, aquaculture, pork and dairy to international markets. The air freight volume is expected to increase significantly in 10 years to accommodate the doubling demand of key perishable products exporting to Asian regions (KPMG, 2019). The large base of potential locations and growing demand make domestic commercial airports the most suitable subjects for further feasibility studies.

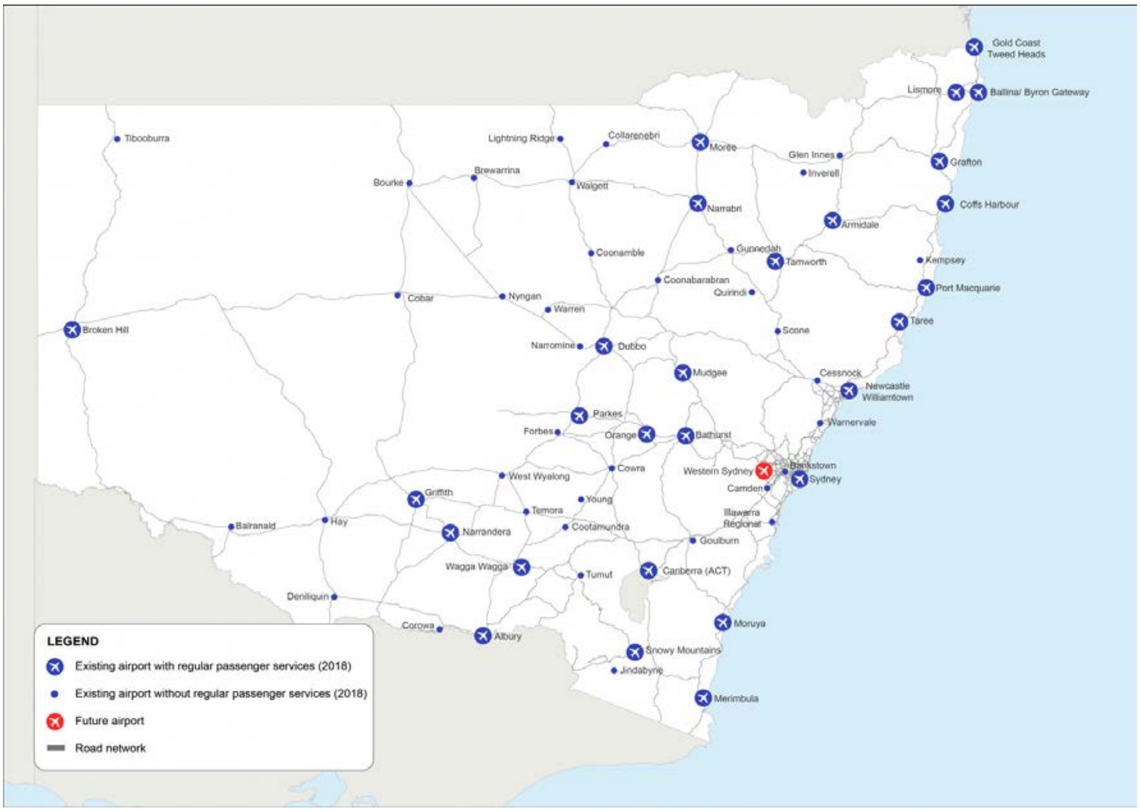



*Figure 13: NSW Air Freight Network (Source: NSW Government)*

## 5.2 Multi Criteria Assessment Framework for e-SAF Hub Location Selection

A Multi-Criteria Analysis (MCA) framework was developed to determine the suitability of NSW e-SAF Hub in selection locations for preliminary design and feasibility study.

Six criteria were selected as essential elements for e-SAF Hub which are:

- **Renewable Energy Availability.** The availability of renewables in the form of solar, wind, or biomass is critical to drive the e-SAF micro-hub. Here we assess the solar and wind potential based on the solar and wind capacity factors available on the Commonwealth National Map tool and database.
- **Water Availability.** $H_2$ production via electrolysis requires a reliable source of water that needs to be pre-treated to deionised water quality. Typical water consumption is between 10-19 kg of deionised water per kg of $H_2$, with theoretical requirements being 9L of water per kg of $H_2$ and the rest required for cooling. Water availability is a vital issue for Australia, and in particular, regional areas that are prone to droughts.
- **$CO_2$ Source Availability.** $CO_2$ is the critical feedstock to make e-SAF, and the costs associated with sourcing $CO_2$ significantly influences the e-SAF costs. Generally, $CO_2$ can be sourced from point source capture, such as from industrial flue gas, or direct air capture (DAC). In terms of costs, DAC is currently more expensive and energy intensive than point source capture. Therefore, sourcing $CO_2$ from industrial flue gas is more economically viable currently although DAC could be more competitive in the near future.
- **Land Availability.** The size of the area available and the existing ownership or occupancy of the land are critical for e-SAF hub deployment. This determines the scale of the project, including the standalone power generation plant and the conversion facility, as well as the barriers in land procurement process.

- **Existing Infrastructure.** The availability of existing infrastructure that can be leveraged includes existing solar and wind farms that are curtailed, an existing electricity distribution network that can be utilised to access potential renewable electricity sources, jet fuel network and storage. Leveraging existing infrastructure is an advantage for an e-SAF hub and can help with the project economics by lowering capital expenditure but is not considered essential for the remote locations in our analysis.
- **Approval and Risk Factors.** Potential approvals and risks that will affect the development of an e-SAF micro-hub is the final criteria considered for each location and includes limitation on land use (e.g., proximity to cultural or heritage listed sites); potential risks to health and safety (e.g., proximity to housing, hospitals, and population density); environmental risks (e.g., local biodiversity and protected flora and fauna); operational risk (e.g., flood and earthquake risks); competing land use (e.g., agriculture); approval requirements (e.g., local, state, or federal level); and public acceptance (e.g., openness of local community to green energy developments).

Each criteria considered was weighted for their relative significance in e-SAF project development, sub-criteria were used to apply a quantitative score. The weighting and scoring for each criteria and sub-criteria considered is detailed in Appendix E.1. An overall percentage score can be calculated for each locations using the MCA to assess the feasibility of for a e-SAF Hub. Important to note that there are other factors could be considered for the MCA framework and weighting allocation of criteria is a relatively subjective process, the framework presented in this paper serving as a guideline for stakeholders to develop own MCA frameworks.

## 5.3 NSW e-SAF Micro-Hub Conceptual Design

A conceptual e-SAF Hub is designed to assess the techno-economic feasibility of such concept. e-SAF is produced as an ASTM compliant fuel that can be blended with conventional jet fuel up to 50% ratio. The e-SAF Hub is designed at scale for domestic commercial airports in NSW.

### 5.3.1 e-SAF Micro-Hub Engineering System Design

We model a small-scale e-SAF production facility that produces 1 tonne per day (TPD) of e-SAF using Fischer-Tropsch process. Figure 13 shows the major flow paths for e-SAF production based on Fischer-Tropsch process. This e-SAF production pathway consists of 5 process areas, namely, A1: $H_2$ production, A2: direct air capture (DAC), A3: reverse water gas shift (RWGS) reaction, A4: Fischer-Tropsch (FT) synthesis, and A5: hydroprocessing. The process simulation results for major flow, obtained using DWSIM, are summarised in the table in Figure 14.

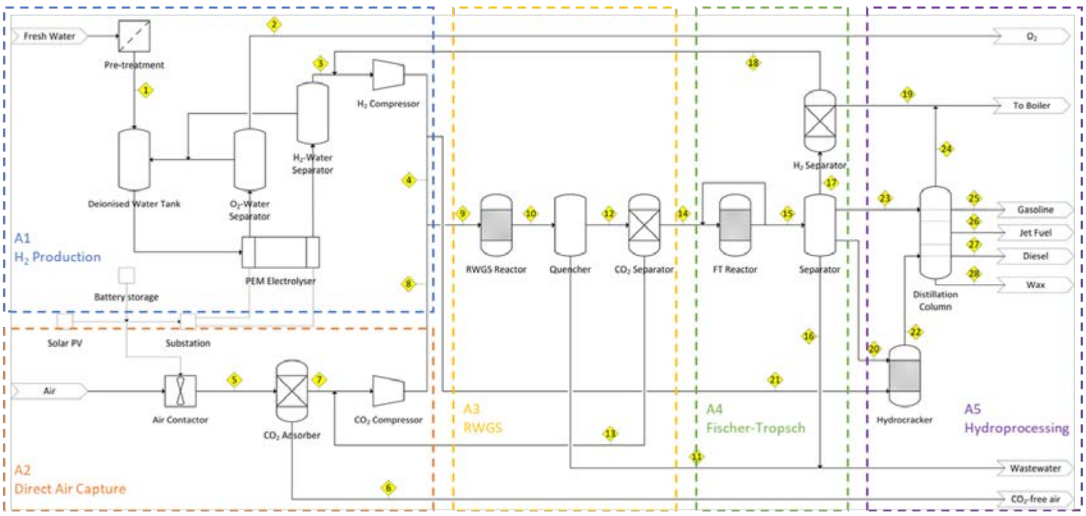
In $H_2$ production area (A1), $H_2$ is produced via electrolysis of sustainable surface water source powered by renewable energy on a 2.5 MW PEM electrolyser. The water feed undergoes pre-treatment consisting of screening, filtration, coagulation, followed by reverse osmosis to produce Type II quality deionised water. The pre-treated water is then fed into an electrolyser. The electrolyser requires renewable electricity that is generated by the solar PV and battery energy storage system passes through a substation to match the voltage requirements of the electrolyser. The electrolyser splits the water into $H_2$ and $O_2$. The $O_2$ stream is released at the anode and the $H_2$ is released at the cathode. Both gas streams are sent through gas-liquid separators to recover the residual water before undergoing a drying phase to remove the remaining moisture. The $O_2$ is either vented to the atmosphere or sold to potential end users. On the other hand, the H2 is compressed to 25 bar.

In direct air capture area (A2), there are two connected chemical loops. First, air is pulled through a contactor by fans and the $CO_2$ in the air is absorbed using an aqueous solution of potassium hydroxide (KOH), forming potassium carbonate ($K_2CO_3$). In the second loop, $CO_3^{2-}$ is precipitated by reaction $Ca^{2+}$ to form $CaCO_3$ while $CO_3^{2-}$ is replenished by dissolution of $Ca(OH)_2$. The $CaCO_3$ is calcined to liberate $CO_2$ producing CaO, which is hydrated or slaked to produce $Ca(OH)_2$. The $CO_2$ is then sent into a condenser to remove water and the $CO_2$ is compressed to 25 bar.

In RWGS reaction area (A3), H2 reacts with $CO_2$ (with a $CO_2/H_2$ molar ratio equal to 2.0) through the RWGS reaction (R1) at 900°C and 25 bar to produce syngas. The resultant gas mixture is cooled and dried to remove water. The remaining gas mixture (syngas) passes through a Selexol $CO_2$ separator to recover and recycle the unconverted $CO_2$ into the RWGS reactor.

In FT-synthesis area (A3), syngas reacts with high-pressure $H_2$ at 220°C and 25 bar to form liquid hydrocarbons and light gas through a Fischer-Tropsch reaction with various chain lengths (Zang, Sun, & Elgowainy, 2021). The resultant gaseous stream mainly consists of CO, $H_2$, and $C_1$-$C_5$ hydrocarbons flows through a $H_2$ pressure swing adsorption (PSA) separator to recover and recycle the unreacted $H_2$. The PSA tail gases, which are combustible gases can be used for power generation (outside the scope of this study. The liquid hydrocarbons with major components of $C_5$-$C_{30}$ are produced from the bottom of the FT synthesis reactor. A separator is used to separate the mixture into the heavier cut ($C_{20}$-$C_{30}$, called wax) for hydrocracking and the lighter cut ($C_5$-$C_{20}$) for distillation.

In hydroprocessing area (A4), the wax reacts with high-pressure $H_2$ at 290°C and 25 bar to be cracked into shorter-chain hydrocarbons < $C_{20}$, which are further separated into light hydrocarbons ($C_1$-$C_4$), gasoline ($C_5$-$C_8$), jet fuel ($C_9$-$C_{14}$), and diesel ($C_{15}$-$C_{20}$) (Zang, Sun, & Elgowainy, 2021).




| Component | Unit | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | °C | 25 | 60 | 60 | 40 | 25 | 40 | 40 | 40 | 900 | 900 | 40 | 40 | 40 | 220 | 220 | 40 | 40 | 40 | 40 | 290 | 40 | 290 | 40 | 40 | 30 | 30 | 30 | 30 |
| Pressure | bar | 1 | 20 | 20 | 25 | 1 | 1 | 1 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 1 | 1 | 1 | 1 |
| Total flow | kg/h | 540.9 | 404.4 | 50.6 | 54.1 | 7E+5 | 7E+5 | 416.1 | 575.6 | 629.7 | 629.7 | 165.6 | 464.1 | 159.5 | 304.6 | 304.6 | 134.9 | 141.9 | 4.3 | 65.8 | 61.8 | 0.8 | 62.6 | 37.9 | 1.7 | 19.7 | 42.5 | 30.4 | 6.2 |
| $N_2$ | kg/h | | | | | 6E+5 | 6E+5 | | | | | | | | | | | | | | | | | | | | | | |
| $O_2$ | kg/h | | 404.4 | | | 2E+5 | 2E+5 | | | | | | | | | | | | | | | | | | | | | | |
| $CO_2$ | kg/h | | | | | 438.0 | 21.9 | 416.1 | 575.6 | 575.6 | 168.4 | 0.6 | 167.9 | 159.5 | 8.4 | 8.4 | 0.1 | 8.1 | | 8.1 | | | | 0.2 | 0.2 | | | | |
| $H_2$ | kg/h | | | 50.6 | 54.1 | | | | | 54.1 | 35.4 | 0.0 | 35.4 | | 35.4 | 4.5 | 0.0 | 4.5 | 4.3 | 0.2 | | 0.8 | 0.4 | 0.0 | 0.4 | | | | |
| CO | kg/h | | | | | | | | | | 259.2 | 0.0 | 259.2 | | 259.2 | 51.8 | 0.0 | 51.7 | | 51.7 | | | | 0.2 | 0.2 | | | | |
| $H_2O$ | kg/h | 540.9 | | | | 7154 | 7154 | | | | 166.7 | 165.0 | 1.7 | | 1.7 | 135.0 | 134.8 | 0.2 | | 0.2 | | | | 0.0 | 0.0 | | | | |
| Light HCs | kg/h | | | | | | | | | | | | | | | 4.2 | 0.0 | 3.7 | | 3.7 | | | 0.4 | 0.5 | 0.9 | | | | |
| Gasoline | kg/h | | | | | | | | | | | | | | | 8.2 | 0.0 | 1.8 | | 1.8 | | | 13.4 | 6.3 | | 19.7 | | | |
| Jet fuel | kg/h | | | | | | | | | | | | | | | 15.3 | 0.0 | 0.1 | | 0.1 | | | 27.3 | 15.2 | | | 42.5 | | |
| Diesel | kg/h | | | | | | | | | | | | | | | 15.4 | 0.0 | 0.0 | | 0.0 | | | 15.0 | 15.4 | | | | 30.4 | |
| Wax | kg/h | | | | | | | | | | | | | | | 61.8 | | | | | 61.8 | | 6.2 | | | | | | 6.2 |

*Figure 14: Process flow diagram and simulation results.*

### 5.3.2 e-SAF Micro-Hub Mass and Energy Conversion Results

In the $H_2$ production system designed, 50.6 kg/h of $H_2$ is generated from 540.9 kg/h of deionised water. $CO_2$ is obtained from the air through direct air capture with a capture rate of 416.1 kg/h of $CO_2$. Subsequently, through RWGS-FT process, the $H_2$ and $CO_2$ are converted into 92.6 kg/h of liquid fuels with naphtha, jet fuel, and diesel carbon yields of 14.6%, 31.7%, and 22.7%, respectively, as shown in Table 6. The carbon content of the $CO_2$ source is 9.5 kmol/h, in which 1.4 kmol/h is converted into gasoline, 3.0 kmol/h is converted into jet fuel, and 2.2 kmol/h is converted into diesel. Therefore, the FT fuel carbon conversion efficiency of the total system design is 69%.

*Table 6: Mass inputs/outputs and calculated carbon conversion efficiency.*

| Mass balance | Mass type | |
|---|---|---|
| Input mass (kg/h) | $H_2$ | 50.6 |
| | $CO_2$ | 416.1 |
| Output mass (kg/h) | Gasoline | 19.7 |
| | Jet fuel | 42.5 |
| | Diesel | 30.4 |
| FT fuel production carbon conversion efficiency (%) | | 69% |

Table 7 summarises the energy inputs and outputs of the system to calculate the power-to-liquid conversion efficiency. The energy inputs are electricity for $H_2$ production, $CO_2$ capture, and RWGS-FT process, and the system energy outputs are FT liquid fuel including naphtha, jet fuel, and diesel. The power consumptions for $H_2$ production and $CO_2$ capture are 8,986.8 MJ/h and 2,996.2 MJ/h, respectively. The net energy consumptions, for RWGS, Fischer-Tropsch, and hydroprocessing processes are estimated to be 345.8 MJ/h of electricity and 530.2 MJ/h of heat. In total, the overall energy requirements for this power-to-liquid plant are 12,327.8 MJ/h of electricity and 530.2 MJ/h of heat. The energy consumption is predominated by the electricity required for $H_2$ generation, reaching nearly 70% of total energy requirements. As energy outputs of the system, gasoline, jet fuel, and diesel have energy production rates of 866.8 MJ/h, 1806.3 MJ/h, and 1319.4 MJ/h, respectively, calculated based on their LHVs (Tran, 2018). Therefore, the total liquid fuel production efficiency is 31%. It is worth mentioning that there is a potential to increase the energy efficiency by coupling with power generation using the combustible tail gas (i.e., light hydrocarbons) coming out from the Fischer-Tropsch process, which is not included in this study.

*Table 7: Energy inputs/outputs and calculated energy conversion efficiency.*

| Energy balance | Energy type | |
|---|---|---|
| Input energy (MJ//h) | Electricity | -12,327.8 |
| | Heat | -530.2 |
| Output energy (MJ/h) | Gasoline | 866.8 |
| | Jet fuel | 1806.3 |
| | Diesel | 1319.4 |
| FT fuel production energy conversion efficiency (%) | | 31% |

### 5.3.3 e-SAF Micro-Hub Economic Analysis

A cost estimation was carried out for the proposed micro-hub. Table 8 summarises the total capital and annual operating expenditures for small-scale e-SAF micro-hub. The total purchased cost (TPC) of main process equipment used in the micro-hub is A$14,847,933. To calculate the total direct plant cost (DC), the costs for installation as well as instrumentation and controls are added to the estimated TPC. Taking into account indirect plant cost (IDC), such as engineering and supervision as well as construction and contractor's fee, the fixed capital investment (FCI) can be determined. Finally, including the working capital (WC), the total capital investment (TCI) is around A$32.2 million. In terms of operation cost, the annual operation and maintenance of the micro-hub accounts for A$1,608,526. With the insurance and plant overhead cost, the total operation cost (TOC) is around A$2.1 million per annum. The levelised cost of synthetic fuels including gasoline, jet fuel, and diesel is then calculated based on the following financial assumptions: discount rate 7%, plant lifetime 20 years, and inflation rate 2.86%. The levelised cost of synthetic fuels produced from the designed micro-hub is estimated to be A$6.5 per kg of synthetic fuels.

*Table 8: Summary of e-SAF micro-hub cost analysis.*

| **Total Capital Investment (TCI)** | |
|---|---|
| Direct Plant Cost (DC) | |
| *Purchased Equipment* | |
| 2.5 MW PEM electrolyser | A$5,410,000 |
| Direct air capture unit | A$4,478,072 |
| RWGS reactor | A$272,428 |
| Fischer-Tropsch reactor | A$266,873 |
| Hydrocracker and distillation column | A$340,560 |
| 4.0 MW PV power plant | A$4,080,000 |
| Total Purchased Cost (TPC) | A$14,847,933 |
| Installation | A$3,711,983 |
| Instrumentation and Controls | A$1,484,793 |
| Total Direct Plant Cost (DC) | A$20,044,710 |
| Indirect Plant Cost (IDC) | |
| Engineering and Supervision | A$6,013,413 |
| Construction Expense and Contractor's Fee | A$2,895,347 |
| Total Indirect Plant Cost (IDC) | A$8,908,760 |
| Fixed Capital Investment (FCI) = DC + IDC | A$28,953,470 |
| Working Capital (WC) | A$3,217,052 |
| Total Capital Investment (TCI) = FCI + WC | A$32,170,522 |
| **Total Operation Cost (TOC)** | |
| Operation and Maintenance | A$1,608,526 |
| Insurance | A$289,535 |
| Plant Overhead Cost | A$210,896 |
| Total Operation Cost (TOC) | A$2,108,956 |

Under current conditions, the levelised cost of synthetic fuels is A$6.5/kg, significantly higher than the traditional fossil jet fuel price (A$1.5/kg) (IATA, 2023). To model the cost reduction opportunities for the designed micro-hub, we develop 3 scenarios: 2023, 2030, and 2050 with projected electrolyser, solar PV, and direct air capture capital costs as listed in Table 9. However, the projection shows that around 50% cost reduction can be achieved in 2030 and 75% in 2050.

*Table 9: Cost reduction opportunities for the NSW E-SAF micro-hub.*

| Cost | 2023 | 2030 | 2050 |
|---|---|---|---|
| Electrolyser capital cost (A$/kW) | A$2,164 | A$758 | A$179 |
| Solar PV capital cost (A$/kW) | A$1,020 | A$768 | A$532 |
| DAC capital cost (A$/ton CO2/year) | A$1,167 | A$584 | A$146 |
| Levelised cost of synthetic fuels (A$/kg) | A$6.5 | A$3.5 | A$1.7 |

### 5.3.4 e-SAF Micro-Hub Risk Management Framework

Considering e-SAF production has not been deployed in NSW, a risk management framework is required to identify potential risks. PESTLE (Political, Economic, Social, Technological, Legal, and Environmental) analysis is a wide-reaching business analysis tool that assesses a project for risks and potential issues in relation to political, economic, social, technological, legal, and environmental factors.

- **Political.** The NSW Government commits to reduce emissions by 70% by 2035 compared to 2005 levels and to reach net zero emissions by 2050, including in aviation sector through SAF technology. While NSW has not formulated SAF roadmap, NSW has all the essential requirements to build a thriving SAF roadmap, particularly, the supporting government policies and programs in clean technology, hydrogen industry, regional development, and industrial precincts, such as the NSW Net Zero Plan and Net Zero Industry and Innovation Program as well as the NSW Hydrogen Strategy and Hydrogen Hub Program. In addition, the implementation of the Australian Carbon Credit Units (ACCUs) by the Federal Government is a driver for the growth of SAF technology uptake. ACCUs are a financial instrument awarded to emissions reduction projects that can help in reducing the total capital expenditure.
- **Economic.** The two primary cost drivers for e-SAF micro-hub is the $H_2$ production cost reflecting the electrolyser and electricity costs as well as the $CO_2$ capture cost. Lowering the capital cost is essential to attract stakeholders to invest in the micro-hub. Nevertheless, there is a significant cost reduction potential for electrolyser, solar PV power plant, and DAC, enabling e-SAF to be more competitive in the future.
- **Social.** The key driver for social factor is the public awareness and acceptance of e-SAF. There may be social barriers to the adoption of e-SAF in NSW, particularly related to safety concerns (Lambert & Ashworth, 2018). Nevertheless, increased education and awareness campaigns on e-SAF could help to overcome those barriers. In addition to public perceptions, the availability of a highly skilled workforce in NSW is a key enabler for successful deployment of e-SAF.
- **Technological.** The designed e-SAF micro-hub adopt FT-based process in which the $CO_2$ is sourced from DAC and the $H_2$ is generated from PV-electrolysis. The technological aspect of this process can be represented by 2 factors: technological readiness level (TRL) and energy efficiency. Currently, the process is still at development stage towards commercialisation with a TRL of 5-6. The overall energy efficiency of the system is around 31%. However, continuous research and development may push the technology to a higher TRL and improve the overall energy efficiency, particularly for the electrolysis hydrogen production and DAC.
- **Environmental**. e-SAF is considered as the ideal component in the aviation industry's efforts to decarbonise while requiring no changes to existing aircraft and infrastructure. e-SAF offer life-cycle greenhouse gas emissions reductions of up to 99% compared to fossil jet fuel when using

renewable electricity throughout the production (World Economic Forum, 2020). The applications of e-SAF will substantially contribute to the NSW's climate target. In addition, e-SAF production diversifies the source of aviation fuel, reducing the aviation sector's dependency on traditional fossil jet fuel. This enhances energy security and reduces the vulnerability of the NSW's aviation industry to oil price fluctuations.

# 6 Conclusion and Next Steps

Overall, this study highlights that NSW has a significant opportunity for leading the development of e-SAF industry to decarbonise aviation. This is largely due to NSW being home to Australia's largest airport, a key international gateway with high demand for SAF. In addition, the state's abundant renewable energy potential and availability of sustainable $CO_2$ sources make several locations in NSW well-suited for e-SAF production hubs (Table 10). Through rigorous modelling, this study demonstrates that e-SAF development can provide significant benefits to the state, including emissions reduction, increased gross value-added (GVA), and the creation of new green job opportunities.

*Table 10: Identified potential locations for e-SAF hubs in NSW.*

| Potential Location | Potential Market | Estimated Demand |
|---|---|---|
| North Coast | Coffs Harbour airport | 20 KTPA of e-SAF |
| Hunter | Newcastle airport, RAAF Williamtown | 50 KTPA of e-SAF |
| Greater Sydney Metropolitan and Central Coast Region | Sydney Kingsford Smith airport, Western Sydney airport, RAAF Richmond | 1.46 MTPA of e-SAF |

Despite the significant benefits of e-SAF for the state, our analysis also identifies several key challenges and corresponding recommendations:

- **Cost Competitiveness:** Our cost modelling shows that the e-SAF is significantly more expensive compared to fossil jet fuel. However, this is expected to decrease as the renewable electricity, direct air capture, and electrolysis technologies evolves rapidly and becomes cheaper. The government should increase R&D funding, particularly in e-SAF technologies, from 2023 to 2030. Establishing an e-SAF R&D Alliance could promote collaboration and innovation. By 2050, investing in national research infrastructure and international collaboration in e-SAF R&D is recommended.
- **Infrastructure Investment:** While the use of SAF, including e-SAF, allows the airlines to use existing fuel distribution infrastructure and existing aircraft technology, the production of e-SAF itself needs significant new infrastructure, such as renewable power plants and transmission, direct air capture facilities, and water electrolysis plants. To attract public and private investment from 2023-2030, the government should conduct feasibility studies and design financial incentives. In the longer term, public-private partnerships and international collaboration on supply chain projects are recommended.
- **Market Adoption:** Encouraging airlines to adopt SAF, including e-SAF is critical. From 2023 to 2030, the government should develop a national e-SAF strategy and establish a National e-SAF Hub Program. By 2050, implementing policies such as emissions reduction targets, SAF mandates, and tax incentives will be vital to facilitate market uptake for SAF, including e-SAF.

Together, these recommendations aim to foster a robust and e-SAF industry in Australia, addressing key challenges through strategic investments and collaboration.

In conclusion, this pre-feasibility study underscores the potential of e-SAF in addressing aviation decarbonisation challenges, particularly in NSW. The recommendations put forth are designed to guide strategic decisions and actions that can contribute to the advancement of e-SAF production and the establishment of a thriving new industry in the region. By implementing these recommendations, we can drive progress towards a more sustainable and environmentally responsible aviation sector in Australia and beyond.

# List of Acronyms

| Acronym | Full |
|---|---|
| ACCU | Australian Carbon Credit Units |
| ARENA | Australian Renewable Energy Agency |
| Avtur | Aviation Turbine Fuel |
| DAC | Direct Air Capture |
| GHG | Greenhouse Gases |
| GW/GWh | Gigawatt/Gigawatt hour |
| I3 Framework | Innovation, Industry and Investment Framework |
| IATA | International Air Transport Association |
| ICAO | International Civil Aviation Organisation |
| IEA | International Energy Agency |
| IP | Intellectual Property |
| IRENA | International Renewable Energy Agency |
| NSW Decarb Hub | NSW Decarbonisation Innovation Hub |
| OCSE | Office of NSW Chief Scientist & Engineer |
| P2X | Power-to-X |
| PFHN | Powerfuels including Hydrogen Network |
| PV | Photovoltaics |
| R&D | Research and Development |
| RD&D | Research, Development and Demonstration |
| REZ | Renewable Energy Zones |
| SAF | Sustainable Aviation Fuel |
| SDG | Sustainable Development Goals |
| STEM | Science, technology, engineering and mathematics |
| UNSW | University of New South Wales |
| UNSW | University of NSW |
| UoN | University of Newcastle |
| UoW | University of Wollongong |
| USYD | University of Sydney |
| UTS | University of Technology Sydney |
| WSU | Western Sydney University |

# References


AEMO. (2022). *Integrated System Plan.*

AEMO. (n.d.). *Transmission costs for the 2022 integrated system plan.* Retrieved from https://aemo.com.au/en/consultations/current-and-closed-consultations/transmission-costs-for-the-2022-integrated system-plan

Airbus. (2023). *ZEROe Towards the world's first hydrogen-powered commercial aircraft.* Retrieved from https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen/zeroe

American Society for Testing and Materials. (n.d.). *Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives (ASTM D4054).* .

Ampol . (2023). *Ampol and ENEOS Partner to Explore Advanced Biofuels Production in Queensland.* Retrieved from https://www.ampol.com.au/about-ampol/news-and-media/eneos-partnership

ARC Centre for the Global Hydrogen Economy. (n.d.). *HySupply Publication.* Retrieved from https://www.globh2e.org.au/hysupply-publication#:~:text=This%20final%20joint%20report%20of,road%20 mapping%20and%20action%20plans.

ARENA. (2023, 01 27). *Recipients Announced for Australia-Germany HyGATE Initiative.* Retrieved from https://arena.gov.au/news/recipients-announced-for-australia-germany-hygate-initiative/

ARENA. (n.d.). *ARENA Knowledge Bank - Hydrogen.* Retrieved from https://arena.gov.au/knowledge-bank/?technology=hydrogen&page=5

ARENA. (n.d.). *German-Australian Hydrogen Innovation and Technology Incubator (HyGATE).* Retrieved from https://arena.gov.au/funding/german-australian-hydrogen-innovation-and-technology-incubator-hygate/

Australia Renewable Energy Agency. (2020). *SunDrive Copper Metallisation Demonstration Project.*

Australia Renewable Energy Agency. (2023, July 22). *Media Release: Renewable Energy Takes to the Skies.* Retrieved from https://arena.gov.au/news/renewable-energy-takes-to-the-skies/

Australia Renewable Energy Agency. (n.d.). *Efficient, Affordable Solar Cells Brn in Sydney Garage.* Retrieved from https://arena.gov.au/blog/efficient-affordable-solar-cells-born-in-sydney-garage/

Australia Renwable Energy Agency. (2023). *Hysata Capillary-fed' Electrolyser Commercial-Scale Demonstration Project.* Retrieved from https://arena.gov.au/projects/hysata-capillary-fed-electrolyser-commercial-scale-demonstration-project/

Australian Competition and Consumer Commission. (2022). *Airline Competition in Australia March 2022 Report.* .

Australian Government . (2022). *Aviation White Paper - Terms of Reference.* Retrieved from https://www.infrastructure.gov.au/infrastructure-transport-vehicles/aviation/aviation-white-paper/terms-of-reference

Australian Government. (2021). *Australia's Emissions Projects 2021.*

Australian Government. (2021, 02 08). *Renewable Energy Capacity Factor Maps.* Retrieved from https://data.gov.au/dataset/ds-ga-a40aaf84-7f29-4d37-8582-45c044d30a0e/distribution/dist-ga-a40aaf84-7f29-4d37-8582-45c044d30a0e-0/details?q=

Australian Government. (2022). *Australian Jet Zero Council.* Retrieved from https://www.infrastructure.gov.au/infrastructure-transport-vehicles/aviation/australian-jet-zero-council

Australian Government. (2022). *Australian Jet Zero Council Terms of Reference.* Retrieved from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.infrastructure.gov.au/sites/default/files/documents/australian_jet_zero_council_terms_of_reference.pdf

Australian Government. (2022). *Australian Jet Zero-style Council prepares for take off.* Retrieved from https://minister.infrastructure.gov.au/c-king/media-release/australian-jet-zero-style-council-prepares-take

Australian Government. (2022). *Aviation White Paper.* Retrieved from https://www.infrastructure.gov.au/infrastructure-transport-vehicles/aviation/aviation-white-paper

Australian Government. (n.d.). *Australian Jet Zero Council.* Retrieved from https://www.infrastructure.gov.au/infrastructure-transport-vehicles/aviation/australian-jet-zero-council

Australian National Audit Office. (2022). *COVID-19 Support to the Aviation Sector.*

Aviation Australia. (2022). *Qantas to Invest $50M in local sustainable fuel production.* Retrieved from https://australianaviation.com.au/2022/03/qantas-to-invest-50-million-in-local-sustainable-fuel-production/

Bajirao. (2012). *Kinetics and Reaction Engineering Aspects of Syngas Production by the Heterogeneously Catalysed Reverse Water Gas Shift Reaction.* Universitaet Bayreuth.

Bergero, C. (2022). Pathways to net-zero emissions from aviation. *Nature Sustainability,* 404-414.

Bioenergy Australia. (2020). *Bioenergy Australia Roadmap Submission.*

Bruce. (2018). *National Hydrogen Roadmap.* CSIRO.

California Governor's Office. (n.d.). *California's Hydrogen Goals.* Retrieved from https://business.ca.gov/industries/hydrogen/

CER. (2023). *Australian carbon credit units (ACCUs).* Retrieved from https://www.cleanenergyregulator.gov.au/Infohub/Markets/Pages/qcmr/march-quarter-2023/Australian-Carbon-Credit-Units.aspx

Clean Energy Finance Corporation. (2022, October). *Case Study: SunDrive Technology Supercharges Solar.* Retrieved from https://www.cefc.com.au/where-we-invest/case-studies/sundrive-technology-supercharges-solar/#:~:text=The%20switch%20to%20copper,silver%20and%20far%20more%20abundant.

CSIRO. (2023). *Sustainable Aviation Fuel Opportunities for Australia.* Retrieved from https://www.csiro.au/en/research/technology-space/energy/sustainable-aviation-fuel

CSIRO. (2023). *Sustainable Aviation Fuel Roadmap.* Canberra: CSIRO.

CSIRO. (2023). *Sustainable Aviation Fuel Roadmap.* Canberra: CSIRO.

CSIRO. (n.d.). *HyResource.* Retrieved from https://research.csiro.au/hyresource/

DCCEEW. (2023). *Australian Petroleum Statistics.* Retrieved from https://www.energy.gov.au/publications/australian-petroleum-statistics-2023

Deloitte. (2017). *Western Sydney Airport Aviation Fuel Supply Corridor Options Paper.*

Electrification and Energy Systems Network. (2023). *Electrification and Energy Systems Network.* Retrieved from https://www.decarbhub.au/networks/electrification-and-energy-systems-network/

Fasihi. (2019). Techno-economic assessment of CO2 direct air capture plants. *Journal of Cleaner Production,* 957-980.

Financial Review. (2022). *BP's green transformation starts with Kwinana.* Retrieved from https://www.afr.com/companies/energy/bp-s-green-transformation-starts-with-kwinana-20220520-p5amzb

German Government. (n.d.). *HyLand – Hydrogen Regions in Germany.* Retrieved from https://www.hy.land/en/

Global Alliance Powerfuels. (2021). *Water Consumption of Powerfuels.* Global Alliance Powerfuels.

Hydrogen Council. (2021). *Hydrogen Insights 2021.*

HyResearch. (2022). *Projects: Research & Development.* Retrieved from Innovations in Sustainable Aviation Fuels (SAF) Production and Deployment at Scale: https://research.csiro.au/hyresearch/innovations-in-sustainable-aviation-fuels-saf-production-and-deployment-at-scale/

HyResource. (2022, Auguest). *Hunter Energy Hub.* Retrieved from https://research.csiro.au/hyresource/hunter-energy-hub/

HyResource. (2022). *Port of Newcastle Green Hydrogen Hub.* Retrieved from https://research.csiro.au/hyresource/port-of-newcastle-green-hydrogen-hub/

HyResource. (2023). *ScaleH2.* Retrieved from https://research.csiro.au/hyresource/scaleh2/

Hysata. (2022, March 15). *Hysata's Electrolyser Breaks Efficiency Records.* Retrieved from https://hysata.com/news/hysatas-electrolyser-breaks-efficiency-records-enabling-world-beating-green-hydrogen-cost/

Hysata. (n.d.). *Hysata Technology Oveview.* Retrieved from https://hysata.com/

IATA. (2021). *Net-Zero Carbon Emissions by 2050.* Retrieved from https://www.iata.org/en/pressroom/pressroom-archive/2021-releases/2021-10-04-03/

IATA. (2023). *Jet Fuel Price Monitor.* Retrieved from https://www.iata.org/en/publications/economics/fuel-monitor/

ICF. (2011). *Fuelling Net Zero: How the Aviation Industry Can Deploy Sufficient Sustainable Aviation Fuel to Meet Climate Ambitions.*

Internal Revenue Services. (2022). *Notice 2023-6: Guidance on new sustainable aviation fuel credits.*

International Air Transport Association. (2022). *Travel Recovery Rebuilding Airline Profitability.* .

International Air Transport Association. (n.d.). *Developing Sustainable Aviation Fuel (SAF).* Retrieved from What is SAF: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-what-is-saf.pdf

International Energy Agency. (2022). *2022 World Energy Outlook* .

International Aviation Transport Association. (2020). *Liquid Hydrogne as a Potential Low-Carbon Fuel for Aviation* .

International Civil Aviation Organisation. (2017). *Working Paper: Defining the ICAO Vision on Aviation Alternative Fuels and Future Objectives.*

International Energy Agency. (2022). *Aviation.* Retrieved from https://www.iea.org/fuels-and-technologies/aviation

International Energy Agency. (n.d.). *Aviation.* Retrieved from https://www.iea.org/reports/aviation

Kang. (2012). Hydrocracking and Hydroisomerization of n-Hexadecane, n-Octacosane and Fischer-Tropsch Wax Over a Pt/SiO2-Al2O3 Catalyst. *Catal. Letters*, 1295-1305.

Khan. (2022). An integrated framework of open-source tools for designing and evaluating green hydrogen production opportunities. *Communications Earth and Environment.*

Konig, Baucks, Dietrich, & Worner. (2015). Simulation and evaluation of a process concept for the generation of synthetic fuel from CO2 and H2. *Energy*, 833-841.

Konig, Freiberg, Dietrich, & Worner. (2015). Techno-economic study of the storage of fluctuating renewable energy in liquid hydrocarbons. *Fuel,* 289-297.

KPMG. (2019). *International Air Freight Connectivity Pre-Feasibility Study.*

Lambert, & Ashworth. (2018). *The Australian public's perception of hydrogen for energy.* The University of Queensland.

Land and Primary Industries Network. (2023). *Land and Primary Industries Network.* Retrieved from https://www.decarbhub.au/networks/land-and-primary-industries-network/

Licella. (2022). *Licella partners with Amcor to deliver recycled content from Australia's first plastic advanced recycling facility*. Retrieved from https://www.licella.com/news/licella-partners-with-amcor-to-deliver-recycled-content-from-australias-first-plastic-advanced-recycling-facility/

McKinsey & Company. (2022). *Taking stock of the pandemic's impact on global aviation.* .

McQueen. (2021). A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future. *Prog. Energy*, 032001.

New H2. (2022). *New H2 Hunter Hydrogen Technology Cluster.* Retrieved from $64m for two hydrogen hubs in NSW: https://www.newh2.net.au/article/nsw-government-announce-64-million-grants-for-hydrogen-hubs

NSW Decarbonisation Innovation Hub. (2023). *NSW Decarbonisation Innovation Hub.* Retrieved from https://www.decarbhub.au/

NSW Government. (2021). *Net Zero Plan.*

NSW Government. (2021). *NSW Hydrogen Strategy.*

NSW Government. (2022). *Climate Change Action Plan 2023–26.*

NSW Government. (2022). *Climate Change Action Plan 2023–26 - Industry-sector advisory groups.* Retrieved from https://www.epa.nsw.gov.au/your-environment/climate-change/policy-and-action-plan

NSW Government. (2022). *NSW 20 Year R&D Roadmap.*

NSW Government. (2022). *NSW 20 Year R&D Roadmap.*

NSW Government. (2022). *NSW Modern Manufacturing Taskforce Report (2022), Making it in NSW.*

OCSE . (n.d.). *NSW Power-to-X* . Retrieved from https://www.chiefscientist.nsw.gov.au/rdnsw/future-industries-reports/nsw-power-to-x-industry-pre-feasibility-study

OCSE. (2019). *NSW Decarbonisation Innovation Study 2019.*

Powerfuels including Hydrogen Network. (2023). *Powerfuels including Hydrogen Network.* Retrieved from https://www.decarbhub.au/networks/power-fuels-including-hydrogen-network/

PwC. (n.d.). *Getting H2 right: Success factors for Australia's hydrogen export industry.* Retrieved from https://www.pwc.com.au/integrated-infrastructure-building-australia/getting-h2-right-australias-competitive-hydrogen-export-industry/producing-at-globally-competitive-prices.html

Qantas. (2022, June 19). *Newsroom. Qantas and Airbus joint nvestment to kickstart Australian biofuels Industry*. Retrieved from https://www.qantasnewsroom.com.au/media-releases/qantas-and-airbus-joint-investment-to-kickstart-australian-biofuels-industry/

Qantas. (2022). *Sustainable Aviation Fuel.* Retrieved from https://www.qantas.com/au/en/qantas-group/acting-responsibly/our-planet/sustainable-aviation-fuel.html#saf

Qantas. (2023, March 30). *Newsroom. Queensland biofuel refinary ot turn agriculture by-products into sustainable aviation fuel.* Retrieved from https://www.qantasnewsroom.com.au/media-releases/queensland-biofuel-refinery-to-turn-agricultural-by-products-into-sustainable-aviation-fuel/

Qantas Group. (2021). *Newsroom. Qantas Group Posts Significant Loss from Full Year of Covid.* Retrieved from https://www.qantasnewsroom.com.au/media-releases/qantas-group-posts-significant-loss-from-full-year-of-covid/

Queensland Government. (2022). New $500 million biorefinery planned for Gladstone. Retrieved from https://statements.qld.gov.au/statements/94951

R. Amal, R. D. (2021). *NSW Power to X Industry Pre-Feasibility Study.* UNSW.

R. Daiyan, I. M. (2023). *Final Report of the Australian German HySupply Project.*

Rezaei, & Dzuryk. (2019). Techno-economic comparison of reverse water gas shift reaction to steam and dry methane reforming reactions for syngas production. *Chem. Eng. Res. Des.*, 354-369.

Schiphol Airport. (2021, October 2021). *Synkero builds a facility in the port of Amsterdam, producing sustainable aviation fuel from CO2.* Retrieved from https://news.schiphol.com/synkero-builds-facility-in-the-port-of-amsterdam-producing-sustainable-aviation-fuel-from-co2/

Shan, L. (2023). *Qantas is confident it will return to 100% of its pre-Covid capacity in 2024.* Retrieved from CNBC: https://www.cnbc.com/2023/02/23/qantas-confident-it-will-return-to-100percent-of-pre-covid-capacity-in-2024.html

Srinivasan. (2021). *CO2 Utilisation Roadmap.* CSIRO.

SunDrive. (n.d.). *SunDrive Industry Technology Background.* Retrieved from https://www.sundrivesolar.com/technology

Sydney Airport. (2023, June 21). *Sydney Airport Traffic Performance May 2023.* Retrieved from https://www.sydneyairport.com.au/corporate/media/corporate-newsroom/sydney-airport-traffic-performance-may-2023

Sydney Airport. (n.d.). *Jet Fuel.* Retrieved from https://www.sydneyairport.com.au/corporate/partner-with-us/jetfuel

Tasmanian Government. (n.d.). *Tasmanian renewable hydrogen industry Development funding program.* Retrieved from https://recfit.tas.gov.au/future_industries/green_hydrogen/tasmanias_funding_and_investment_strategy

Training Centre for the Global Hydrogen Economy. (n.d.). *Training Centre for the Global Hydrogen Economy.* Retrieved from https://www.globh2e.org.au/training

Tran. (2018). Desulfurization of JP-8 jet fuel: challenges and adsorptive materials. *RSC Advances*, 7301-7314.

UK Government. (n.d.). *UK Jet Zero Council* . Retrieved from https://www.gov.uk/government/groups/jet-zero-council#ceo

University of Technology Sydney. (n.d.). *Key Technologies, Context & Opportunities in the Renewable Hydrogen Economy.* Retrieved from https://open.uts.edu.au/uts-open/study-area/engineering-management/key-technologies-context--opportunities-in-the-renewable-hydrogen-economy/

UNSW. (n.d.). *Trailblazer for Recycling and Clean Energy.* Retrieved from https://www.smart.unsw.edu.au/research-programs/trailblazer-recycling-and-clean-energy#:~:text=Hosted%20by%20UNSW%20and%20in,clean%20energy%20solutions%20and%20systems.

Virgin Australia. (2021). *Newsroom. Virgin Australia commits to net zero by 2050.* Retrieved from https://newsroom.virginaustralia.com/release/virgin-australia-commits-net-zero-2050

Virgin Australia. (2019). *Newsroom. Virgin Australia's sustainable aviation fuel flies one million kilometres.* Retrieved from https://newsroom.virginaustralia.com/release/virgin-australia%E2%80%99s-sustainable-aviation-fuel-flies-one-million-kilometres

Virgin Australia. (n.d.). *Sustainable Aviation Fuel.* Retrieved from https://www.virginaustralia.com/au/en/about-us/sustainability/sustainable-fuel/

WA Government. (n.d.). *Public knowledge sharing reports: WA Renewable Hydrogen Fund.* Retrieved from https://www.wa.gov.au/government/document-collections/public-knowledge-sharing-reports-wa-renewable-hydrogen-fund

Western Sydney Airport. (n.d.). *Western Sydney Airport.* Retrieved from https://www.westernsydney.com.au/the-airport

World Economic Forum. (2020). *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation.* World Economic Forum.

Zang, Sun, & Elgowainy. (2021). *The Modeling of Synfuel Production Process: ASPEN Model of FT production with electricity demand provided at LWR scale.* Argonne National Laboratory.

# Appendix

# Appendix A: Global SAF Supply Chain Project Mapping

This mapping stocktakes most recent e-SAF supply chain projects globally based on ICAO, IATA and IEA database to identify key industry players.

**Infinium.** Infinium is both a technology and project developer for e-SAF. Their market differentiator is that they convert syngas generated from renewable hydrogen and waste carbon dioxide through their proprietary 'chain limiting' catalysts within a Fischer-Tropsch reactor system that minimises wax production and optimises liquid fuel production[11]. The company has two commercial facility in the USA and one project under development in France. Project Pathfinder in Corpus Christi, Texas, USA where electrofuels are generated for offtake by Amazon for decarbonising their heavy transport. Project Roadrunner in West Texas in USA is poised to be the world's largest e-fuel facility when operational which will focus mostly on e-SAF, with IAG and American Airlines as off-taker and Brookfield Renewable and Breakthrough Energy Catalyst as investors. The facility is expected to be in production in late 2026. The company's Project Reuze in France will utilise waste CO2 from a steel plant in Dunkirk, France, with green hydrogen supplied by ENGIE using their 400 MW electrolysers to generate e-fuels, making it one of the largest announced synthetic fuel facility in Europe.

**Twelve.** Lawrence Berkeley National Laboratory's first Cyclotron Road cohort spinout Twelve is pioneering e-fuel market through their direct electrochemical CO2 to syngas electrolyser that can then be converted into e-SAF. The company is developing its first commercial demonstration-scale facility targeting ~190,000 litre per annum in Moses Lake in Washington USA with production expected to commence in 2025[12]. The company has also signed a 14 year off-take contract with IAG for 785,000 t of e-SAF.

**Rotterdam e-SAF Hub.** The Rotterdam e-SAF Hub is being developed by Power2X on tank storage company Advario's site in the Port, with a targeted capacity to generate 250,000 t of e-SAF annually by 2030[13]. The proposed Hub will convert renewable methanol generated from green hydrogen and biogenic CO2 source. For the Hub, Advario will develop advanced storage and logistics infrastructure with a capacity of approximately 230,000 cubic meters to ensure a stable supply chain for the e-SAF.

**DG Fuels.** DG Fuels is developing large-scale SAF production facilities in the US using Fischer-Tropsch reactor where CO2 is sourced from sustainably sourced cellulosic biomass (like agricultural and forestry residues) with renewable hydrogen produced via electrolysis powered by renewable electricity. Their planned facilities, including projects in Louisiana and Minnesota, aim to produce substantial quantities of SAF, exemplified by their offtake agreement with Air France-KLM for 600,000 metric tons of SAF to be delivered between 2027 and 2036 from their Louisiana plant.

**Nordic Electrofuel.** Founded in 2015, Nordic Electrofuel is developing a pilot e-fuel facility in Herøya Industrial Park, Porsgrunn, Norway, which is expected to be operational in 2026 with a yearly production capacity of 10 million litres of synthetic fuel including e-SAF. The CO2 source for the facility is from blast furnace waste gas from a local Ferro/Silicon-Manganese plant, which will then be used in a reverse water gas shift and Fischer-Tropsch reactor with renewable hydrogen to generate 8,000 t of syncrude which will be refined to generate e-SAF[14]. The company has signed a long-term offtake supply of synthetic fuels with P2X-Europe for 8,000 t per annum. The company is also planning expansion in the Middle East, signing a MoU with Royal Commission for Jubail and Yanbu.

**HIF Global.** HIF Global's focus is using Methanol-to-Jet (MtJ), a two-step process involving the synthesis of methanol from green hydrogen (produced via renewable electricity-powered electrolysis) and captured CO2, followed by the catalytic conversion of methanol into jet fuel-suitable hydrocarbons. The company has deployed this technology across a growing global portfolio of project, including a facility in Chile, the Haru Oni Project in Magallanes, has been operational since 2022, initially focusing

[11] *https://www.infiniumco.com/technology*
[12] *https://www.twelve.co/post/twelve-s-first-of-a-kind-e-saf-jet-fuel-plant-in-washington-state-receives-project-finance-construct*
[13] *https://www.power2x.com/our-focus/project-development/*
[14] *https://nordicelectrofuel.no/e-fuel_pilot/*

on e-Methanol production but with plans to expand into e-Gasoline and potentially e-SAF, serving as a vital demonstration of their technology at scale. In the United States, HIF Global is developing multiple projects in Texas, exploring potential e-SAF production and partnering with technology and engineering firms Johnson Matthey and Honeywell UOP. Notably, in Australia, their planned facility near Burnie, Tasmania, is a key focus for e-SAF production, strategically located to leverage the region's abundant hydropower resources for green hydrogen generation.

**Synhelion.** The company's solar-to-liquid technology relies on converting solar energy into heat with the aid of solar receivers coupled state-of-the-art solar towers which allow attainment of high temperature in excess of 1500oC, which is then used in thermochemical reactor that produces syngas, which can then be converted into synthetic fuels such as e-SAF. In this manner, the company's production pathway differs from other Power-to-Liquid (PtL) pathways that rely on almost exclusively on various forms of electrolysis. At present, the company has a demonstration plant located in Julich in Germany, built in collaboration with the German Aerospace Agency (DLR). The company is now preparing for the development of its first commercial plant, Project Rise, in Spain, that will target 1,000 t per annum solar fuel by 2027[15.]

**Project SkyKraft.** Project SkyKraft is a collaborative effort between SkyNRG and Skellefteå Kraft to establish a pioneering facility for producing e-SAF in Northern Sweden. Aiming at 100,000 t of e-SAF production annually, the project was initiated in 2022 and will leverage biogenic CO2 sources in the region with renewable energy sourced from hydroelectricity.

**Arcadia eFuels.** Arcadia eFuels' Naboo project in Teeside, the UK has secured £12.3 million, aiming to develop a commercial scale power-to-liquid plant to convert biogenic CO2 and green hydrogen into fuels. The project is anticipated to start operation in 2029, with a planned capacity of 80 KTPA (100 million litres per annum). In 2024, Arcadia eFuels' Project ARC in Gregory, Texas, was awarded a $14.6 million Fueling Aviation's Sustainable Transition (FAST) Grant. The project is currently at the pre-front-end engineering design (pre-FEED) stage and is expected to begin commercial operations in 2028, with a capacity of 80 KTPA (100 million litres per annum).[16]

**Carbonshift PtL.** Willis Sustainable Fuels (Carbonshift PtL) is developing an e-fuels production refinery in Teesside, UK.[17] The facility will use power-to-liquid technology to convert CO2 and green hydrogen into sustainable aviation fuel (SAF). Expected to be operational by 2026, the plant will produce up to 14 KTPA of SAF at full capacity. The project has received £4.7 million from the Department for Transport's Advanced Fuels Fund.

[15]*https://synhelion.com/our-plants/plant-rise*
[16]*https://www.gazettelive.co.uk/news/teesside-news/teesside-sustainable-plane-fuel-projects-28125481*
[17]*https://teesvalley-ca.gov.uk/news/big-boost-for-sustainable-aviation-fuel-on-teesside-as-five-firms-win-multimillion-pound-funding/*

# Appendix B: NSW P2X and SAF Workshops

## B.1 PFHN P2X Workshops

Workshop attendees for the P2X Workshops were listed in Table 11. Notably, some stakeholders submitted feedback to PFHN and OCSE as unable to attend scheduled workshops.

*Table 11 PFHN P2X Workshops Attendees*

| Workshop 1 | Workshop 2 | Workshop 3 | Workshop 4 | Workshop 5 |
|---|---|---|---|---|
| NSW Government<br>OECC NZIIP CTI<br>Team<br>Business Finland<br>NSW Government<br>NZIIP HEI and NLCIF<br>Team<br>DCCEEW<br>NSW Government<br>Hydrogen Strategy<br>Team<br>CEFC<br>Investment NSW | GHD<br>Orica<br>Jemena<br>Bluescope<br>APA Group<br>BOC<br>University of<br>Wollongong | ATCO<br>Fortescue Future<br>Industries<br>HIF Australia<br>Origin Energy<br>Port of Newcastle<br>Qantas | Clarke Energy<br>ENEOS<br>Rheinmetall<br>Star Scientific<br>ThyssenKruup<br>Nucera<br>University of<br>Wollongong<br>Vast Solar<br>HySata | Australian Hydrogen<br>Council<br>Beyond Zero<br>Emissions<br>Clayton Utz<br>Climate KIC<br>NERA<br>Standards Australia<br>UNSW |

## B.2 OCSE SAF Workshops

Workshop attendees were listed in Table 12. Notably, some stakeholders submitted feedback to PFHN and OCSE as unable to attend scheduled workshops.

*Table 12: OCSE SAF Workshops Attendees*

| OCSE Workshop | Bioenergy Australia Workshop for SAFAANZ |
|---|---|
| Algion<br>ANU<br>ARENA<br>Austrade<br>Australian Hydrogen Council<br>Business Finland<br>CEFC<br>CSIRO<br>Deloitte<br>Department of Regional NSW<br>Fichtner Australia<br>Future Food Systems CRC<br>HIF Asia Pacific<br>Investment NSW<br>Masdar Tribe Australia<br>NSW DPI<br>Regional Growth NSW Development Corporation<br>Southern Green Gas Ltd<br>Sumitomo Mitsui Banking Corporation<br>The University of Newcastle<br>The University of Sydney<br>ThyssenKrupp Uhde<br>UNSW (ARC Training Centre for the Global Hydrogen<br>Economy)<br>Masdar Tribe Australia | Airlines for Australia and New Zealand (A4ANZ)<br>Bioenergy Australia<br>Boeing<br>Clean Energy Programs, OECC<br>CSIRO<br>Deloitte<br>Department of Regional NSW<br>EnergyLink Services<br>Fulcrum BioEnergy<br>Hydrogen Strategy, OECC<br>Investment NSW<br>Licella<br>Melbourne Airport<br>Neste<br>Qantas<br>Queensland Futures Insitute<br>Sunshine Coast Airport<br>Sydney Airport<br>Transport for NSW<br>US Grains Council<br>Virgin Australia<br>Wagner |

# Appendix C: NSW e-SAF Market Modelling

## C.1 Demand Modelling Methods

The scenarios developed to model the aviation energy demand in NSW include business as usual, reduced fossil, and net zero scenarios. The proportions of the use of fossil jet fuel, SAF, and non-emitting propulsion for those 3 different scenarios from 2023 to 2050 are summarised in Table 13, 14 and 15 (Bergero, 2022).

*Table 13: Energy consumption percentage for business as usual scenario.*

| Year | Long-, medium-, & short-haul | | |
|---|---|---|---|
| | Fossil jet fuel | SAF | Non-emitting propulsion |
| 2023 | 100% | 0% | 0% |
| 2025 | 100% | 0% | 0% |
| 2030 | 100% | 0% | 0% |
| 2035 | 100% | 0% | 0% |
| 2040 | 100% | 0% | 0% |
| 2045 | 100% | 0% | 0% |
| 2050 | 100% | 0% | 0% |

*Business as usual scenario use only fossil jet fuel. Table A1 includes both short-haul and medium- and long-haul flights, and there is no distinction between the three since all flights use fossil jet fuel.

*Table 14: Energy consumption percentage for reduced fossil scenario.*

| Year | Long- & medium-haul | | Short-haul | | |
|---|---|---|---|---|---|
| | Fossil jet fuel | SAF | Fossil jet fuel | SAF | Non-emitting propulsion |
| 2023 | 100% | 0% | 100% | 0% | 0% |
| 2025 | 98% | 2% | 98% | 2% | 1 |
| 2030 | 95% | 5% | 92% | 5% | 3% |
| 2035 | 83% | 17% | 78% | 16% | 6% |
| 2040 | 61% | 39% | 56% | 36% | 8% |
| 2045 | 46% | 54% | 41% | 48% | 11% |
| 2050 | 35% | 65% | 30% | 57% | 13% |

*Based on distance flown by plane, the split is 54% short-haul, 25% medium-haul, and 21% long-haul. We are assuming that this split remains constant into the future. We group medium- and long-haul and differ them from short-haul aviation since we assume that longer flights cannot use non-emitting propulsion systems (hydrogen and electricity).

Table 15: Energy consumption percentage for net zero scenario.

| Year | Long- & medium-haul | | Short-haul | | |
|---|---|---|---|---|---|
| | Fossil jet fuel | SAF | Fossil jet fuel | SAF | Non-emitting propulsion |
| 2023 | 100% | 0% | 100% | 0% | 0% |
| 2025 | 89% | 11% | 88% | 11% | 2% |
| 2030 | 71% | 29% | 63% | 25% | 12% |
| 2035 | 54% | 46% | 42% | 37% | 21% |
| 2040 | 36% | 64% | 25% | 45% | 31% |
| 2045 | 18% | 82% | 11% | 49% | 40% |
| 2050 | 0% | 100% | 0% | 50% | 50% |

*Based on distance flown by plane, the split is 54% short-haul, 25% medium-haul, and 21% long-haul. We are assuming that this split remains constant into the future. We group medium- and long-haul and differ them from short-haul aviation since we assume that longer flights cannot use non-emitting propulsion systems (hydrogen and electricity).

The quantity of aviation energy, described as PJ to accommodate all types of energy sources (fossil jet fuel, SAF, $H_2$, and electricity), is estimated and projected based on historical annual demand in NSW from 2010 to 2022 (Table 20). It is assumed that the energy density of fossil jet fuel used is 34.7 MJ/L (Bergero, 2022).

Table 16: Historical NSW annual avtur demand from 2011 to 2022.

| Year | Avtur demand in ML | Avtur demand in PJ |
|---|---|---|
| 2011 | 3273.6 | 113.6 |
| 2012 | 3359.5 | 116.6 |
| 2013 | 3461.5 | 120.1 |
| 2014 | 3370.3 | 116.9 |
| 2015 | 3393.8 | 117.8 |
| 2016 | 3694.7 | 128.2 |
| 2017 | 3823.0 | 132.7 |
| 2018 | 3600.8 | 124.9 |
| 2019 | 3485.6 | 121.0 |
| 2020 | 1549.6 | 53.8 |
| 2021 | 1248.6 | 43.3 |
| 2022 | 2251.8 | 78.1 |

## C.2 Production Modelling Methods

The cost for e-SAF is estimated as Equation 1. We are assuming a conversion efficiency of 80%. The FT unit cost is set to be constant at around A$0.35 per kg. The constants 0.4 and 3.14 are the weight of $H_2$ and $CO_2$ needed to produce 1 kg of $CH_2$ ($3H_2 + CO_2 \quad CH_2 + 2H_2O$) (Bergero, 2022).

*Equation 1:*

$$CH_2 \ cost = FT \ unit \ cost + \frac{(H_2 \ unit \ cost \times 0.4) + (Carbon \ unit \ cost \times 3.14)}{Conversion \ efficiency}$$

To calculate the projection cost for e-SAF, cost reduction opportunities from the FT unit (World Economic Forum, 2020), $H_2$ production unit (PwC, n.d.), and $CO_2$ capture unit (Fasihi, 2019) are considered as summarised in Table 26.

*Table 17: Projected FT, $H_2$ production, and $CO_2$ capture costs.*

| Year | FT cost (A$/kg FT fuels) | $H_2$ cost (A$/kg H2) | $CO_2$ cost (A$/kg $CO_2$) |
|---|---|---|---|
| 2023 | 0.35 | 7.43 | 0.50 |
| 2025 | 0.34 | 6.10 | 0.40 |
| 2030 | 0.33 | 4.50 | 0.15 |
| 2035 | 0.31 | 3.50 | 0.12 |
| 2040 | 0.30 | 2.45 | 0.10 |
| 2045 | 0.28 | 2.10 | 0.09 |
| 2050 | 0.27 | 1.65 | 0.08 |

# Appendix D: NSW e-SAF Hub Pre-Feasibility

## D.1 Multi Criteria Assessment Framework for e-SAF Hub Location Selection

The weighting and scoring for each criteria and sub-criteria under the Multi Criteria Assessment Framework developed for e-SAF Hub location is presented in Table 18.

*Table 18: Multi criteria analysis framework for the identification of potential e-SAF micro-hub locations in NSW.*

| Criteria | Description | Consideration | Weighting | Score range |
|---|---|---|---|---|
| Demand | Proximity to airports is considered. | The closer the location to airports enables co-location of production and demand, cutting costs required for transportation. | 30% | 5 – Airports within 100 km<br>0 – Airports > 100 km away |
| Renewable Energy Availability | For solar and wind, capacity factors are considered. | The higher the capacity factor the larger the availability of energy to drive electrolysis. | 20% | 5 – CF > 30%<br>4 – CF = 20-30%<br>3 – CF < 20% |
| Water Availability | Factors to be considered include potential source, quantity required, and quality. | Source dictates the sustainability of water supply. Quantity dictates scale of H2 generation. Quality dictates the pre-treatment required, in turn the cost and complexity. | 20% | Source:<br>5 – Desalinated water<br>4 – Recycled water or fresh water<br><br>Quantity:<br>5 – High quantity<br>4 – Moderate quantity<br>3 – Low quantity<br>2 – Unknown quantity<br><br>Quality:<br>5 – Minimum treatment<br>4 – Medium treatment<br>3 – Heavy treatment |
| CO2 Source Availability | Proximity to industrial emissions are considered. | The closer the location to industrial emissions enables deployment of point source capture which is a cheaper option to direct air capture. | 10% | 5 – Point source capture<br>4 – Direct air capture |
| Land Availability | Consideration factors are the availability of land, size of land available, and current land ownership. | The availability of land and the size dictate the project scale for the standalone power plant and the conversion process. Land ownership dictates the acquirement process. If land is owned by government, the easier it is to acquire for project. If land is privately owned and occupied, additional cost and time would be required to relocate occupants and purchase land for project. | 5% | Availability:<br>5 – Land available<br>0 – Land not available<br><br>Size of land available:<br>5 – Scale potential > 1 MW<br>4 – Scale potential < 1 MW<br><br>Land ownership:<br>5 – Government owned<br>4 – Privately owned |
| Existing infrastructure | Availability of solar and wind plants and electricity network are considered. | Proximity to already available solar and wind farm and electricity distribution network means they can be leveraged for project design. | 5% | Proximity to available RE source and electricity network:<br>5 – Distance within 50 km<br>4 – Distance within 150 km<br>3 – Distance > 150 km away |

| Criteria | Description | Consideration | Weighting | Score range |
|---|---|---|---|---|
| Approval and risk factors | Health and safety risks, environmental risks, approvals, and community acceptance are considered. | Potential risks to safety and local environment have to be managed. Securing approvals and public acceptance are also critical to realise the project development. | 10% | HSE risks:<br>5 – Risks are manageable and accepted<br>4 – Risks are manageable with controls<br>0 – Risks are too high and uncontrollable<br><br>Approvals:<br>5 – Approval required at local level 4 – Approval required at local and state level<br>3 – Approval required at local, state, and federal level<br><br>Public acceptance:<br>5 – Community openly accepts development<br>0 – Community openly rejects development |

## D.2 Micro-Hub Design Process Simulation

The e-SAF micro-hub is simulated by DWSIM software using Peng-Robinson (PR) package. In general, the micro-hub comprises 5 process areas: A1: $H_2$ production, A2: Direct air capture, A3: RWGS, A4: Fischer Tropsch, A5: Hydroprocessing.

### A1: $H_2$ Production

The first reaction area, $H_2$ production, evaluates the water demand and power demand for water electrolysis in a PEM electrolyser. Water for $H_2$ production is supplied from fresh water, pre-treated via screening, filtration, coagulation, and reverse osmosis, then stored in a water tank. Typically, a PEM electrolyser requires 10.7 kg water feed to produce 1 kg of $H_2$ (Global Alliance Powerfuels, 2021). To calculate the electrolyser power rating, the PEM electrolyser efficiency is assumed to be 80%; therefore, a 2.5 MW capacity of PEM electrolyser is needed to produce the $H_2$ for the designed micro-hub. The electricity is sourced from solar PV power plant dedicated for the micro-hub and passed through a substation (transformer and rectifier) in advance to adjust the voltage. The PEM electrolyser is operated under isothermal conditions at 60 °C (the temperature is maintained using a cooler) and the operating pressure is 20 bar. The $O_2$ and water are separated in a gas-liquid separator, and the $O_2$ is filtred through a molecular sieve to be vent to the atmosphere. The $H_2$ and a small amount of water enter the $H_2$ separator, and the $H_2$ gas passess through the molecular sieve for further drying. The $H_2$ is then used as a feed for RWGS. The water in the $O_2$ and $H_2$ separators are recycled back into the water tank.

### A2: Direct Air Capture

In Direct Air Capture (DAC) area, air is drawn in through a contactor unit by a fan and the $CO_2$ is absorbed using a potassium hydroxide (KOH) aqueous solution, forming potassium carbonate ($K_2CO_3$) in solution (McQueen, 2021). Subsequently, the $K_2CO_3$ is precipitated as calcium carbonate ($CaCO_3$) in the pellet reactor and the regenerated KOH solution is recycled back to the contactor. The $CaCO_3$ is fed into a steam slaker for drying at 300 °C before it is calcined at 900 °C. Upon calcination, the $CaCO_3$ is decomposed into CaO and $CO_2$. After that, the CaO is hydrated in the steam slaker, generating $Ca(OH)_2$ for the anionic exchange in the pellet reactor. The gas out from the calciner is passed through a condenser to remove any water and the resulting dry $CO_2$ is compressed as feed for RWGS reaction. The $CO_2$ capture efficiency is assumed to be 95% and the energy requirement is estimated to be 2,000 kWh/tonne $CO_2$.

## A3: RWGS

RWGS area contains the RWGS reaction, syngas cooling and drying, compressors, and $CO_2$ separator. The RWGS reaction is modeled based on the reaction equilibrium using $Ni/Al_2O_3$ catalyst (Bajirao, 2012). The RWGS reaction takes place at 900°C and 25 bar (Konig, Baucks, Dietrich, & Worner, 2015) with a $CO_2$ conversion of 70%. The RWGS is an endothermic reaction, operating under isothermal conditions at 900 °C, requiring a heat supply of 304.7 MJ/h to maintain constant temperature. In addition, the feedstock needs to be preheated to 900°C before entering RWGS reactor, requiring 1253.9 MJ/h of heat.

Syngas produced from the RWGS is cooled to 40°C and then quenched to remove water and compressed to 25 bar using a 5-stages intercooling compressor. The Selexol $CO_2$ separation unit uses ethylene glycol as a solvent that absorbs $CO_2$ in the absorber at 25 bar and releases $CO_2$ from flash tanks for $CO_2$ recycling. The total compression power consumption of the RWGS area is 344.9 MJ/h. The syngas produced form the Selexol $CO_2$ separation unit is used as feedstock for the FT synthesis reaction in the A4 Fischer-Tropsch area.

## A4: Fischer-Tropsch

The Fischer-Tropsch area consists of FT fixed-bed reactor, wax/liquid/gas separator, and pressure swing adsorption (PSA) H2 separator. The FT reactor feeds an $H_2$/CO mixture with a molar ratio of 2.0 and use cobalt-based catalyst to convert 80% of CO into hydrocarbons at 220 °C and 25 bar. To maximise CO conversion an internal recycling is applied where unreacted syngas is fed back to the FT reactor inlet. The hydrocarbon product distribution is defined using the Anderson-Schulz-Flory distribution shown in Equation 2.

*Equation 2:*

$$x_n = n \times (1-\alpha)^2 \times \alpha^{n-1}$$

where α is 0.934, n is the carbon number in $C_nH_{2n+2}$ produced from the FT reaction (Equation 3) and $x_n$ is the mass ratio of $C_nH_{2n+2}$ in the total hydrocarbon production distribution. The mass ratio and molar ratio distributions of $C_nH_{2n+2}$ with carbon numbers from 1 to 20 is shown in Figure 14, whereas the heavier hydrocarbons are assumed to have an average carbon number of 29.

*Equation 3:*

$$nCO + (2n+1)H_2 \rightarrow C_nH_{2n+2} + nH_2O$$

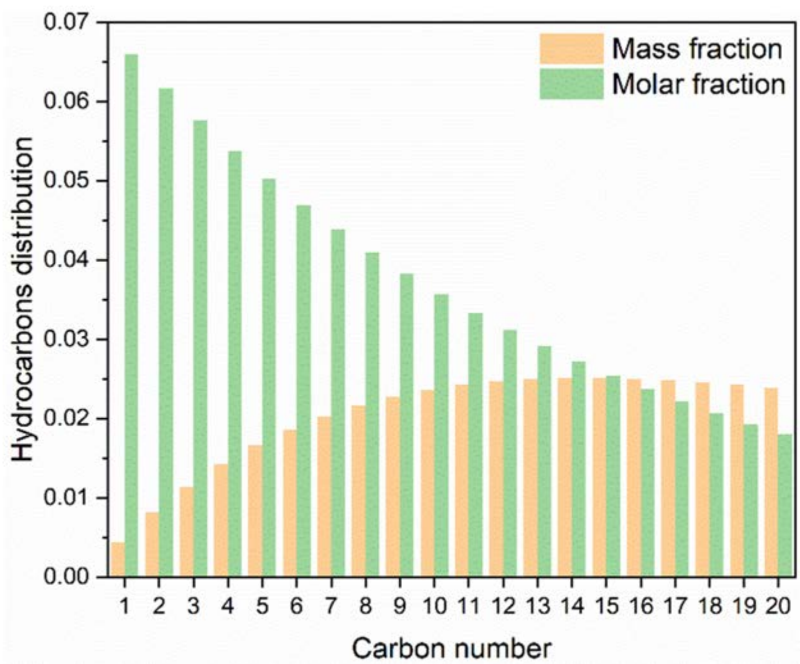



*Figure 15: Distribution of hydrocarbons produced from the FT synthesis reactor with carbon numbers from 1 to 20.*

Prior to entering the FT synthesis reactor, the syngas temperature is set to the desired temperature of 220°C by introducing 145.1 MJ/h of heat. The FT synthesis reaction is exothermic; therefore, the reactor is cooled by a cooling tower to maintain an operating temperature of 220°C, releasing 1,212.8 MJ/h of heat. Subsequently, the mixture is cooled down to 40°C, releasing 426.6 MJ/h of heat, to separate water from the mixture. Wax is also separated to undergo hydrocracking reaction, while the FT liquid fuels product is pumped to the distillation column. The total pump power consumption of Fischer-Tropsch process area is 0.2 MJ/h.

Flue gases with the major components $H_2$/CO/$C_1$-$C_4$ are produced from the top of the FT reactor. A PSA unit is used to separate and recycled unconverted H2 in the flue gas with a high purity. Tail gases from the PSA unit can be used for combustion to generate power for the system. However, this study does not include the utilisation of tail gases for power generation.

### A5: Hydroprocessing

The hydroprocessing area mainly includes a hydrocracking reactor and a fuel distillation tower. The hydrocracking process cracks 90% of the wax into lighter hydrocarbons at 290°C at 25 bar with a $H_2$/wax feed molar ratio of 2.6. The distribution of hydrocarbons produced is illustrated in Figure 26, using Pt/Si-Al catalyst (Kang, 2012). The FT fuel is produced from the hydroprocessing area. The lighter hydrocarbons ($C_5$-$C_{20}$) from hydroprocessing and the FT synthesis area are separated into liquid products of gasoline, jet fuel, and diesel, by distillation. The hydroprocessing reaction and distillation process take place at an elevated temperature (<290°C). The heat requirement and power consumption in the hydroprocessing area are estimated to be 465.9 and 0.72 MJ/h, respectively.

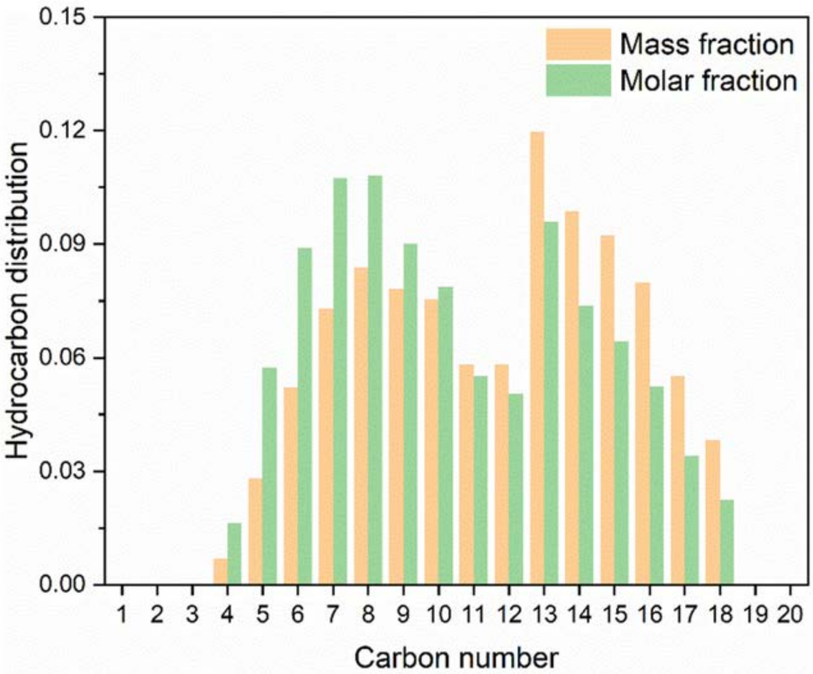



*Figure 16: Distribution of hydrocarbons from the hydrocracking reactor with carbon numbers from 1 to 20.*

## D.3 Micro-Hub Cost Analysis Methodology

To evaluate the costs for synthetic fuels products, the levelised cost (LC) was used as the metric. The LC is evaluated based on the net present value (NPV) of the total capital investment (TCI), total operation cost (TOC), and the amount of FT liquid fuels generated discounted over the project life as shown in Equation 4.

*Equation 4:*

$$LC(A\$/kg) = \frac{\sum_{i=1}^{n} \frac{(TCI+TOC_i)}{(1+r)^i}}{\sum_{i=1}^{n} \frac{FT\ liquid\ fuels\ produced_i}{(1+r)^i}}$$

Here, the TCI represents the total capital cost, TOC, represents the annual operation cost, and the FT liquid fuels produced represents the annual FT liquid fuels production rate in kg/year for year, r is the discount rate (assumed to be 7%), and n represent the project life (herein considered to be 20 years). Please note that an inflation rate of 2.86% is assumed in the calculation.

TCI is the total amount of money needed to supply the necessary micro-hub facilities plus the amount of money needed as working capital for operation of the micro-hub facilities. Herein TCI includes direct plant cost (purchased equipment, installation, and instrumentation and controls), indirect plant cost (engineering and supervision as well as construction expense and contractor's fee), and working capital. TOC is all expenses directly connected with the manufacturing operation or the physical equipment of a micro-hub itself. These include operation and maintenance (O&M), insurance, and plant overhead cost (POC). The estimation of each cost component is summarised in Table 19.

*Table 19 Estimation of capital investment and operation cost components.*

| **Total Capital Investment (TCI)** | |
|---|---|
| Direct Plant Cost (DC) | |
| *Purchased Equipment* | |
| PEM electrolyser (Khan, 2022) | Current: A$2164/kW<br>2030: A$758/kW<br>2050: A$179/kW |
| Direct air capture unit | Current: A$1167/tonne per annum CO2<br>2030: A$584/tonne per annum CO2<br>2050: A$146/tonne per annum CO2 |
| RWGS reactor (Rezaei & Dzuryk, 2019) | A$120/tonne per annum CO |
| Fischer-Tropsch reactor (Konig, Freiberg, Dietrich, & Worner, 2015) | A$100/tonne per annum feed |
| Hydrocracker and distillation column (Konig, Freiberg, Dietrich, & Worner, 2015) | A$420/tonne per annum FT fuels |
| PV power plant (AEMO, n.d.) | Current: A$1020/kW<br>2030: A$768/kW<br>2050: A$532/kW |
| Installation | 25% of Purchased Equipment |
| Instrumentation and Controls | 10% of Purchased Equipment |
| Indirect Plant Cost (IDC) | |
| Engineering and Supervision | 30% of DC |
| Construction Expense and Contractor's Fee | 10% of FCI |
| Fixed Capital Investment (FCI) | DC + IDC |
| Working Capital (WC) | 10% of TCI |
| Total Capital Investment (TCI) | FCI + WC |
| **Total Operation Cost (TOC)** | |
| Operation and Maintenance (O&M) | 5% of TCI |
| Insurance | 1% of FCI |
| Plant Overhead Cost (POC) | 10% of TOC |
| Total Operation Cost (TOC) | O&M + Insurance + POC |